Performance Comparison of IEEE 802.11ax, 802.11ac and 802.11n Using Network Simulator NS3

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Abstract. Wireless protocols are upgrading very rapidly. The current market scenario usually uses three wireless protocols namely 802.11ax, 802.11ac, and 802.11n. IEEE 802.11ax, a sixth-generation protocol popularly known as HE (High Efficiency) is said to have achieved 30% higher performance in terms of throughput than older protocol 802.11ac known as VHT (very high throughput). In this paper, performance evaluation of different wireless protocols namely 802.11ax, 802.11ac, and 802.11n operating on frequency bands of 2.4 and 5 GHz. The throughput of all three protocols is calculated on MCS-0 to 11 (Modulation and Coding Scheme) with a common channel width of 20, 40, and 80 MHz. Bandwidth of 160 MHz is not considered in the evaluation. Though it can achieve more throughput because, in practical urban scenarios, it is rarely used. Bandwidth sharing for all three protocols is also simulated and analyzed. For simulation, open-source Network Simulator NS3 is used which takes lesser time to set up the network, provides a precise level of simulation for wireless networks, and minutely mimics real-world wireless networks scenarios. Simulations show that for a single antenna of 5 GHz band at 80 MHz bandwidth 802.11ax achieved 18% higher throughput, whereas at 20 MHz bandwidth, it shows 50% improvement compared to 802.11ac. Further, it is seen that 802.11ax can achieve two times faster throughput than 802.11n at 20MHz bandwidth in the 5 GHz band with a single Antenna.

Keywords: Wireless protocol 802.11ax · 802.11ac · 802.11n · Network Simulator NS3 · performance comparison · throughput

1 Introduction

The Internet of Things (IoT) can have enormous potential because they enhance human's ability to interact with objects in the physical world. The field has evolved due to advancements in wireless protocol, sensors, actuators, and microprocessors. Different communication protocols are utilized for interoperability among these devices. Wi-Fi, Bluetooth, ZigBee, and LoRA are the four main networking protocols that have played a pivotal role in delivering immersive IoT applications. The protocols mentioned are commonly

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applied in various areas such as managing homes, smart structures, sophisticated measuring, and keeping track of health and physical fitness. [1–6] The uses of IoT are limitless, and Wi-Fi provides numerous possibilities for these applications. Various versions of Wi-Fi have been created to meet the diverse needs of network applications.

Wi-Fi was developed to replace the wired Ethernet which uses fast data speed and is valued for simplicity and power efficiency. Bluetooth was developed for serial wire replacement. It has a quality-of-service overhead for voice communication but it is less power-intensive than Wi-Fi. Bluetooth can only support a network of eight devices and has a significant pairing delay. This method is the favored choice for wireless transmission of information across limited distances. It employs UHF radio waves with a wavelength that falls under the ISM band and operates within a frequency range of 2.4 to 2.485 GHz. Based on the applications, there are three different versions of Bluetooth technology: Bluetooth, iBeacon, BLE(Bluetooth Low Energy or Bluetooth 4.0). ZigBee was created to facilitate the construction of extensive sensor networks that require low-power nodes at an affordable price. Its coverage range is limited to 10–100 m, and it has a data rate of 250 Kbps, which is significantly lower than Wi-Fi or Bluetooth. The IEEE 802.15.4 radio is utilized by ZigBee, and it is commonly employed in various sense-and-control applications such as home or building automation, advanced measuring, and health or fitness monitoring.

Each of these widely used protocols is based on an industry radio standard. Several industry alliances and partnerships are in place to encourage the adoption of these protocols and ensure interoperability. The prevailing protocol employed for WLAN (Wireless Local Area Networks) is known as Wi-Fi. It adheres to the IEEE 802.11 standard and operates using the ISM frequencies of 2.4 and 5 GHz. If one of the devices within a range of 20–40 m is connected to the internet, other devices can access the internet via Wi-Fi. The highest possible data rate for the 802.11n standard can reach 600 Mbps, and this rate is influenced by factors like the frequency channel used and the number of antennas involved.

Wireless protocols have reached their capacity limitations due to recent advancements in the Internet of Things, video conferencing, low-latency online gaming, high-definition video streaming, etc. As a result, the 802.11ax wireless protocol was swiftly adopted since it can effectively handle higher client densities. This is because of its additional channel-sharing functionality that utilizes MU-MIMO.

