Network Throughput Improvement in Wi-Fi 6 over Wi-Fi 5: A Comparative Performance Analysis

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***Abstract*—Wi-Fi version 6 or the IEEE 802.11ax protocol, is the newest generation of Wi-Fi standard, which supports better throughput than its predecessor IEEE 802.11ac, known as Wi-Fi 5. Both of these standards have several physical (PHY) layer enhancements, such as higher channel bandwidths (40/80/160 MHz) and multi-user multiple-input and multiple-output abbreviated as MU-MIMO. IEEE 802.11ax now supports MU-MIMO for both uplink and downlink, whereas Wi-Fi 5 can support only downlink MU-MIMO. In addition, Wi-Fi 6 uses orthogonal frequency-division multiple access which is popularly known as OFDMA technology and a higher spectral efficiency, and as a result, Wi-Fi 6 can upsurge the average throughput/area in dense networks. Moreover, modulation and coding scheme (MCS) 10 and 11 are introduced in Wi-Fi 6, which further help improve the network throughput. Therefore, it is expected that Wi-Fi 6 will significantly outperform Wi-Fi 5. To this end, in this research paper, we present a proportional network throughput analysis of IEEE 802.11ac (Wi-Fi 5) and IEEE 802.11ax (Wi-Fi 6), and also discuss the key features of these two WLAN standards. For the simulation, we use NS3, where it has been observed that Wi-Fi 6 can drastically improve the network throughput compared to Wi-Fi 5.**

***Index Terms*—WiFi 5; WiFi 6; IEEE 802.11ac; IEEE 802.11ax; network throughput**

I. Introduction

Wireless technologies like Wi-Fi provides wireless communication services to everyone and supports mobility for people scattered throughout the world. IEEE 802.11 protocols signify to the set of networking standards that define communication for Wireless Local Area Networks (WLANs). High-frequency radio waves are being used by WLANs instead of cables for connecting the devices in Local Area Networks (LANs). IEEE standard consists of a series of technological advances that have been developed over many years. The main objective of the novel IEEE 802.11 standards like IEEE 802.11ac protocol [1] and IEEE 802.11ax protocol [2], is to increase the throughput. The newest sixth- generation of wireless protocol, IEEE 802.11ax also known as Wi-Fi 6, offers better performance than the previous fifth-generation wireless protocol, IEEE 802.11ac also known as Wi-Fi 5, in the same operating frequency of 5 GHz. The aim of Wi-Fi 6 is to increase the average throughput per-area in a compact environment, and thus Wi-Fi 6 is also known as *High Efficiency WLANs (HE-WLANs)* [2]. IEEE 802.11ax not only offers better speed, it also offers larger coverage range compare to previously used Wi-Fi network standards, such as IEEE 802.11a/g/n/ac. IEEE 802.11ac and IEEE 802.11ax standards are officially labelled as Wi-Fi 5 and Wi-Fi 6, individually, by Wi-Fi Alliance. In this research paper, we use IEEE 802.11ac protocol and IEEE 802.11ax protocol, and their corresponding official labels Wi-Fi 5 and Wi-Fi 6 interchangeably.

By using the channel bonding feaure of physical (PHY) layer, both IEEE 802.11ac and IEEE 802.11ax standards use 20, 40, 80, or 160 MHz channel. In order to exploit multipath propagation, the aforementioned standards also use multiple-input and multiple-output (MIMO) technology. Wi-Fi 6 supports both uplink and downlink of multi-user multiple input and multiple output (MU-MIMO) technology to further improve throughput [2]. However, IEEE 802.11ac can support only downlink MU-MIMO [1]. In Wi-Fi 6, the overall improvement in throughput is only possible due to utilization of orthogonal frequency- division multiple access (OFDMA) and a higher spectral efficiency. Novel modulation and coding scheme values, MCS 10 and 11, are introduced in IEEE 802.11ax standard, in which quadrature amplitude modulation (QAM) 1024 is applied. Another significant change in IEEE 802.11ax is an increase in the fast Fourier transform (FFT) number, which is followed by fourfold decrease within the spacing between the subcarriers and a fourfold increase within the image length in time domain. The key difference between the IEEE 802.11ax and IEEE 802.11ac is that the increase of the subcarriers variety, which results in subcarrier spacing reduction. As discussed in [3], in single user (SU) scenarios, throughputs in IEEE 802.11ax outperform IEEE 802.11ac by approximately 64% and 85% in consistent and undependable channels, respectively. In Multi User-MIMO scenarios, IEEE 802.11ax throughputs overtake IEEE 802.11ac standard by approximately 263% and 270% in dependable and undependable channels, respectively [3].

