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# Understanding the Key Features of Wi-Fi 6 and Exploring the Effect of Modulation Scheme on Throughput Rate

**Mohammed Shakir Mahmood**
Scholarships and Cultural Relations Directorate, Ministry of Higher Education and Scientific Research, Baghdad, Iraq

**Maad Modher Khalil**
University of Diyala, Iraq, maadalomar@gmail.com

**Abstract:** Today, the number of smart devices and applications are increasing day by day, whereas the older versions of Wi-Fi stander, i.e., n/a/g cannot meet the greed and need of these devices. Thus, the development of applications and devices has called to design of a new Wi-Fi version. Hence, a new Wi-Fi 6 vision has been promoted based on 802.11 IEEE stander. The scope of this paper has focused on the study and overview of Wi-Fi 6 features. As well as, exploring the simulation tools that can be used to implement 802.11ax. A simulation has been done by using NS-3 to measure the effect of modulation and coding schemes on the throughput rate. Where a scenario of the network model was taken on a single AP with a node and the MCS value range is (0 to 7), the channel width (20, 40, 80 or 160 MHz) and the guard interval (800ns, 1600ns or 3200ns). The time of simulation was set to 10 seconds. Hence, the output results explained that the change of modulation properties can increase/reduce the throughput rate.

**Keywords:** wi-fi 6, 802.11ax, modulation and coding schemes, throughput rate

## Introduction

Wi-Fi has become the world's omnipresent technology. It offers free Wi-Fi for thousands of devices and provides a growing number of users with Internet access. Wi-Fi is also replacing wired internet connectivity unwaveringly [D. López-Pérez]. Each version of 802.11 standards significantly enhances the broadband speed in order to adapt to new service applications and reduce the gap in wireless network bandwidth [D. López-Pérez], [G. Naik]. A broader range of Wi-Fi access terminals is used in the form of video conferencing, wireless interactive VR, mobile teaching and other service applications [L. G. Giordano]. Further- more, the advancement of the Internet of Things (IoT) offers more and more smart home terminals. Improvements in Wi-Fi networks that handle different types of terminals are therefore crucial. This fulfils device bandwidth requirements for various types of terminal applications [A. Yang].

On the other side, the low performance of Wi-Fi net-works resulting from connections to multiple terminals needs to be tackled in the next generation Wi-Fi standard. Hence, 802.11ax proposes to fix this gap, and in 2019 the 802.11ax standard was ratified [D. López-Pérez], [A. Yang]. Moreover, by implementing innovations such as uplink MU-MIMO, multi-access orthogonal frequency division (OFDMA), and high-order 1024-QAM coding, 802.11ax is designed to address network capacity and transmission efficiency concerns from factors such as usage of spectrum resources and multi-user access [M. Yang]. Compared to IEEE 802.11ac (Wi-Fi 5), 802.11ax seeks to achieve a fourfold increase in total user throughput and more than threefold increase in concurrent user numbers in dense user environments [M. Yang]. The new 802.11ax stander contains new features that have been adopted in other older standards such as n , p, v, ah, etc. All features are present in 802.11ax, although only a few of these features were present in older standards [L. G. Giordano], [A. Yang]. The integration of all the features is what makes 802.11ax unique. The High Efficiency (HE) acronym, as opposed to the Very High Throughput (VHT) acronym, clearly shows where the heart of the technology lies. Dedicated to performance, maximum throughput numbers can be taken seriously [E. Khorov].

In more details, the Orthogonal Frequency Multiple Access Division (OFDMA) is the most important of the new functions [H. Mishra], [A. Kiryanov]. The other most important feature along with Beamforming is its default approval for MU- MIMO 8x8, uplink, and downlink. This together with an- other feature, BSS colouring, promises more efficient spatial reuse by mitigating interference from the co-channel (especially for 80/160 MHz channels). Standard MCS 10 and 11 support for up to 1024 QAM also helps to enhance maximum throughput [D. López-Pérez], [H. Mishra]. The new improvement in power-saving emerges from Target Wake

Time (TWT), which is quite advantageous for mobile and IoT devices. In outdoor scenarios, longer guard intervals make the signal more robust [A. Kiryanov].

