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***Abstract*—The High-Efficiency (HE) standard is considered as generation Wi-FI 6, which is an improvement of legacy 802.11 standards. The new Wi-Fi 6 of 802.11ax standard aims to improve throughput and minimize latency. One of the significant applications of 802.11ax standard will be in dense wireless scenarios such as the Industrial Internet of Things (IIoT). How much 802.11ax as HE standard will improve the throughput compared to 802.11n as Hight-Throughput (HT) standard? The aim of this paper is to tackle this question using the NS3 simulator. This performance comparison will be based on throughput parameters such as the modulation and coding scheme (MCS), the Channel Bounding, and the Guard Interval. The comparison is carried out over the two ISM bands of 2,4 and 5 GHz. The results show that the 802.11ax standard can achieve four times throughput higher than the 802.11n over the same simulation conditions.**

***Index Terms*—Throughput Performance, High Throughput Mode, High Efficiency Mode, Channel Bounding, Guard Interval.**

## I. INTRODUCTION

The basic 802.11 standards were implemented in 1997. The physical layer of the wireless standards is impacted by several parameters which define the radio channel characters. These parameters such as the frequency band, channel number, bandwidth, modulation type, and coding ratio. The physical and MAC layers determine the throughput, which is considered one of the most critical QoS parameters of wireless link performance (depending on the application). The first wireless standards achieved the target throughput based on the modification techniques. The first efficient changes in the channel bandwidth were released in the 802.11n [1] standard as Wi-Fi 4. Two new techniques were implemented in IEEE802.11n, named as High Throughput wireless mode (HT). The first technique was to increase the channel bandwidth from 20 to 40 MHz, and the second one is utilizing the MIMO (multiple input multiple outputs) technologies. MIMO with $4\times4$ can increase the channel capacity up to 4 times compared to the SISO technology used in the legacy standards such as 802.11b and 802.11g. The 802.11n is currently still used in some old wireless devices and supported by the new personal devices. The market and mobile applications demand higher and higher throughput and channel utilization. The new standards such as Wi-Fi 5 of IEEE802.11ac [2] which is termed as Very High Throughput (VHT), and Wi-Fi 6 of the 802.11ax [3] standard which is termed as High Efficiency (HE) are presented as new wireless LAN generations. The target of the new 802.11 standards was to improve the channel throughput and reduce packet latency. One of the objectives of releasing the Wi-Fi 6 of 802.11 ax is to increase the average throughput compared with Wi-Fi 5 of 802.11 ac. Several new evolution have been introduced in the Wi-Fi 6 of 802.11ax standard to achieve the desired throughput. The main change were related to the physical layer. First, a new Modulation and Coding Scheme (MCS) has been implemented. The number of MCS for 802.11n (HT) was from 0 to 7 levels, and 802.11ac (VHT) has MCS from 0 to 9. However, the new 802.11ax (HE) has MCS from 0 to 11 levels. Moreover, The 802.11ax was one of the first wireless technologies with very high modulation levels like QAM- 1024. On the other hand, besides the MIMO of Wi-Fi 4, Wi-Fi 6 also uses the OFDMA technology to improve the uplink channel and minimize the access delay. Using the OFDM and/or OFDMA technology impacts the maximum channel throughput. This throughput is related to the bandwidth specified by channel data transmission. The third main change is related to the symbol length and Guard Interval (GI) in the time domain. Throughput analysis of WiFi-6 based on intensive simulation is presented in this article. This paper targets to present a clear understanding of the 802.11ax standard. This paper sections are ordered as follows, Section II presents brief of researches related to the paper area. In Section III, the paper presents a background of 802.11n and 802.11ax standards. Moreover, section IV presents detailed information about 802.11n and 802.11ax standards. The simulation scenario and its results are collected in section V, where the authors measure the throughput performance for both standards in two bands of 2.4 and 5 Ghz. Section VI concludes the paper results and suggested future work.