In this paper, performance evaluation of different versions of WiFi protocols namely 802.11ax, 802.11ac, and 802.11n operating on 2.4 and 5GHz frequency bands is carried out. The throughput of all three protocols is calculated on MCS-0 to 11 (Modulation and Coding Scheme) with a common channel width of 20, 40, and 80 MHz. Bandwidth sharing for all three protocols is also simulated and analyzed. All the simulations are performed using open-source Network Simulator NS3.

The following document is structured as follows: In Sect. 2, a review of relevant literature is presented, along with an overview of all three standards. Section 3 presents the features of the Network Simulator NS3 and the simulation models. Section 4 discusses the simulation and analysis of 802.11ax, 802.11ac, and 802.11n standards. Finally, Sect. 4 concludes of the paper.

2 Literature Review

802.11ax [7], 802.11ac [8], 802.11n [9] are widely used IEEE standards for wireless local area network [10]. Additional features and amendments in 802.11ax standard are discussed in [11]. The work suggests that Unplanned wireless deployment may cause inefficiencies in the network since 802.11ax can operate up to 10 Gbps. The research concludes that incorporating Dynamic Channel Bonding (DCB) and OFDMA can increase the efficiency of spectrum usage in the standard.

Ravindranath et al. discussed the performance enhancements of the 802.11ac protocol in comparison to 802.11n in [12]. The research concluded that the 802.11ac protocol, It can be called as Very High Throughput, can attain data rates up to 2.3 Gbps when operating with 5 GHz frequency. This was accomplished by improving features from the 802.11n protocol, such as the support for wider bandwidths of 80 and 160 MHz, extended MIMO support, and better coding schemes at the Physical Layer (PHY).

The authors of [13] conducted a comprehensive review of IEEE 802.11ax. The research discusses the requirements, scope, and features of the 802.11ax amendment and why it is necessary. The coexistence of 802.11ax and LTE (Long Term Evolution) is also explored. The study highlights the suitability of 802.11ax for IoT (Internet of Things) scenarios. The research concludes that the 802.11ax amendment enables efficient spectrum utilization and provides the best user experience in high-density WLAN networks.

In [14] Machrouh et. al. Compare the performance of throughput for 802.11ax and 802.11ac. They conclude that the 802.11ax provides improved throughput by using OFDMA and a higher coding scheme. In [15] Darwish and Mohamed have also discussed the high throughput and efficiency of 802.11 wireless standards. The 802.11 versions simulated in this paper are discussed next.

2.1 802.11n

802.11n appeared at an important time in 802.11's development when smartphones were getting popular. Former PHYs were designed exclusively for the 2.4 GHz Industrial, Scientific, and Medical (ISM) band and featured direct sequence and frequency hopping PHYs. When the 5 GHz spectrum was made available for unlicensed usage, 802.11a was developed. The goal of 802.11g was to make the 802.11a technology available in the 2.4 GHz range. However, 802.11n was developed while both bands were accessible. The maximum data rate of 802.11n is 600 Mbps, as presented in Table 1. The highest modulation is 64-QAM which is based on the MCS-7 standard. It uses 0.4 and 0.8 μs guard band. The channel bandwidth supported is 20 and 40 MHz.

Backward combability is provided in 802.11n for the legacy 802.11 formats, as discussed in [16]. The latest developed Physical layer convergence protocol defines High Throughput (HT) and operates in two modes: mixed mode (802.11a/b/g and n) and Greenfield mode (802.11n). It has the capability to handle up to four spatial streams. 20 and 40 MHz channel bonding, resulting in higher throughput and low interference.

802.11n offers till 600 Mbps of data rates and increased MAC's efficiency due to its Frame aggregation approach. It divides the expense of each transmitter's access to

Table 1. 802.11n specifications

Maximum data rate	600 Mbps
RF Band	2.4 and 5 GHz
Highest modulation	64-QAM
Guard band	0.4 µs, 0.8 µs
Channel width	20, 40 MHz

the medium over several smaller frames. Aggregation increases efficiency by 50% to around 75%, depending on the type of data being transferred [16].

2.2 802.11ac

Table 2 shows the major specifications of 802.11ac. As seen in the figure maximum data rate of 802.11ac is 2.3 Gbps. This allows high-definition video streaming. The highest modulation is 256-QAM which is the MCS-9 standard. It uses 0.4 and 0.8 µs guard band. Bandwidth supported by channel are 20, 40, 80, and 160 MHz. Physical speeds greater than 500 Mbps are supported for a single connection.