For more information, Table I explores the differences between IEEE stander related to 802.11n, 802.11ac and 802.11ax and the new features of Wi-Fi 6 [D. López-Pérez], [G. Naik], [H. Mishra]–[D. G. Filoso]. The Wi-Fi 6 features will provide for user and companies a unique experience related to the network environment of Wi-Fi. For instance, the enhanced functionality would increase the performance of batteries on smartphones, tablets and IoT computers [D. López-Pérez], [H. Mishra]. Better Wi-Fi coverage and 2.4 GHz support make the 802.11ax ideal for IoT devices [R. P. F. Hoefel], [J. S.-C. Hsin].

In brief, the IEEE 802.11 specifications set certain specific stipulations and on which the wireless devices are approved by the Wi-Fi alliance [D. López-Pérez]. The new 802.11ax standard, the 11ac standard’s replacement, aims to address all of our concerns by improving the way Wi-Fi operates. While promising higher velocities, it also promises more efficiency [H. Mishra]. Moreover, the 802.11ax standard aims to accommodate a large number of simultaneous connections, respectively. It enhances the user experience in a crowded network environment for both upload and download operations [A. Kiryanov]. It also promises significant power efficiency improvements that will boost IoT and Portable devices [R. P. F. Hoefel].

The motivation of this study is to explore new IEEE standard 80.211ax related to WiFi 6 and discuss the new features and characteristics. Also, to know the simulations tools that can be used to simulate 802.11ax. Finally, a simulation experiment by NS-3 has been done to explain the impact of modulation and coding schemes in the throughput rate.

Table 1. 802.11n, 802.11ac, and 802.11ax Comparison

| **IEEE stander** / **Properties** | **802.11n (Wi-Fi 4)** | **802.11ac (Wi-Fi 5)** | **802.11ax(Wi-Fi 6)** |
|---|---|---|---|
| **Frequency bands** | 2.4 GHz and 5 GHz | 5 GHz only | 2.4 GHZ, 5 GHz, 6 GHz |
| **Channel size (MHz)** | 20,40 | 20, 40, 80, 80 + 80, and 160 | 20, 40, 80, 80 + 80, and 160 |
| **Frequency multiplexing** | OFDM | OFDM | OFDM and OFDMA |
| **OFDM symbol Time (µs)** | 3.2 | 3.2 | 12.8 |
| **Guard interval (µs)** | .04 or .08 | .04 or .08 | .08, 1.6, or 3.2 |
| **Modulation** | Binary Phase-Shift Keying (BPSK), Quadrature PhaseShift Keying (QPSK), 16-QAM, 64-QAM | BPSK, QPSK, 256-QAM 16-QAM, 64-QAM, | BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM, 1024-QAM |
| **MU-MIMO** | N/A | DL | DL and UL |
| **OFDMA** | **N/A** | **N/A** | DL and UL |

## Why New IEEE AX Stander

Wi-Fi service’s primary function was to deal with high- density networks such as large public spaces. The high-density keyword refers to many users, i.e. 20 devices that need to win a high-quality connection simultaneously [D. López-Pérez], [M. Yang]. Onward this represents a challenge for companies to address all of this request, in particular the nature of different applications. On the other hand, due to the emerging IoT applications and devices that can increase the complexity of the Wi-Fi network task [J. S.-C. Hsin], [D.-J. Deng]. For example, there are many IoT devices in the university, home, company and the other parts, which expects more Wi-Fi challenges.

In more, Wi-Fi 6 addresses the efficiency of wireless networks through many dimensions [H. Mishra]. Although

Wi- Fi innovation has traditionally concentrated on achieving higher data peak rates for a consumer, Wi-Fi 6 does this with a radically different focus. Onward, Wi-Fi 6 has been designed to increase both overall efficiency and capacity. This move from speed to capability and reliability in priority aligns with the broader macro trends towards ever higher average data rates per device as networks compete with more users' device and higher deployments of densities.

In summary, Wi-Fi 6 improvements in the performance 2.4 GHz and 5 GHz band. Also, the throughput average increases per station by at least four times in dense deployment scenarios. About the indoor and outdoor operations, the IEEE 802.11ax stander enhancement environments maintenance and improvement of power efficiency in stations. The new Wi-Fi 6 features also play on enhancement the traffic management an efficient way in a variety of environments.