## II. RELATED WORK

IEEE802.11n standard as a wireless network has been deployed worldwide due to its low costs with high-speed transmissions feature. The paper [4] proposes the throughput drop estimation model for interferences of two interfered links under various conditions. However, the paper [5] estimates the throughput drop for multiple wireless links under interferences, where the 40 and 20 MHz bandwidth channels were considered. The paper observed that the use of channel bonding could improve the channel capacity while reducing channel interference. This paper studies the drop by comparing the measured throughput value with the estimated one under various network topologies. While this paper [6] proposes a simple solution for the guard interval with a modulation coding scheme to optimize the throughput of a wireless network. This paper analyzes the effect of the modulation and coding schemes beside the guard interval value under the bit error rate. Numerical results of this paper show an increase in the throughput of the wireless network. The survey in [7] discusses the impact of PHY/MAC layer enhancements in HT-WLANs over transport/application OSI layers. This paper lists significant open challenges that can be used for developing wireless next generation. The paper [8] carries out experiments by employing commercial equipment and quantifies the comparison provided by the 802.11ac standard when compared to 802.11n standard. The paper's experimental results show that in the 5Ghz band with a specific MIMO configuration, the 802.11ac standard provides better throughput when compared with 802.11n. As far as we know, no deep study is considering comparing the 802.11ax and the legacy Wi-Fi standard. Especially when the study has considered the throughput and uplink delay perspectives. This paper [9] provides a deep comparison of uplink MU- and SU-MIMO based on the delay and throughput. The authors of the paper [10] develop a throughput maximizing for the 802.11ax networks. The proposed scheduler work in the downlink and uplink directions. The proposed scheduler was evaluated using the NS3 simulator and compared with the legacy of 802.11 standards. Simulation results show that the proposed scheduler increases the throughput as well as decreases the delay regardless of the station's number. The authors of the paper [11]suggest a machine learning-based technique for the improvement of the channel performance using prediction learning. The paper investigates the channel performance using MATLAB simulation scenarios under various configurations. The paper results show that overall performance improvement is more than 80% . The work [12] introduces the new wireless generation of 802.11be, which is termed Extremely High Throughput (EHT). This paper presents the primary timelines and objectives of this new Wi-Fi generation and describes its main implemented features and enhancements. The paper provides simulation results to evaluate the potential throughput gains by EHT and demonstrates important aspects such as backward compatibility with legacy wireless technologies.

## III. Background for 802.11n and 802.11ax

The IEEE802.11n standard operates in two bands of 2,4 and 5 GHz. A new frequency band of 6 GHz has been utilized in the last generation of the 802.11ax standard. Furthermore, IEEE802.11n uses the MIMO (Multiple Input Multiple Outputs) technologies in addition 802.11n standard uses (Orthogonal Frequency Division Multiplexing ) OFDM modulation. There is new modulation deployed in new technologies. The 802.1ax standard uses the new modulation of (Orthogonal Frequency Division Multiple Access) OFDMA. The following parameters are used to compare between two standards of 802.11n and 802.11ax and are related to the throughput metric of channel utilization.

### A. *Channel Bonding*

By combining two 20 MHz channels as a single 40 MHz wireless channel, it is possible with this technique to increase the channel data rate. This Channel Bounding (CB) approach has been used since releasing 802.11n as Wi-Fi 4 to increase throughput and backward compatibility. Increasing the wireless channel bandwidth is the most straightforward way to increase the channel data rate. This technique of improving the throughput is used in all the generations of the 802.11 standards, in which 40, 80, and, 160 MHz bandwidth channels are implemented by bonding the basic or legacy 20 MHz channels. The 40 MHz channel is implemented by combining two adjacent 20 MHz channels. Similarly, the two adjacent 40 MHz channels are implemented together with the 80 MHz channel. The wider channels used in 802.11 standards, such as WiFi 4 and 6, lead to a high probability of channel overlap in frequency and space, especially in scenarios of high-density stations. Improving the throughput by channel bounding may lead to overlap and interference wireless issues.

### B. *Modulation and Coding Schemes*

The choice of modulation type and coding rate on Modulation and Coding Schemes (MCS) is the most influential item on the performance of the communication link. While IEEE802.11n has only a 9 MCS index., the 802.11ax, on the other hand, has 11 MCS. The higher the modulation index, the more data rate, but it requires a better channel quality at the receiver side, i.e., a higher Signal to Noise Ratio (SNR). Modulation depends on how many bits are allocated to each symbol during the transmission. The higher the code rate yields to more data rate. At any time, modulating scheme for a higher data rate will lead to increase the error rate, This may, at some point, increase the error rate, which will decrease the data rate and throughput.