Contribution: In this research paper, we present a comparative performance analysis of IEEE 802.11ac standard and IEEE 802.11ax standard, and in that context, we specifically discuss the throughput enhancement in Wi-Fi 6 compared to Wi-Fi 5. Therefore, this paper highlights the network throughput improvement in the latest Wi-Fi 6 over its predecessor Wi-Fi 5. Moreover, we discuss the key features of these two WLAN standards, along with the major performance improvement factors in Wi-Fi 6. The performances of Wi-Fi 5 and Wi-Fi 6 standards are analyzed with different MCS and channel bandwidths. In addition, to understand the high efficiency of Wi-Fi 6 in a congested area, we compute the average throughput of both IEEE 802.11ac and 802.11ax standards in a dense network scenario consisting of several wireless stations. For the simulation, we use network simulator (NS) version 3.36, in which two infrastructure networks are created – one for Wi-Fi 5 and another one for Wi-Fi 6. Based on the simulation analysis, it is observed that Wi-Fi 6 significantly improves the network throughput compared to Wi-Fi 5.

Organization of the paper: This paper is organized as follows. Section II presents the related works. Section III discusses the key features of IEEE 802.11ac and IEEE 802.11ax and the performance improvement factors in IEEE 802.11ax compared to IEEE 802.11ac. A comparative performance analysis of Wi-Fi 5 and Wi-Fi 6 is presented in Section IV. Finally, Section V gives the conclusion of this paper.

II. Related Works

The work in [4] compares the performances of IEEE 802.11ac standard and IEEE 802.11ax standard using NS-3 simulation and finds out that the protocol IEEE 802.11ax yields better throughput with higher MCS and clients rather than IEEE 802.11ac which can work at a maximum potential of MCS 9 and can serve lesser clients than IEEE 802.11ax. The authors in [5] focus mainly on the average throughput, delay, jitter, optimum range for goodput, and effect of station (STA) density per access point (AP) in IEEE 802.11ac networks. That work also evaluates the performance in NS-3 and the obtained results indicate that terribly high information transmission rates are possible by IEEE 802.11ac networks. The work in [6] compares the throughput of Wi-Fi 6 and Wi-Fi 5 for a single user. As mentioned in [6], even in a single user environment, 2 level frame aggregation in Wi-Fi 6 surpasses Wi-Fi 5 fairly by 29% and 48% in dependable and undependable channels, respectively.

Considering varying number of stations, the authors in [3] explore the advanced uplink mechanism of Wi-Fi 6 and its performance analysis, which shows that Wi-Fi 6 performs better than its successful predecessor Wi-Fi 5. In that work, the authors find out that in a SU scenario, the throughput of Wi-Fi 6 beats Wi-Fi 5 by around 64% and 85% in dependable and undependable channels, correspondingly. In case of Multi User-MIMO, throughput of Wi-Fi 6 outperforms the throughput of Wi-Fi 5 by up to 263% and 270% in both dependable and undependable channels, respectively. In [7], it is discussed how the throughput of Wi-Fi 5 decreases in a condensed network. In that work, the authors use the NS-3 simulator and create a local dense network to test the throughput of both Wi-Fi 5 and Wi-Fi 6 networks. The work in [8] compares the performance Wi-Fi 5 and Wi-Fi 6 in a residential system. To analyze the functioning improvement of IEEE 802.11ax with respect to IEEE 802.11ac, the work [8] compares the performance of both of these standards in a multi-user (MU) downlink scenario in a residential space.

However, bearing in mind the diverse groupings of MCS and channel widths, the performance judgment of Wi-Fi 5 and Wi-Fi 6 is yet uncovered, where it would be further interesting to study a comparative impact of different amount of stations on the performance of the aforementioned two network standards. Therefore, in this work, we consider the aforementioned unrevealed scenarios and accordingly present a comparative throughput analysis of IEEE 802.11ac and IEEE 802.11ax standards.