Table 2. 802.11ac specifications

Maximum data rate	2.4 Gbps
RF Band	5 GHz
Highest modulation	256-QAM
Guard band	0.4 µs, 0.8 µs
Channel width	20, 40, 80, 160 MHz

802.11ac has several notable features, including multi-user MIMO [17] that can support up to 4-clients, There is backing to enable wider channels with a maximum of 160 MHz bandwidth and the adoption of more compact modulation techniques like 256-QAM. This enables a high data rate and supports up to eight spatial streams [18]. After the advent of MIMO, many of the methods were used to boost speed in 802.11ac 802.11ac builds on established strategies and elevates them to a new level. According to [19], 802.11ac's multi-user MIMO functionality empowers an Access Point (AP) to broadcast data to multiple clients concurrently, instead of merely enhancing the number of data streams intended for a single client.

2.3 802.11ax

802.11ax is the latest amendment in the WLAN protocol. It has made changes in the physical layer of legacy 802.11 for improvement. As shown in Table 3 maximum data rate of 802.11ax is 9 Gbps. The highest modulation is 1024-QAM which is the MCS-11 standard. The protocol supports guard bands of 0.8, 1.6, and 3.2 μs, as well as channel bandwidths of 20, 40, 80, and 160 MHz. The protocol maintains backward compatibility with preceding 802.11a/b/g/n/ac standards. The protocol operates in two modes: multi-user mode and single-user mode. Multi-user mode facilitates concurrent transmission whereas single-user mode, data is transferred sequentially following media access. Multi-user mode is further divided into Downlink and Uplink Multi-user. The foundation of multi-user downlink is the data that the Access Point transmits simultaneously for a number of connected wireless stations.

Table 3. 802.11ax specifications

Maximum data rate	9 Gbps
RF Band	2.4 or 5 GHz
Highest modulation	1024-QAM
Guard band	0.8, 1.6, 3.2 μs
Channel width	20, 40, 80, 160 MHz

802.11ax is also called HE (Higher efficiency) as it utilizes radio frequency more efficiently. The majority of the 802.11ax enhancement is focused on the physical layer. This includes the use of OFDM with a multi-user feature. The older 11n/ac uses OFDM with a single user. It also provides better traffic management. Another significant improvement is the Access Point (AP) can monitor both uplink and downlink transmission to multiple clients. This feature includes backward compatibility with older protocols and operates on both 2.4 GHz and 5 GHz.

Both 802.11ac and 802.11ax Access Points may receive and deliver data concurrently to multi-users (MU) using functionalities provided by multi-link MU-MIMO. This functionality gives Access Point the freedom to serve user clients in their immediate vicinity. Both protocols leverage technologies like Orthogonal Frequency Division Multiple Access (OFDMA) and multi-user MIMO. 802.11ax is also capable of transmit beam forming which is the technique of MIMO that improves SNR at receiver space [20].

3 Simulation and Analysis

3.1 Simulation Model

The Network Simulator NS3 is an open-source and freely available simulator. That is widely used by both businesses and the research community. There are several validation experiments of NS3 that makes sure that its 802.11 models are accurate [19]. Hence NS3.37 is used for the simulation and analysis of 802.11ax, 802.11ac, and 802.11n in this paper.

The source code of NS3 is written in Python and C++. It provides models for wireless and wired networks with different topologies. Figure 1 shows the network topology used in the simulation. It is an infrastructure-based wireless network with five stations connected to an Access point.

Fig. 1. Network topology used for Simulation

MCS (modulation and coding schemes) 0–11 utilised for the simulated network. Fixed-rate Infrastructure mode is used to simulate 802.11ax, 802.11ac, and 802.11n. Frame aggregation features like AMSDU and AMPDU are used to achieve higher throughput. Table 4 presents the simulation parameters. Simulation is performed on only one spatial stream as the focus of this comparison is to observe how different standards perform in the same scenario. In the simulation, the guard bands as per Table 4 are included. Simulation is carried out for 60 s for every scenario. Constant Position mobility model is used in the simulation. The transport layer protocol from Station to AP is UDP type.

3.2 Simulation Results

The network scenario used for simulation is shown in Fig. 1. It is an infrastructure-based network with one access point and five stations. Table 5 shows the basic simulation parameters. 802.11n can support MCS-7 (64-QAM) whereas 802.11ax's higher coding scheme can support up to MCS-11 (1024-QAM) which gives higher throughput as it can carry more data than 64-QAM.

Figure 2 shows that 802.11ax achieves the highest throughput irrespective of the guard interval and coding scheme. A higher coding scheme clearly transfers more packet data which results in higher throughput. Lower coding schemes transfer fewer data regardless of wireless standards.