**802.11AX Components Enhancement**

802.11ax has strengthened communication through the rapid advancement of the working theory of Wi-Fi net-works. We'll review some of the most significant features and characteristics in this section.

## OFDMA

OFDMA is a function put in 11ac. OFDMA is currently working in the LTE (long term evolution) 4G cellular standard [D. López-Pérez], [D. Weller]. By creating more subcarriers (Resource Units) to support different clients with varying bandwidth requirements, OFDMA makes better use of the frequency spectrum. OFDMA is a multiuser variant of the multiplexing single-user orthogonal frequency division (OFDM), where users are allocated sub-sets of carriers known as sub-carriers [D.-J. Deng], [D. Weller]. The radios of 11 ax also support OFDM for backward compatibility with clients of a, g, n and ac [D. Weller].

In fact, OFDMA is extracted from OFDM simply by assigning the sub-channels to different users at the same time interval, while in OFDM all the bandwidth is as- signed to one user at each time interval [D. López-Pérez], [H. Mishra], [D. Weller]. The discrepancy between OFDM and OFDMA is depicted in Fig. 1 a and b [D. López-Pérez]. The smaller allocations of frequencies are called resource units. They allow an access point to synchronize contact with multiple clients allocated to separate resource units (both up-link and down-link) [B. Bellalta]. The data may be transmitted to several users by subdividing the channels into smaller sub-carriers [D. López-Pérez]. This simultaneous transmission enjoys reduced MAC overheads [B. Bellalta]. It is also benefiting from decreased overhead medium contention [K. Wang]. It is also benefiting from decreased overhead medium contention [D. López-Pérez]. The access point may decide to assign the entire channel to a single client, or partition it to serve multiple clients as shown in Fig. 1 b, depending on the client request. OFDMA leads to better frequency reuse and reduced overall latency making it more efficient [M. Yang].

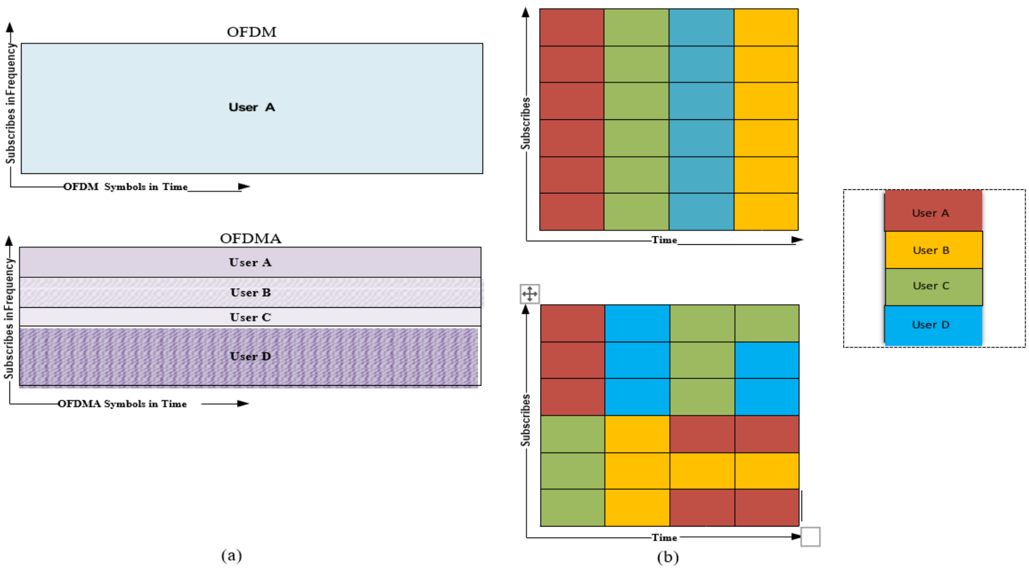


Figure 1. Difference between ODFM and OFDMA Frequency Allocation over Time

**Subcarriers**

Subcarriers are a smaller canal of bandwidth [H. Mishra]. The wireless a, g, n, ac OFDM subcarriers were 312.5 kHz wide so the subcarriers are orthogonal, thereby preventing inter- channel interference [D. Weller]. The 20 MHz channel is set to more symbol times of 12,8 us, thereby reducing the spacing to 78,125 kHz and raising the total number of subcarriers to 256, as shown in Fig. 2 [D. López-Pérez], [H. Mishra], [D. Weller].