III. Overview and Performance Improvements in Wi-Fi 6 Compared to Wi-Fi 5 Standard

The IEEE 802.11ac standard (Wi-Fi 5) works only in the channel bandwidth of 5 GHz to avoid high interference levels, whereas the IEEE 802.11ax standard works fine in both the 2.4 GHz and 5 GHz channel bandwidths [9], which help produce more throughput than its predecessor. Using the 2.4 GHz band, it is possible to provide the internet access to a larger area by compromising the speed; whereas, using the 5 GHz band, it is possible to provide better speed by compromising larger area. In future, IEEE 802.11ax will also be able to work with the 6 GHz band courtesy of Wi-Fi 6E. Due to various hardware limitations, IEEE 802.11ac was never able to reach its maximum theoretical potential of 6.9 Gbps data rate. On the other hand, as technology got improved, IEEE 802.11ax stands in a better position than IEEE 802.11ac to reach closer to deliver its maximum theoretical potential of 9.6 Gbps data rate. In the best condition, IEEE 802.11ax uses 1024 QAM as compared to 256 QAM of IEEE 802.11ac, making the symbol duration 4 times wider than Wi-Fi 5, which lets more data transfer. Another feature that comes in Wi-Fi 6 is Basic Service Set (BSS) coloring, which deals with the interference from neighboring cells and increases the overall capacity. Next, we discuss the key features of Wi-Fi 5 and Wi-Fi 6.

A. Key Features of IEEE 802.11ac standard and IEEE 802.11ax standard

IEEE 802.11ax is regressive compatible with all the previous Wi-Fi versions like IEEE 802.11ac/b/g/n, etc., which means that all the features of those versions are also present in Wi-Fi 6 but in improved manner, and it consists of some more new features which make it more powerful and provide better performance than all the previous versions. In congested scenarios like busy train-station or airports etc., the average throughput of IEEE 802.11ax has increased by 4 times than its immediate predecessor IEEE 802.11ac.

Although the channel width and data rate of Wi-Fi 6 are similar as of Wi-Fi 5, the IEEE 802.11ax standard comes with new MCS sets, i.e., MCS 10 and MCS 11 with a new MCS sets (MCS 10 and 11) with 1024 QAM modulation as compared to the 256-QAM of Wi-Fi 5. The higher MCS values increase the physical layer data rate up to 25%. One of the most significant changes in Wi-Fi 6, which makes it better than all of its predecessors is that it supports both uplink and downlink

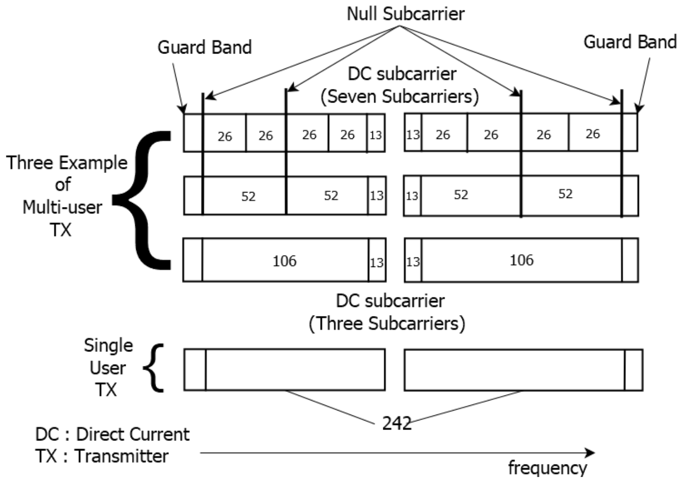

Fig. 1: Resource unit allocation in OFDMA

MIMO up to 8 users, allowing the data to come from 8 users and forwarding the data to 8 other users simultaneously. This approach makes the data transmission faster.