### C. *Guard Interval*

Guard Interval (GI) is the time required between transmitted symbols. As an example, the 802.11n uses a complex modulation technique which is named as an OFDM. Where some of the input data blocks are coded as a single OFDM symbol. In order to achieve the desired performance, the symbols should be decoded correctly. Inter-symbol interference (ISI) comes from the multipath nature of wireless RF transmission, where each path has its delay and strength profile. Therefore, different symbols would intefer with each other. The guard interval between symbols is usually shorter than the delay spread. Setting the guard interval to be larger than the delay-spread of the channel means a significant loss in the throughput as well as an unacceptable latency. The value of GI should be determined carefully where its value impact throughput and delay.

## IV. Comparison of 802.11n and 802.11ax standards

IEEE802.11n standard is now commonly used as the wireless interface on PCs, tablets, and smartphones. Where 802.11ax nowadays is a faster version of 802.11 standards, it integrates the advantages of mobility of wireless and gigabit ethernet of link throughput. Nowadays, with the Internet of Things scenarios, wireless networks can support more clients as dense networks with larger and stable throughput; these networks can handle more video streams, a higher delivery ratio, and lower delays. In this article, the NS3 simulator has been used to demonstrate performance improvements in 802.11ax standard when compared with 802.11n standard.

### A. OVERVIEW OF 802.11N STANDARD

The 802.11n standard essentially builds on the original 802.11 standards. This 802.11n standard includes different technologies to improve the throughput. As an example, it includes multiple-antennas MIMO technology. It also has 40MHz channel bonding built by combining two adjacent 20MHz channels. Furthermore, it has aggregated multiple frames as one frame before the packet has to be ready for transmission. This aggregate of multiple frames as one frame enhances 802.11n communication performance. In the 802.11n standard, the MIMO technology deploys multiple antennas to improve the quality of transmitting and/or receiving signals better than the SISO technology. The 802.11n standards support 1×1 to 4×4 antennas for improving the data rates. For example, 802.11n can provide a high throughput by the bonded channel of 40 MHz channels, and 802.11n achieves a high data rate when it uses the short guard interval of 400 ns with the 4 × 4 MIMO technology. The 802.11n standard operates in both 5 GHz and 2.4 GHz RF bands and is compatible with the legacy 802.11 standards, such as 802.11 a/b/g. 802.11n works with 20 MHz primary channels, it supports a channel bonding to improve throughput by double the physical layer data rate, 802.11n combine two adjacent primary 20 MHz channels, which are worked together to make one 40 MHz channel. The MIMO architecture together with deploying the channel bounding, can further increase the transmission and receiving data rate. However, the channel bounding concept has a drawbacks impact on the interference with other neighbors using the same frequencies, especially in the 2.4 GHz band. IEEE802.11n standard has various modulations and error-correcting codes denoted by the MCSs index. The 802.11n standard has 7 modes (MCS-0 to MCS-6). In the 802.11n standard, the amount of OFDM sub-carriers is improved by deploying the basic 20 MHz channels. With this improvement in 802.11n, the total OFDM sub-carriers become 52 usable sub-carriers to support High Throughput (HT). Furthermore, with the 40 MHz channel bonding, it can be increased up to 108 usable sub-carriers in HT.

### B. OVERVIEW OF 802.11AX STANDARD

The wireless standard has challenges to be deployed in the dense scenarios of the wireless network. The new generation of wireless standard is termed as 802.11ax standard and named as the high-efficiency wireless (HEW). This new generation of 802.11ax differs from the previous wireless standard which mainly targets throughput improvement, 802.11ax standard also considers the network performance of the dense scenarios, such as improvements of single user and area throughput. 802.11ax standard targets to achieve four times at least of the 802.11ac average throughput improvement, especially in specific dense scenarios. IEEE802.11ax standard performance has been achieved by these features, especially the physical and MAC enhancements that need to be assessed. 802.11ax standard provides new modulation and coding technologies. Firstly, by deploying a very high modulation level of 1024- QAM, the maximum data rate could be further improved. Theoretically, 802.11ax standard can obtain higher throughput compared with legacy 802.11 standards. Secondly, dual carrier modulation technology enhances the robustness of channel transmission. A new subcarrier division mechanism is deployed by 802.11ax standard, which is more efficient compared to the legacy 802.11 standards. In 802.11ax standard, the traditional 20 MHz band is converted to 256 subcarrier spacing, this division is four times the legacy 802.11 standards. This new subcarrier generation mechanism leads to more efficient and precise scheduling of OFDMA, and further, it improves spectrum efficiency. 802.11ax standard enhances the multiple access by deploying OFDMA and MU-MIMO to guarantee the MU concurrent transmission in frequency and spatial domains. This provides an improving the efficiency of wireless networks. The enhancement of channel bounding in 802.11ax standard enables to transmit on non-continuous channels. This technique improves wireless channel utilization. Spatial reuse technology enhances 802.11ax standard capability and interference management ability, especially in dense scenarios. Another significant improvement of 802.11ax standard is the service reservation technique. Specifically, based on the master device control and management capabilities, 802.11ax standard deploys target wakeup time to enhance the scheduling and QoS of wireless network by employing different service times for different clients.