Table 4. Simulation Parameters

MCS	MCS-0 to MCS-11	MCS-0 to MCS-9	MCS-0 to MCS-7
Guard Interval	0.8us, 1.6us, 3.2us	0.4us, 0.8us	0.4us, 0.8us
Channel Width	20, 40, 80 MHz	20, 40, 80 MHz	20, 40 MHz
Frequency	2.4, 5 Ghz	5 Ghz	2.4, 5 Ghz
Spatial Stream	1	1	1
Mobility model	Constant position mobility model		
Simulation time	60 s		

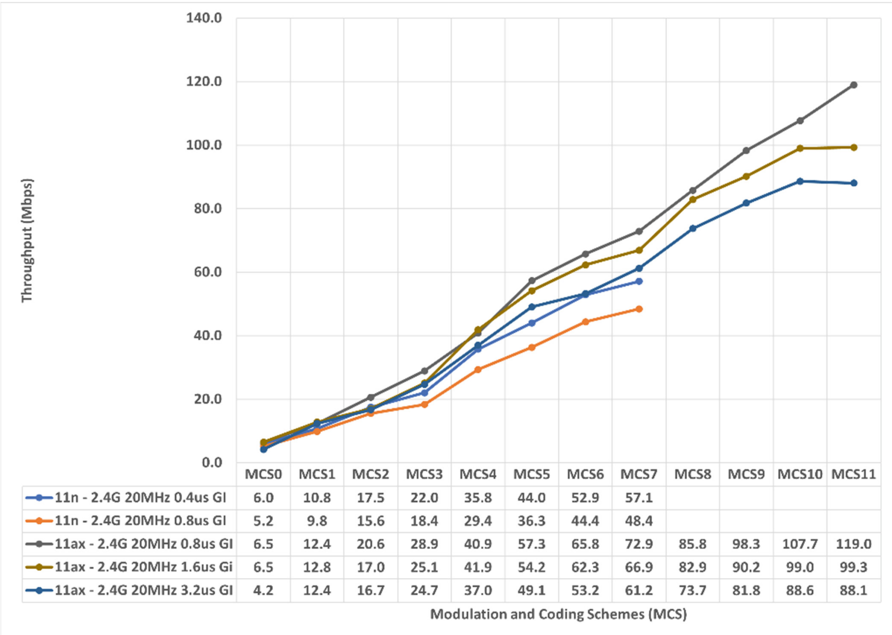
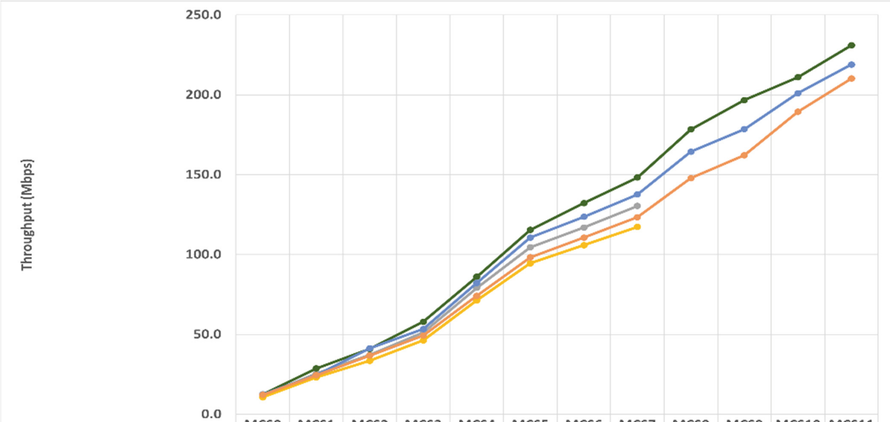
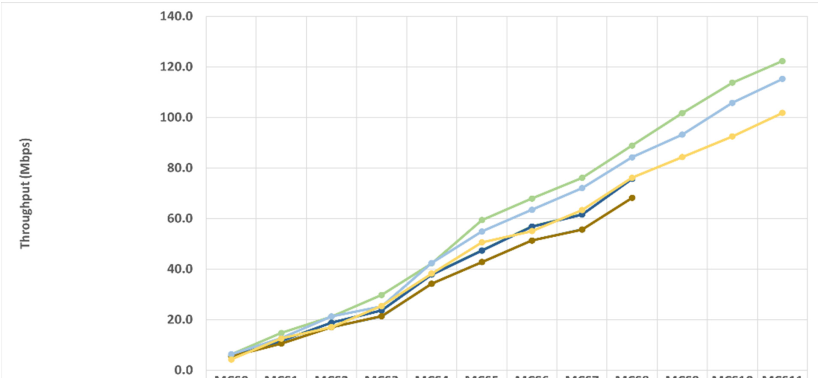