In a dense network, IEEE 802.11ac fails to give its best result and cannot work in its full potential [7]. IEEE 802.11ax aims to improve that section and gives better performance even in dense networks. Wi-Fi 5 standard uses Orthogonal Frequency Division Multiplexing abbreviated as OFDM technology [6], [10]. It is a form of the multi-carrier modulation which is capable of sending and receiving voice and data signals at the same time without having to be filtered. OFDM avoids the noise or interference without compromising the throughput. OFDM also uses multiple carriers by which the data can be transmitted parallelly within the OFDM signal. But, the problem with OFDM is that it can handle only one user at a time, and if there are multiple senders want to send information, they have to send it one after another, making it a time-consuming process. However, in IEEE 802.11ax standard, the modified version of OFDM is used, known as OFDMA [4]. It allows multiple users to send data simultaneously with the same throughput and without any interference. OFDMA divides the available bandwidth in smaller portions, known as Resource Units (RU), which can be used by multiple devices to connect with multiple clients at the same time. Fig. 1 shows the RU allocation in OFDMA.

For short packets of data, OFDMA also has 3 times higher throughput than single user OFDM. It combines the transmission and sends the frames to multiple end points simultaneously. This is more efficient with low latency transmission, allowing it to be the first choice of internet of things (IoT) devices, video streaming, online games, etc. Another feature added to IEEE 802.11ax is Quiet Time Period (QTP), which allows the standard to have Station-To-Station (S2S) and both transmissions of uplink and downlink types in WLANs. In [11], how the new QTP-based transmission in WLANs works with IEEE 802.11ax has been investigated.

1) Enhancements in Physical Layer in IEEE 802.ax: In Wi-Fi 5, only downlink MU-MIMO is supported, and it is only up to 4 users. Whereas, in Wi-Fi 6, both uplink and downlink MU-MIMO are supported for up to 8 users [9]. As a result, up to 8 times capacity is increased in uplink and up to 2 times capacity is increased in downlink. Wi-Fi 6 maintains the same channel bandwidth as IEEE 802.11ac standard, but IEEE 802.11ax standard increases the FFT by 4 times as compared to its predecessor IEEE 802.11ac standard, which means that in Wi-Fi 6, 4 times more subcarriers are present in a given bandwidth resulting in more data to be transmitted in a unit time to multiple users. In the time domain, the 4 times more subcarrier of Wi-Fi 6 translates into a longer OFDM symbol length [10]. In addition, Wi-Fi 6 modifies the guard interval (GI) for both indoor and outdoor data transmissions. For indoors, a long OFDM symbol with 0.8 μs GI allows the improvement of the user time domain efficiency due to the lower GI overhead. In the case of outdoor transmissions, a longer OFDM symbol combined with 3.2 μs GI addresses the longer delay spread in an outdoor environment, allowing a more robust and long-range data transmission [9]. Table I represents the difference of the PHY features between Wi-Fi 5 and Wi-Fi 6.

B. Performance Improvement Factors in Wi-Fi 6

Novel Wi-Fi 6 has several performance improvement factors which are discussed as follows.

1) High Efficiency: In comparison with Wi-Fi 5, the most important change in Wi-Fi 6 is improving efficiency and reducing delay. The immediate predecessor of Wi-Fi 6 uses the OFDM technology that can serve only one user at a time, whereas Wi-Fi 6 supports OFDMA which supports multiple user at the same time and thus reduces the delay of sending packets. In addition, Wi-Fi 6 also has improved the spatial data flow from 4 to 8. The average latency of Wi-Fi 6 is 20 ms, which is 10 ms less than that of Wi-Fi 5. Due to high efficiency and reduced latency, Wi-Fi 6 allows allows additional devices to connect to the network, however the steadiness of the network would not decline.

2) Throughput Enhancement: The primary objective of Wi-Fi 6 is improving the network throughput in congested network scenarios, such as shopping malls, corporate offices, and congested residential apartments. Wi-Fi 6 is projected to have a maximum capacity of about 9.5 Gbps in 2.4 and/or 5 GHz and has the aim of providing four times higher throughput than that of Wi-Fi 5. Supposing an OFDM-based PHY layer in which every OFDM symbol duration is prolonged from 3.2 μs (Wi-Fi 5) to 12.8 μs (Wi-Fi 6). The two new MCS values enhance the PHY rate of Wi-Fi 6. Moreover, Wi-Fi 6 surpasses its predecessor Wi-Fi 5 in an undependable channel more than in a dependable channel because IEEE 802.11ax standard empowers more Aggregated MAC Protocol Data Units (A-MPDUs) in a transmission. These MPDUs are often short so as to keep up an outsized success transmission chance, and therefore IEEE 802.11ax allows several short MP- DUs, with a comparatively greater success transmission probability. Table II presents the comparison of the maximum theoretical throughput of IEEE 802.11ac and IEEE 802.11ax standards.