There are three types of sub-companies: data sub-companies, pilot sub-companies and unused sub- companies. Sub-carriers of data are used to relay data [A. Yang],[R. P. F. Hoefel]. The pilot subcarriers are used for the synchronization of step details and monitoring of other parameters between the access point and client. Unused subcarriers are used against interference from neighboring channels or sub-channels as guard band subcarriers, or null subcarriers. With Uplink-OFDMA the manufacturer reports a better range of 80.

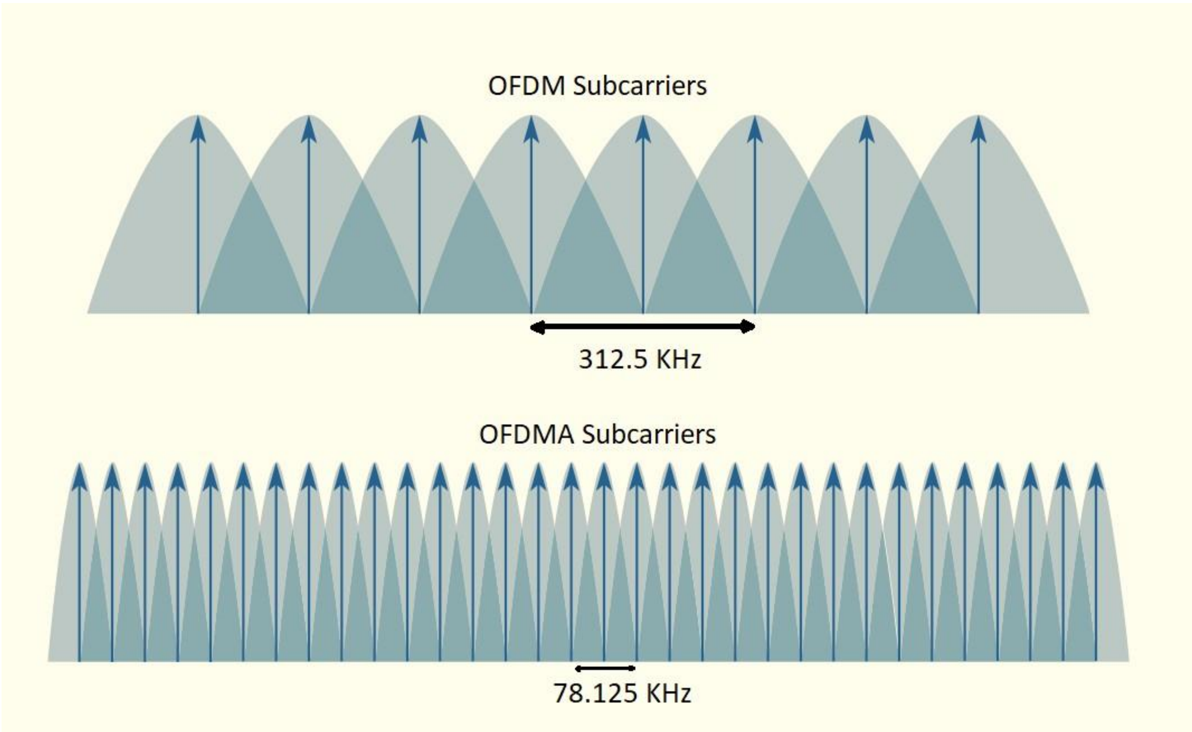


Figure 2. OFDM vs OFDMA Subcarriers

**Resource Units**

Once an 802.11n / ac AP transmits to 802.11n / ac users on an OFDM Channel, the whole channel frequency space is used for any channel transmission autonomous down-link [K. Wang]. When using an OFDM with 20 MHz Both subcarriers are used as channels for each individual trans- mission [D. López-Pérez], [H. Mishra], [K. Wang]. In other words, for the connection among the AP and a single OFDM client, the intact 20 MHz channel is required. The same applies to any uplink communication between a single 802.11n / ac client and the 802.11n / ac AP [D. Weller]. For client communication to the AP, the intact 20 MHz OFDM channel also is required [B. Bellalta]. An OFDMA channel, as shown in Fig. 3, comprises a total of Subcarriers 256 [D. Weller]. These sub-carrying companies can be divided into smaller Subchannels known as resource units (RUs) [H. Mishra]. Once dividing a 20 MHz channel, the 26, 52, 106, and 242 subcarrier RUs can designate by an 802.11ax AP, approximately equivalent to 2 MHz, 4 MHz, 8 MHz, and 20 MHz, respectively [D. López-Pérez], [D. Weller].