TABLE I
COMPARISON BETWEEN 802.11N AND 802.11AX

| No | Wireless Standards | Wifi 802.11n | Wifi 802.11ax |
|---|---|---|---|
| 1 | Bands (GHz) | 2.4 and 5 | 2.4 and 5 |
| 2 | Channel Width (MHz) | 20 and 40 | 20, 40, 80, and 160 |
| 3 | Guard Interval (ns) | 400 and 800 | 800,1600 and 3200 |
| 4 | Highest Modulation | 64-QAM | 1024-QAM |
| 5 | Modulation Coding Scheme | 0-7 | 0-11 |

TABLE II
NS3 SIMULATION CONFIGURATION

| No | Settings | Value(s) |
|---|---|---|
| 1 | Simulation Version | 3.35 |
| 2 | Simulation Time | 10 sec |
| 3 | Topology | Infrastructure of Access Point with Single Station |
| 4 | Payload Size | 1472 B |
| 5 | Wireless Standard | *802.11n & 802.11ax* |
| 6 | Modulation Techniques | OFDM & OFDMA |
| 7 | Distance | 5 m |
| 8 | Channel Bounding | 20,40,80 and 160 Mhz |
| 9 | Guard Interval | 400,800,1600 and 3200 ns |
| 10 | Band | 2.4 & 5 Ghz |
| 11 | Down Link Ack Sequence Type | MU-BAR |

## V. NUMERICAL RESULTS

The throughput performance of 802.11n and 802.11ax standards are compared in Table I. The NS3 configuration of the throughput comparison using simulation scenarios is listed in Table II. Through this simulation and measurements, the channel bounding and guard interval changed based on the wireless standard deployed of 802.11n and 802.11ax. This is for simulating different scenarios where channel bounding and guard interval impact the throughput from one side and may lead to interference from another side. Also, simulation scenarios pay attention to the MCS index of compared standards as a variable impact on the throughput performance.

### A. 802.11n Performance

The throughput is used as a metric to evaluate the high throughput standard of 802.11n in both bands of 2.4 and 5 GHz. The throughput of the single station, which uses 802.11n