TABLE I: PHY Features Comparison between Wi-Fi 5 and Wi-Fi 6

Features	**IEEE 802.11ac**	**IEEE 802.11ax**
OFDM constellation order	256-QAM	1024-QAM
OFDM symbol duration	3.2 μs	12.8 μs
OFDM guard interval	0.4 or 0.8 μs (10 or 20% overhead)	0.8, 1.6, or 3.2 μs (5, 10, or 20% overhead)
Maximal data rates	433 Mbps (for 80 MHz, 1 SS)	600.4 Mbps (for 80 MHz, 1 SS)
	6933 Mbps (for 160 MHz, 8 SS)	9607.8 Mbps (for 160 MHz, 8 SS)
Subcarrier spacing	312.5 kHz	78.125 kHz
Basic channel access	CSMA/CA	OFDMA above CSMA/CA
Random channel access	DCF, EDCA	Uplink-OFDMA above CSMA/CA
MU transmission direction	Only downlink MU-MIMO	Both downlink and uplink MU-MIMO
Fragmentation	Static fragmentation	Flexible fragmentation

TABLE II: Comparison of the Maximum Theoretical Throughput of Wi-Fi 5 and Wi-Fi 6 Considering the Guard Interval of 800 ns for a SU

MCS index	**Type of modulation**	**Coding rate**	**Data rates (Mbps)**							
			20 MHz		**40 MHz**		**80 MHz**		**160**	
			IEEE 802.11ac	**IEEE 802.11ax**	**IEEE 802.11ac**	**IEEE 802.11ax**	**IEEE 802.11ac**	**IEEE 802.11ax**	**IEEE 802.11ac**	**IEEE 802.11ax**
0	BPSK	1/2	6.5	8.6	13.5	17.2	29.3	36.0	58.5	72
1	QPSK	1/2	13	17.2	27	34.4	58.5	72.1	117	144
2	QPSK	3/4	19.5	25.8	40.5	51.6	87.8	108.1	175.5	216
3	16-QAM	1/2	26	34.4	54	68.8	117	144.1	234	282
4	16-QAM	3/4	39	51.6	81	103.2	175.5	216.2	351	432
5	64-QAM	2/3	52	68.8	108	137.6	234	288.2	468	576
6	64-QAM	3/4	58.5	77.4	121.5	154.9	263.3	324.4	526.5	649
7	64-QAM	5/6	65	86.0	135	172.1	292.5	360.3	585	721
8	256-QAM	3/4	78	103.2	162	206.5	351	432.4	702	865
9	256-QAM	5/6	N/A	114.7	180	229.4	390	480.4	780	961
10	1024-QAM	3/4	N/A	129.0	N/A	258.1	N/A	540.4	N/A	1081
11	1024-QAM	5/6	N/A	143.4	N/A	286.8	N/A	600.5	N/A	1201

3) Options of More Frequency Bands: IEEE 802.11ac standard supports only the 5 GHz band, but IEEE 802.11ax supports both the 2.4 GHz and 5 GHz channel bandwidths [4], thus allowing it to cover wider areas (utilizing the 2.4 GHz channel) and provide the internet with better speed to the users (utilizing the 5 GHz channel).

4) Data Transmission Speed: The transmission rate of Wi-Fi 6 has improved 3 times more than that of its predecessor. Wi-Fi 5 supports the maximum transmission rate of 6.9 Gbps; whereas, the transmission rate of Wi-Fi 6 can reach up to 9.6 Gbps. Based on the 9.6 Gbps transmission, we would be able to use the download speed of 1228 MB/s or 1.2 GB/s.