The 802.11ax AP defines how to use multiple RUs in a 20 MHz path, which can be used with in multiple combinations [D. Weller]. The AP can delegate just one client at a time to the whole channel, or it can break the channel to serve multiple clients at the same time. For example, an 802.11ax AP can communicate (up-link or down-link) using an 8 MHz sub-channel simultaneously with a single 802.11ax client and three other 802.11ax clients using 4 MHz sub-channels [D. Weller].

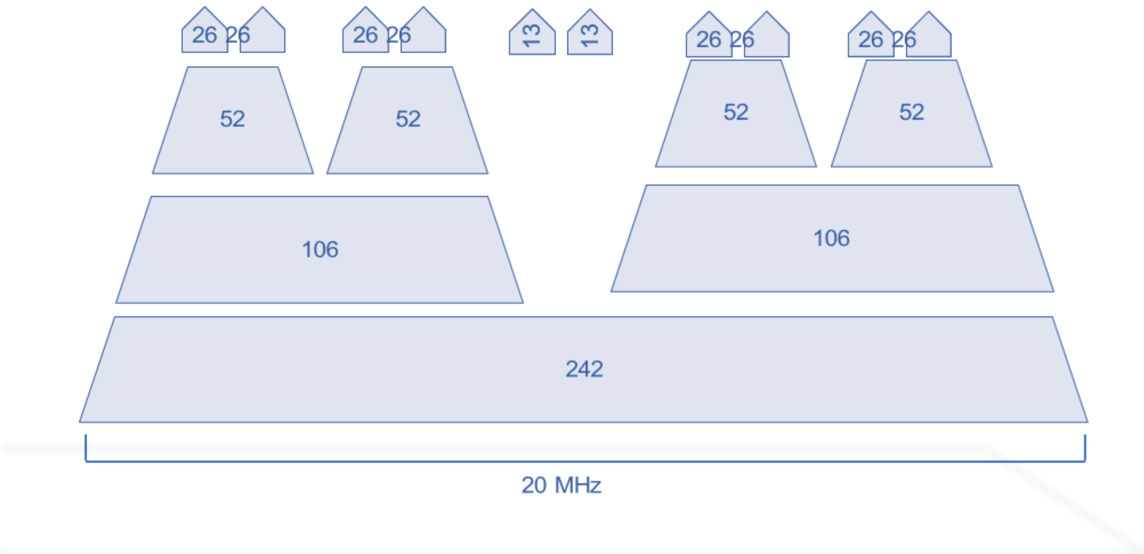


Figure 3. OFDM vs OFDMA Subcarriers

**MU-MIMO**

Multi-user, multiple-input multiple-output (MU- MIMO) is a system that allows multiple users to operate at the same time Transfer or receive data from an AP, rather than round-robin [A. Kiryanov]. As shown in Fig. 4, the main factor is the inclusion of multiple antennas, which can help achieve multiplexing and spatial diversity [D. López-Pérez], [A. Kiryanov], [D. Weller]. When several antennas exist, they can be used to transmit the same or different data set depending on what one is trying to accomplish. Thus an access point with N antennas is able to communicate simultaneously with N devices instead of one device at a time [A. Kiryanov]. In more, the 802.11ax draught amendment proposes several major MU-MIMO improvements including grouping of data frames and other frames among multiple users to minimize overhead and improve the response time for uplink [A. Kiryanov]. It will also use trigger frames to signal 802.11ax clients cooperate in MU-MIMO messaging uplinks [D. Weller]. 802.11ax is made to enable up to 8x8x8 MU-MIMO in both downlink and uplink, allowing for simultaneous operation of up to eight users and substantially higher data throughput [D. López-Pérez], [A. Kiryanov].