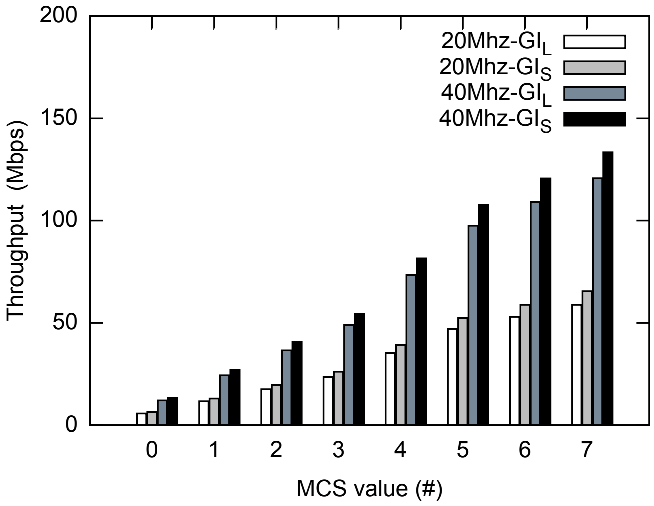


Fig. 1. 802.11n OFDM 2.4Ghz band

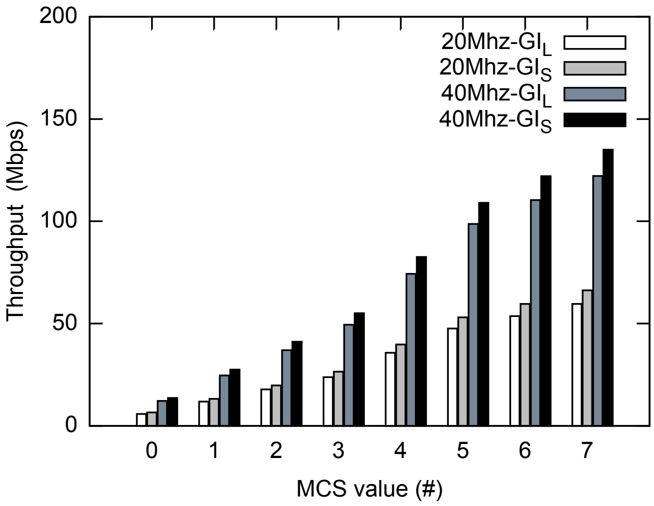


Fig. 2. 802.11n OFDM 5Ghz band

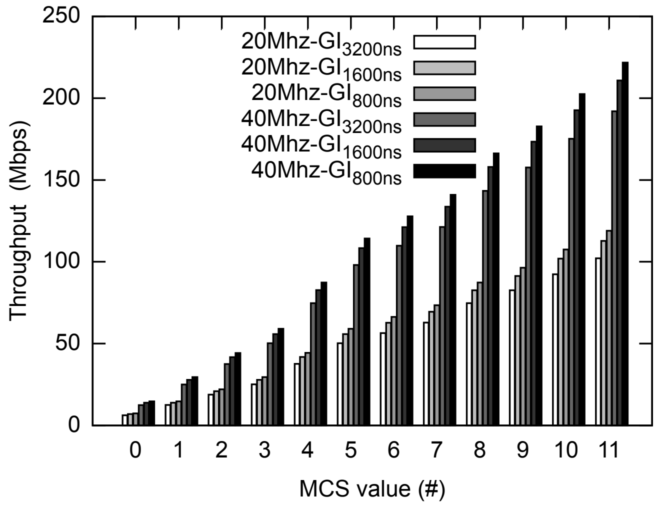


Fig. 3. 802.11ax OFDM 2.4Ghz band

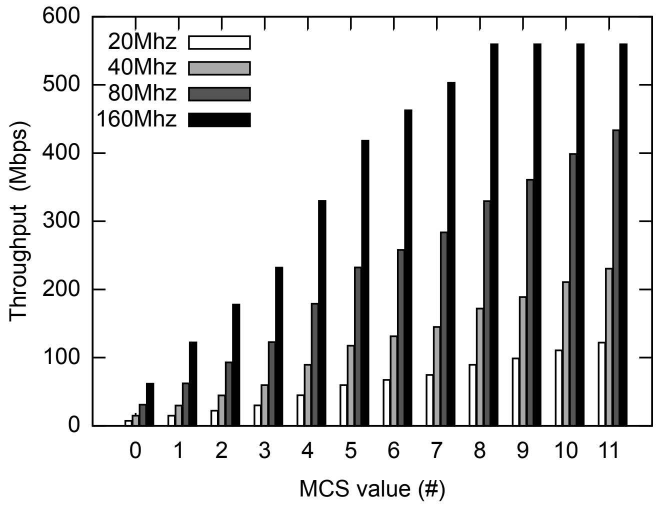


Fig. 4. 802.11ax OFDM 5Ghz band of 3200ns Guard Interval

with OFDM modulation in the 2.4 GHz band, is shown in Figure 1. Figure 1 shows the throughput of different MCS indexes as a function of channel bounding. Essentially, channel bounding is related to guard interval to minimize the probability of interference. Therefore, 802.11n scenarios consider the short $GI_S$ and long $GI_L$ of the guard interval time as 400 and 800ns, respectively. The throughput of a single station that uses 802.11n with OFDM modulation in the 5 GHz band is shown in Figure 2. Figure 1 and Figure 2 show that throughput is impacted by guard interval around 20% where it impacts by 70% regarding channel bounding. This indicates that the MCS index is impacted by channel bounding, especially when using the highest modulation technique of the highest MCS index.