5) Security Enhancement: There is a significant change in the security feature provided by the Wi-Fi 6. Earlier versions like IEEE 802.11ac supports only Wi-Fi Protected Access better known as WPA and Wi-Fi Protected Access 2 better known as WPA2, which are vulnerable to the brute force attacks if users depend upon a vulnerable password or passphrase. Moreover, WPA and WPA2 do not provide forward secrecy, i.e., if one unauthorized or malice person finds out the pre-shared key (PSK), the person can potentially decipher all packets encoded using that Pre- Shared Key (PSK), which can be gathered by hackers without users knowledge. IEEE 802.11ax supports the latest and modified Wi-Fi Protected Access 3 (WPA3). When a user logs in to a communal network, WPA3 signs up an unknown device via a process rather than the traditional shared password or shared passphrase method. WPA3 uses a system known as Wi-Fi Device Provisioning Protocol (DPP) which let the users to use technologies like quick response (QR) Codes or Near Field Communication (NFC) to allow devices connect to the network. WPA3 helps prevent brute force attacks better than WPA2 and also allows users to enter the password only one time, so there is no chance of retry if the password is false.

6) Power Consumption Minimization: In Wi-Fi 5, when one device (terminal device) is interacting with the router (i.e., transmitting the data through a router), all other devices are alive and waiting to receive the data. This approach consumes a huge power as all the available devices have to be active during the entire session when the terminal device uses the router. But, in Wi-Fi 6, a new technology, called Target Wake Time (TWT), has been introduced, which allows the other devices to go into sleep mode when one device is interacting with the router. Therefore, a lot of battery life would be saved, and consequently Wi-Fi 6 is very much useful for IoT devices and other devices, which solely depend upon battery life.

IV. Performance Analysis of Wi-Fi 5 and Wi-Fi 6

We present a performance comparison between IEEE 802.11ac and IEEE 802.11ax networks. For that purpose,

TABLE III: Simulation Parameters

Parameter	**Value**
Wireless Networks	IEEE 802.11ac standard and IEEE 802.11ax standard
Guard interval	800 ns
MIMO antenna	2
Data mode and control mode	Constant rate wifi manager
Mobility model	Gauss Markov mobility model (“Bounds: Rectangle (0, 400, 0, 400)”, “Alpha”:0.85, “TimeStep”:0.5s, “MeanVelocity”:UniformRandomVariable [Min=800,Max=1200], “NormalDirection”:NormalRandomVariable [Mean=0.0, Variance=0.2, Bound=0.4]”, “MeanDirection”:UniformRandomVariable [Min=0, Max=6.283185307])
Path loss model	Log-normal path loss model (loss exponent=3.0)
Propagation delay model	Constant speed propagation delay model
Bit error rate (BER)	0.03
Simulation time	10 s
Number of runs of each simulation scenario	10

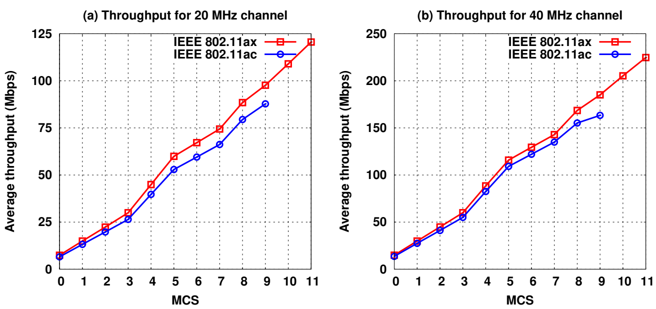

Fig. 2: (a) for 20 MHz channel (b) for 40 MHz channel

we use NS-3.36 [12] in which we create two infrastructure networks, where one of them is centered on IEEE 802.11ac and the other one uses the IEEE 802.11ax standard. Each of the infrastructure networks contains one AP and several wireless stations, where the quantity of stations ranges from 10 to 50 Packets are transmitted from the AP to the stations and vice versa. The TCP throughput is calculated with traffic payload of 1448 bytes. We execute each simulation scenario for 10 times. We have used signal-to-interference-plus-noise ratio (SINR) to measure the signal quality of the wireless channel, and we randomly vary the SINR during the simulation. To analyze the throughput performance under different MCS values and channel widths, we set the number stations to 10. Table III presents details of the simulation parameters.