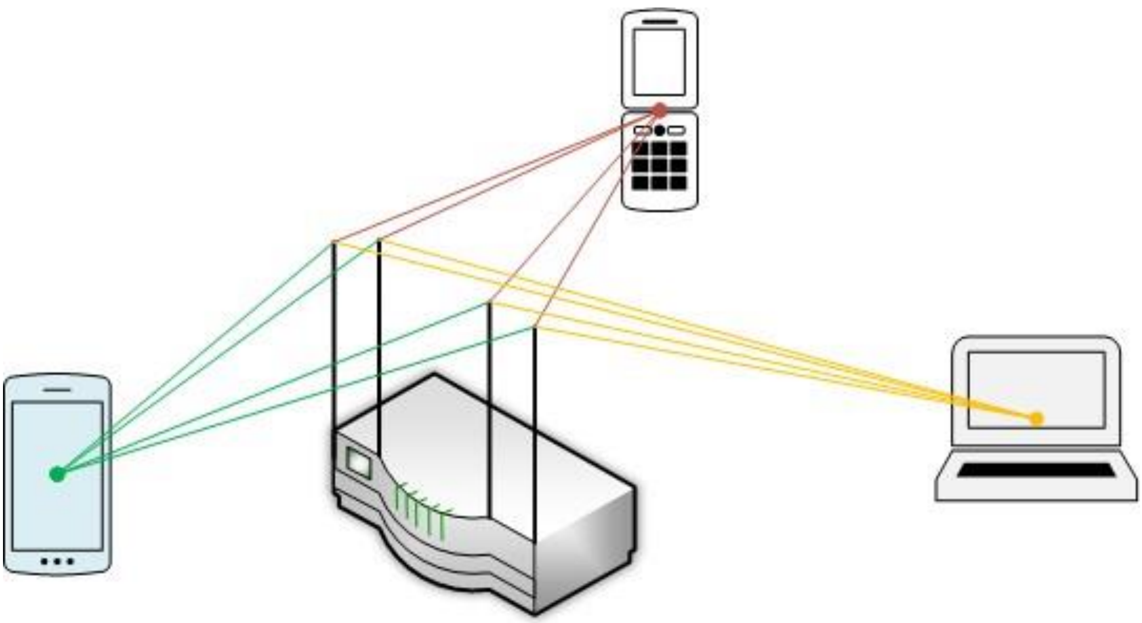

Figure 4. Multi-user Multiple Input Multiple Output Concept

**Spatial Reuse**

Wi-Fi typically uses CSMA-CA (Carrier Sense with Multiple Access collision avoidance) to ensure that at any given time only one radio is transmitting in the channel. When the 802.11 radio hears PHY preamble of some other radio at a 4 dB (4 dB higher than Noise Floor) signal detection threshold, it defers transmission [H. Mishra]. This overhead conflict becomes a big problem when there are so many Wi-Fi access points surrounding it, such as in an apartment complex or in any public space with several APs [E. Khorov], [H. Mishra].

This is commonly referred to as Co-Channel Interference, which is called Overlapping Basic Service Sets (OBSS), where each point of entry is a Basic Service Set (BSS) [D. G. Filoso]. This phenomenon greatly impacts perceived data volumes [A. Kiryanov], [D. G. Filoso]. The data rate is about 55-65 percent of what the advertised rates are due to all the postponed transmission and waiting [D. Weller]. By giving a numerical identifier called BSS Color to each BSS, 802.11ax proposes to fix this issue. The BSS colour allows a receiving station to distinguish the activity in order to increase efficiency [D. López-Pérez]– [L. G. Giordano]. Uses the correct channel access rules for spatial reuse BSS from which a PPDU originates so that the station [K. Wang].
In a word, the bit of colouring is discovered by the colouring of BSS for physical header related to the frame of 802.11ax [K. Wang]. In more, the client of 802.11a/b/g/n is unable to understand the bits of colour bits due to they are applying a strange physical header format [D. López-Pérez], [K. Wang]. Thus, the access of channel relies on detecting of colour. The operation of carrier sense can be arranged by new IEEE 802.11ax stander that depended on the foundation of the colour of the BSS which improves the performance [D. Weller].