### *B. 802.11ax OFDM Performance*

Similar to the 802.11n standard in the 2.4 GHz band, the 802.11ax standard has the following bounding channels of 20 and 40 MHz channel width. The IEEE 802.11ax standard with OFDM modulation in 2.4 GHz band is shown in Figure 3. Figure 3 shows that the throughput increases about 20% regarding guard interval when it changed from 3200 to 800ns. But throughput increased by about 60 % when using MSC 11, especially at a channel width of 160 Mhz. Figure 4 provides OFDM results of the 5 GHz band for 802.11ax standard with channel bounding of 20 MHz, 40 MHz, 80 MHz, and 160 MHz Figure 4 shows the throughput results when the guard interval time equals 3200ns. Figure 5 and Figure 6 show the throughput results of 1600 and 800 ns, respectively. The simulation results of Figure 4 show that the throughput performance using a 40 MHz channel is about doubled when compared with the primary 20 Mhz channel. The 80 MHz channel as Figure 5 and Figure 6 provide are more than two times increase in throughput performance for the lowest MCS and about three times higher throughput for the highest MCS, while the 160 MHz channel provides three times increase in throughput for the lowest MCS and five times when highest order of MCS index is being used.

### *C. 802.11ax OFDMA Performance*

This section demonstrates the 802.11ax standard in the 2.4 and 5 GHz bands using OFDMA technology, the 802.11ax standard has following bounding channels of basic 20 Mhz and 40 MHz channel with guard intervals of 800.1600 and 3200 ns. Throughput of 802.11ax standard with OFDMA modulation in

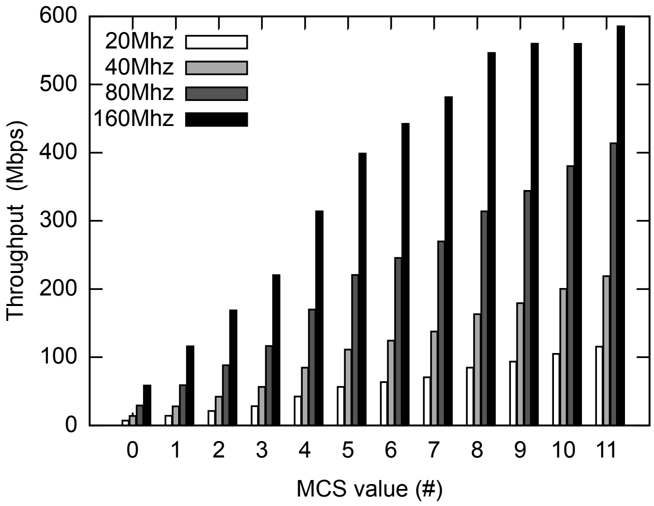


Fig. 5. 802.11ax OFDM 5Ghz band of 1600ns Guard Interval

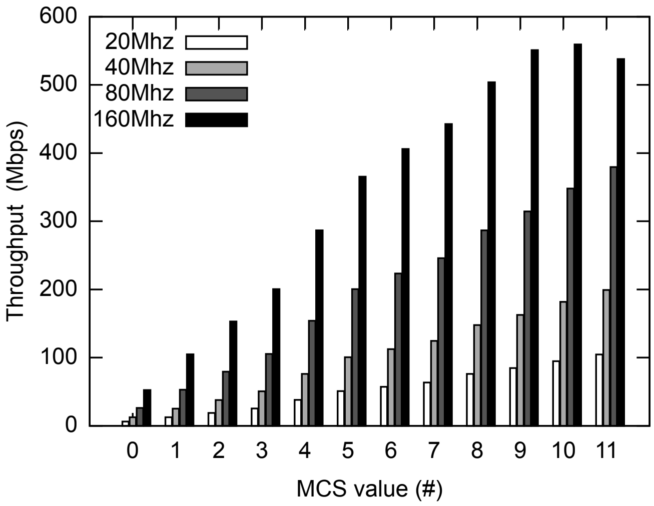


Fig. 6. 802.11ax OFDM 5Ghz band of 800ns Guard Interval

2.4 Ghz band is shown in Figure 7 . Figure 7 shows that the throughput increases about 5% regarding guard interval when it changed from 3200 to 800ns. But throughput increased by about 70% when using MSC 11 specially at channel width of 160 Mhz. In Figure 8 provides OFDMA results of the 5 GHz band for 802.11ax standard with channel bounding of 20 MHz, 40 MHz, 80 MHz and 160 MHz. The Figure 8 shows the throughput results when the guard interval time equal 3200ns. Where Figure 9 and Figure 10 show the throughput results of 1600 and 800 ns respectively. The simulation results of Figure 8 show that the throughput performance using a 40 MHz channel is about one and half times of the basic 20 Mhz channel. The 80 MHz channel as Figure 9 and Figure 10 provide are more than two and half times increase in throughput performance for the lowest MCS and about three times higher throughput for the highest MCS. while the 160 MHz channel provides two times increase in throughput for the lowest MCS and four times at highest MCS index of 802.11ax standard.