A. Throughput Analysis under Different Channel Widths

Fig. 2 shows the variance between the average throughput of Wi-Fi 5 and Wi-Fi 6 in 20 MHz and 40 MHz channel widths. It is known to us that Wi-Fi 6 supports till 1024-QAM modulation, and thus Wi-Fi 6 can provide the throughput till the MCS index 11. But, IEEE 802.11ac provides the throughput up to MCS 9, as IEEE 802.11ac supports a maximum of 256-QAM modulation. In Fig. 2, in the beginning of the graph, the difference in the outputs of both the standards is marginal. However, a significant difference is visible from the MCS 4, i.e., 16 QAM, where IEEE 802.11ax starts to give better throughput compared to IEEE 802.11ac, and this trend

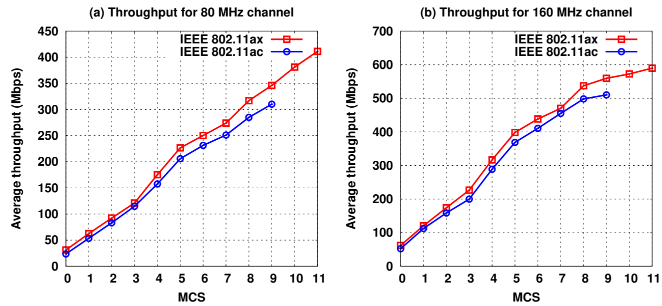

Fig. 3: (a) for 80 MHz channel (b) for 160 MHz channel

continues till the end of the graph. For instance, in the scenario of 20 MHz channel, the maximum average throughput of IEEE 802.11ac reaches approximately 87 Mbps, whereas novel Wi-Fi 6 reaches approximately 123 Mbps, as shown in Fig. 2(a). In case of the 40 MHz channel (Fig. 2(b)), the maximum average throughput of IEEE 802.11ax reaches nearly 230 Mbps, and in that scenario, Wi-Fi 5 achieves the maximum possible throughput of approximately 160 Mbps.

Fig. 3 shows how the average throughput varies for wider channel widths like 80 MHz and 160 MHz in Wi-Fi 5 and Wi-Fi 6 standards. From Fig. 3(a), it has been observed that the average throughput of IEEE 802.11ax standard reaches more than 400 Mbps for the maximum MCS value of 11, i.e., 1024-QAM modulation, which is approximately 2 times of the average throughput in the 40 MHz channel in Wi-Fi 6. The average throughput of Wi-Fi 5 reaches more than 300 Mbps for the maximum MCS value of 9, i.e., 256-QAM modulation, which is the maximum supported MCS in IEEE 802.11ac. In 160 MHz channel (Fig. 3(b)), the maximum average throughput of novel Wi-Fi 6 touches nearly 600 Mbps for MCS 11, and in case of its predecessor Wi-Fi 5, the maximum average throughput is approximately 500 Mbps for MCS 9. Therefore, it is clearly noted from Fig. 3 that there is always a difference of approximately 100 Mbps in the average throughput of Wi-Fi 5 and Wi-Fi 6, irrespective of the channel widths.

Hence, from Fig. 2 and Fig. 3, it is proven that the average throughput for both the standards increases as the MCS increases, and the enhancement in the channel widths further increases the average throughput. In that context, Wi-Fi 6 outperforms Wi-Fi 5. This is because Wi-Fi 6 uses higher spectral efficiency and is based on OFDMA.

B. Throughput Analysis under Different Number of Stations

From Fig. 4(a), which uses a 20 MHz channel bandwidth and modulation and coding scheme index of 0, it is noted that when the amount of stations is less, i.e., 10, the average throughputs of both Wi-Fi 6 and of Wi-Fi 5 are achieved to a maximum level. This is because when the amount of stations is 10, there is low congestion and signal interference, compared to that of higher number of stations. For IEEE 802.11ax, the average throughput is approximately 7.5 Mbps, whereas IEEE 802.11ac achieves average throughput of approximately 6.5 Mbps. As the amount of stations rises, the average throughput