**Target Wake Time**

The need for regular scheduling in the new scheduling framework called Take Wake Time (TWT) [K. Wang]. It greatly decreases beaconing and may use TWT setup frames between the client and the access point where the client is able to negotiate a scheduled TWT [B. Bellalta]. For various kinds of traffic asks each client has up to 8 scheduled wake-ups. For instance, VoIP can be scheduled more frequently than weather forecasts, messages can be scheduled more frequently than emails, etc [D. López-Pérez], [H. Mishra]. The access point generates a wake-up schedule and delivers on a TWT broadcast procedure to the clients.For instance, VoIP can be scheduled more frequently than weather forecasts, messages can be scheduled more frequently than emails, etc [D. Weller]. The access point generates a wake-up schedule and delivers on a TWT broadcast procedure to the clients [Q. Chen].

On a standard wake schedule, stations can agree with the AP to allow them to awaken only when appropriate, thus reducing energy usage and contention within the Basic Service Set (BSS), i.e. the wireless network defined by the AP and associated stations. Two are the key concepts in order to illustrate how TWT operates [Q. Chen]. The length of the TWT session or Session Period (SP) is the period during which the information is collected or transmitted by the wake station [D. López-Pérez], [H. Mishra], [A. Kiryanov], [Q. Chen]. The TWT Agreement is the final agreement to specify the particulars of the TWT SPs to which the station will belong, such as the time(s) for the station to awaken [Q. Chen], obtained after an agreement between the AP and the station. Indeed, one TWT arrangement allows the station to participate in the routine awakening of many TWT SPs [Q. Chen].
The TWT feature in IEEE 802.11ax is therefore based on the implementation of IEEE 802.11ah. It also includes, besides the individual TWT, the Broadcast TWT. This new type of arrangement should allow the efficiency of the TWT service to be enhanced and the new IEEE 802.11ax multi-user capabilities to be better utilized.

**Effect of Modulation and Coding Schema on Data-rate**

The Modulation and Coding Scheme (MCS) index values can be used to set the required data rate for access to the Wi-Fi network [D. López-Pérez], [H. Mishra], [D. Weller]. The value of the MCS is essentially the secret to recapitulating the number of spatial streams [A. Kiryanov]. In the meantime, during connection to the wireless AP, the modulation and coding rate styles become possible [D. Weller]. In reality, the initial MSC value relies on the resource of variables, which refers to the nature of the hardware and local interference [A. Kiryanov]. More precisely, if the Wi-Fi connection or wireless connection can not be sustained due to an error connection, such as multiple CRC errors on the link, then MSC value can be decreased to reduce the error rate [K. Wang].

More acceptable form of modulation / coding rate selection will effectively contribute to lowering the error price. However, this method may have a direct effect on the transition of the average data rate. In fact, the MSC can detect the type of link, i.e., wireless or Wi-Fi, but this does not reflect the actual [D. G. Filoso]. As an example, the table below will explore the range of MCS index values [M. Yang], [A. Kiryanov]. In more, various features may have a direct impact on the data rate [M. A. Rahman], [M. A. Rahman]. The 802.11ax modulation and coding rate that can decide how data is transmitted over the air can reach up to 1024-QAM [A. Kiryanov], [D. G. Filoso], [D. Weller]. In comparison, the 802.11n max range can exceed 64-QAM. Using a simple modulation like BPSK, on the other hand, will help repair the error-link connection. Furthermore, the frequency range has also expanded from 20MHz to 160MHz[L. G. Giordano]. However, the frequency of the channels in 802.11n / ac can not exceed 80MHz. The Guard Interval (GI) is called a short pause time [D. Weller].

This time can be set between the transmissions of the packet to allow any incorrect information to be dropped. Similarly, the data rate is mainly influenced by the intensity and distance of the received signal (SNR) [A. Kiryanov]. There- fore, for greater data-rate reliability, several variables have to be taken into account.

## Simulation Tools

Firstly, MATLAB and NS-3 are the simulation tools that can use for 802.11ax. MATLAB has developed to be able to deal with new stander. MATLAB provides many functions such as waveform generation for high-efficiency (HE) Wi-Fi formats, OFDMA, etc., which make easy to simulate Wi-Fi 6. In contrast, NS-3 is open-source soft- ware. NS-3 in version 3.30 starts support 802.11ax stander. It provides spatial reuse features and other functions. For more details, the next section provides a simple scenario to explorer the effect of modification Modulation and Coding Schema on the date-rate average.