*D. Throughput Performance Comparison*

The set of throughput simulation comparisons for both 802.11n and 802.11ax standards is summarized based on the

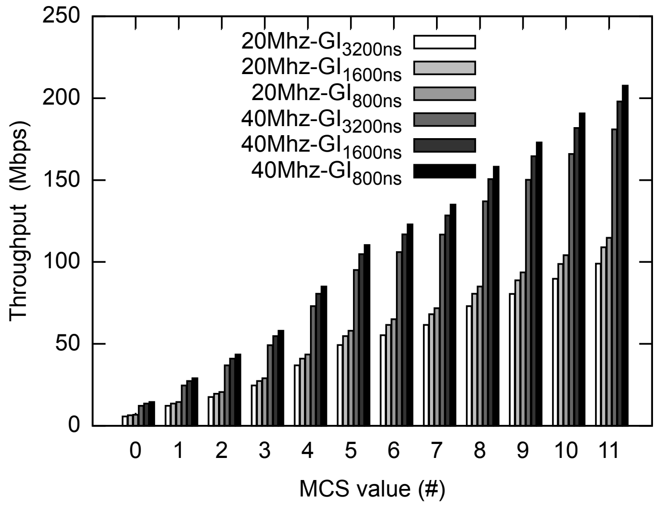


Fig. 7. 802.11ax OFDMA 2.4Ghz band

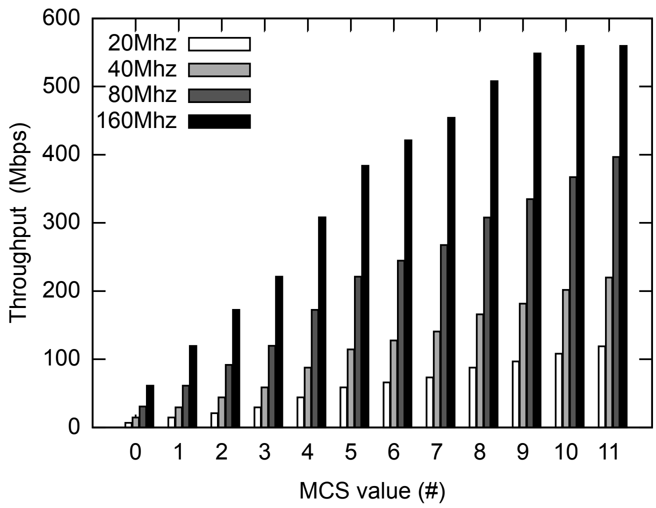


Fig. 8. 802.11ax OFDMA 5Ghz band of 3200ns Guard Interval

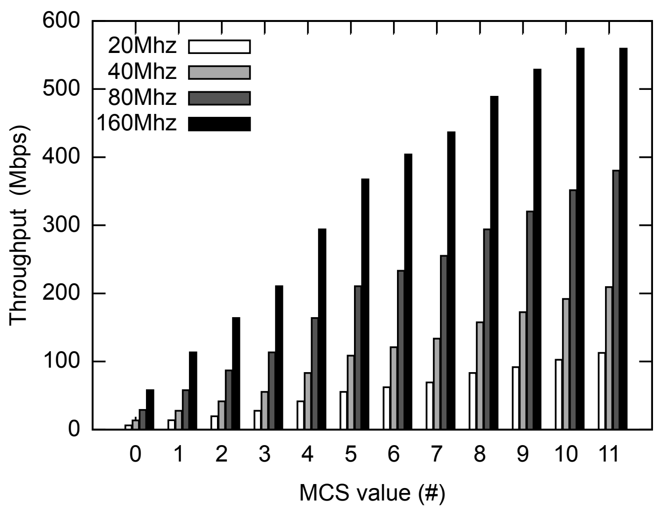


Fig. 9. 802.11ax OFDMA 5Ghz band of 1600ns Guard Interval

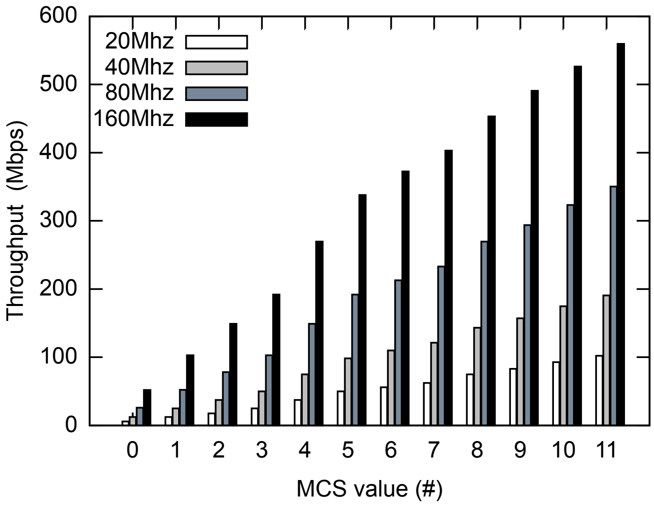


Fig. 10. 802.11ax OFDMA 5Ghz band of 800ns Guard Interval

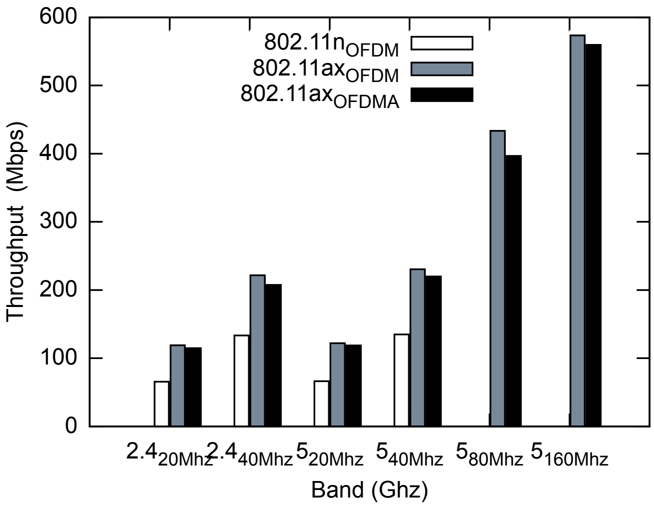


Fig. 11. Throughput Comparison Summary

modulation of OFDM and OFDMA. The throughput increased significantly and quickly when deploying 802,11ax in both modulation and bands. This fact can be observed from the Figure 11. The paper analyzed the throughput performance available for 802.11n and 802.11ax standards for selected attributes in the MCS index, channel bounding, and guard interval. All simulation results of high throughput MCS for a different channel widths of 20,40,80 and 160 MHz were included in the comparison. The comparison also considers different available guard intervals times 400,800,1600 and 3200ns. One has to notice that the value of 800 ns is the shortest for 802.11ax standard while 400 ns is the shorter for the 802.11n standard. The results are presented in Figure 11. In the case of the 2.4 Ghz band, Figure 11using 20 and 40 Mhz channels 802.11ax has higher throughput of $\approx$ 40 to 60 % when compared with 802.11n standard. The results show that for the 5 Ghz band the highest possible throughput is for 802.11ax standard with the following attributes: channel width equals 160 MHz, MCS=11, GI=800 ns, for OFDM and OFDMA . Where it reaches four times when comparing 802.11ax with 802.11n standard using the following attributes: channel width 40 MHz, MCS=7, GI=800 ns.

## VI. Conclusion and Future Work

This paper presents a simulation-based analysis of the main improvements of the 802.11ax standard over 802.11n. The NS3 simulator has been used as the primary tool for the simulation analysis. The NS3 provides a reliable and quantitative basis for network simulations. Simulation scenarios consider many parameters which are set to test the maximum throughput of the network. These parameters include channel bonding, guard interval, and MCS index for both bands of 2.4 and 5 GHz. Paper results show that the 802.11ax standard achieves higher throughput than 802.11n. Furthermore, 802.11ax has better channel utilization by deploying a higher MCS index. In future work, the authors plan to investigate the impacts of the coexistence of other wireless communications standards that transmit in the same frequency bands on the throughput and latency performance of the IEEE802.11ax.

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