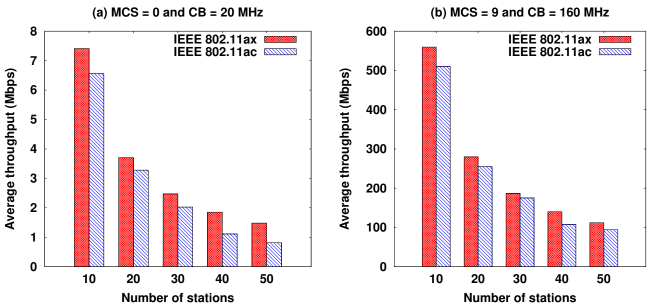

Fig. 4: (a) MCS = 0 and CB = 20 MHz (b) MCS = 9 and CB = 160 MHz

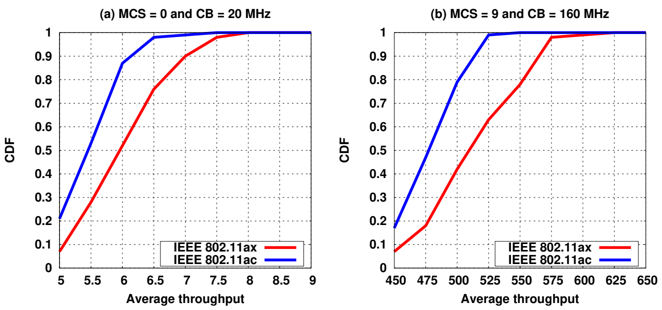

Fig. 5: (a) MCS = 0 and CB = 20 MHz (b) MCS = 9 and CB = 160 MHz

for both the standards decreases noticeably. When the amount of stations is 50, the average throughput of IEEE 802.11ax is approximately 1.5 Mbps, whereas the throughput drops to less than 1 Mbps in IEEE 802.11ac. From Fig. 4(b), when the channel bandwidth is 160 MHz, i.e., the maximum possible bandwidth with MCS 9 (in this case, we are not using MCS 11 since IEEE 802.11ac does not support more than MCS 9), the average throughputs of Wi-Fi 5 and Wi-Fi 6 are approximately 90 Mbps and 120 Mbps, respectively. Moreover, it is observed that when the amount of stations is lesser than 50, the achievable average throughput in Wi-Fi 6 is also always greater than that of Wi-Fi 5. Due to the utilization of greater spectral efficiency, Novel Wi-Fi version 6 (IEEE 802.11ax standard) is able to provide high throughput efficiency in dense networks, compared to IEEE 802.11ac standard.

C. Average Throughput Distribution

Fig. 5 demonstrates how the cumulative distribution function (CDF) of the average throughput depends on different MCS values and channel widths. For MCS 0 and channel width 20 MHz, it is noted that the probability distribution of the average throughput in IEEE 802.11ax is concentrated in the 6.5–8 Mbps range, whereas IEEE 802.11ac provides a lower distribution of the average throughput (6–7 Mbps) than IEEE 802.11ax, as demonstrated in Fig. 5(a). The average throughput increases as the MCS and channel width increase, and consequently the CDF of the average throughput gets improved, as demonstrated in Fig. 5(b). From this diagram, it is observed that the distribution of throughput in case of IEEE 802.11ax is concentrated in the 525–575 Mbps range, which is expressively higher than that of Wi-Fi 5 (up to 525 Mbps).

V. Conclusion

In this work, we present a comparative throughput analysis of Wi-Fi 5 and Wi-Fi 6. We identified that the high throughputs are achievable when different high MCS and wider channel widths are applied, and in that case, Wi-Fi 6 provides better performance than Wi-Fi 5. When the strength of the signal of that channel is high, as the channel width and MCS increase, the average throughput increases, which can lead to a better throughput distribution. In case of the analysis with both channel bandwidths of 80 MHz and 160 MHz, there is always a difference of approximately 100 Mbps of average throughput between IEEE 802.11ac and IEEE 802.11ax. Moreover, IEEE 802.11ac standard is resilient for large node densities; whereas, in congested network scenarios, Wi-Fi 6 provides higher average throughput than Wi-Fi 5. As a result, Wi-Fi 6 helps improve network efficiency, and this improvement is observed under different MCS and channel widths. Therefore, this work can help understand the throughput enhancement in Wi-Fi 6, which can lead to the further improvement of Wi-Fi 6 in future research works in the direction of HE-WLANs.

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