## Performance Evaluation

The scenario of the network model is considered that there is a single AP with a node. the MCS value is belong to (0 to 7), the channel width (20, 40, 80 or 160 MHz) and the guard interval (800ns, 1600ns or 3200ns). The time of simulation is set 10 seconds. To enable the stander 802.11ax in NS-3, that needs to call a specific function as explained below:

**i f** ( frequency == 5 . 0 ) {w i f i . SetStandard (WIFI_PHY_STANDARD_80211ax_5GHZ ) ;}
**else if** (frequency==2.4) {wifi.SetStandard (WIFI_PHY_STANDARD_80211ax_4GHZ ) ;}

This code shows how to set the 802.11ax and how it can change the frequency range. The change of MSC index, GI, and channel width can fluctuate with throughput. To enhance the throughput, that needs to select the suitable MSC index. It clears that the range of throughput increase with change MSC index, which means changes the modulation type, frequency, code rate. According to that, the new wi-fi version can get higher throughput rate comparing to the older Wi-fi version. Thus, the Table 2 explores how the throughput rate can effect with different value of guard interval, and channel width related to MSC. Thus, the change of MSC index value and properties has a direct impact on throughput rate.

Table 2 Effect of Varies MSC on throughput Rate

| **Channel width** | **GI** | **Throughput rate (mbit/s) with MSC index** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **MCS = 0** | **MCS = 1** | **MCS = 2** | **MCS = 3** | **MCS = 4** | **MCS = 5,** | **MCS = 6** | **MCS = 7** |
| 20 MHz | 3200 | 6.62047 | 13.2975 | 19.9568 | 26.6656 | 40.0278 | 53.463 | 60.0435 | 66.85 |
| 20 MHz | 1600 | 7.31643 | 14.8048 | 22.186 | 29.6755 | 44.4886 | 59.3181 | 66.7369 | 74.1476 |
| 20 MHz | 800 | 7.72623 | 15.6374 | 23.4719 | 31.4772 | 47.0734 | 62.8838 | 70.8279 | 78.5589 |
| 40 MHz | 3200 | 13.2409 | 26.609 | 39.9383 | 53.463 | 80.0556 | 105.793 | 118.455 | 131.017 |
| 40 MHz | 1600 | 14.7388 | 29.5931 | 44.3896 | 59.351 | 89.0266 | 117.02 | 130.869 | 144.817 |
| 40 MHz | 800 | 15.5714 | 31.3889 | 46.9438 | 62.9545 | 94.0714 | 123.5 | 138.14 | 152.631 |
| 80 MHz | 3200 | 27.7855 | 55.8159 | 83.6567 | 110.789 | 162.226 | 211.191 | 235.277 | 258.771 |
| 80 MHz | 1600 | 30.8461 | 61.983 | 92.9833 | 122.51 | 178.795 | 232.211 | 258.573 | 284.341 |
| 80 MHz | 800 | 32.5901 | 65.6736 | 98.1271 | 129.237 | 188.489 | 244.427 | 271.976 | 299.08 |
| 120 MHz | 3200 | 55.5403 | 110.541 | 161.583 | 210.993 | 302.245 | 385.188 | 428.267 | 466.895 |
| 120 MHz | 1600 | 61.6756 | 122.164 | 178.103 | 232.063 | 331.03 | 420.552 | 466.697 | 508.391 |
| 120 MHz | 800 | 65.3815 | 128.792 | 19.9568 | 244.477 | 347.847 | 440.83 | 488.657 | 530.945 |

## Conclusion

This paper discusses in details Wi-Fi 6 features and functions to overcome on Wi-Fi challenges in the old versions. A compare between Wi-Fi 6 and old versions is placed to identify the different characteristics between them. Simulation tools have gotten much interest in this research by implement NS-3 to design a simple network topology that includes the features of WI-FI 6. The simulations design focuses on the study and analysis of the effect the type of modulation and coding on Wi-Fi 6 throughput performance. The results discovered that the throughput rate could achieve the performance with dynamically change with the change of modulation features compare to the old Wi-Fi versions.

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