Fig. 2. Throughput vs MCS for 20 MHz bandwidth 2.4 GHz band



	MCS0	MCS1	MCS2	MCS3	MCS4	MCS5	MCS6	MCS7	MCS8	MCS9	MCS10	MCS11
11n - 2.4G 40MHz 0.4us GI	11.7	25.5	37.2	51.2	79.2	104.6	116.9	130.5				
11n - 2.4G 40MHz 0.8us GI	10.7	23.1	33.6	46.3	71.3	94.6	105.9	117.4				
11ax - 2.4G 40MHz 0.8us GI	12.4	28.7	41.0	58.0	86.1	115.5	132.2	148.2	178.3	196.7	211.0	231.0
11ax - 2.4G 40MHz 1.6us Gi	12.5	24.6	41.3	53.4	82.3	110.6	123.6	137.7	164.4	178.5	201.0	219.0
11ax - 2.4G 40MHz 3.2us GI	12.2	24.5	36.7	49.3	74.2	98.3	110.7	123.4	147.8	162.2	189.4	210.2

Fig. 3. Throughput vs MCS for 40 MHz bandwidth 2.4 GHz band

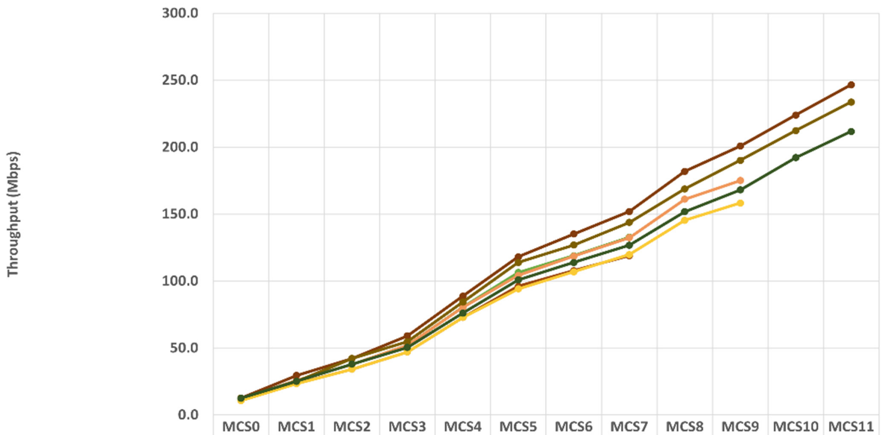


	MCS0	MCS1	MCS2	MCS3	MCS4	MCS5	MCS6	MCS7	MCS8	MCS9	MCS10	MCS11
11n - 5G 20MHz 0.4us GI	6.1	11.7	18.8	23.7	37.9	47.4	56.9	61.7				
11n - 5G 20MHz 0.8us GI	5.5	10.6	17.1	21.3	34.3	42.8	51.4	55.7				
11ac - 5G 20MHz 0.4us GI	6.1	11.6	18.8	23.7	37.9	47.3	56.8	61.6	75.7			
11ac - 5G 20MHz 0.8us GI	5.5	10.6	17.0	21.4	34.2	42.8	51.4	55.7	68.2			
11ax - 5G 20MHz 0.8us GI	6.3	14.8	21.2	29.8	42.3	59.4	68.0	76.1	88.9	101.7	113.8	122.4
11ax - 5G 20MHz 1.6us Gi	6.3	12.7	21.3	25.3	42.5	54.9	63.5	72.0	84.3	93.2	105.8	115.3
11ax - 5G 20MHz 3.2us GI	4.3	12.6	17.1	25.4	38.2	50.6	55.1	63.4	76.1	84.3	92.5	101.8

Fig. 4. Throughput vs MCS for 20 MHz bandwidth and 5 GHz band

As seen in Fig. 3, similar results are seen for 20 MHz and 40 MHz channel bandwidth for 802.11n and 802.11ax standards. 802.11ax 40 MHz can achieve 77% higher throughput than 802.11n. For 802.11n and 802.11ax, 40 MHz bandwidth achieves almost two times higher throughput.

For 802.11n protocol at 20 MHz maximum throughput achieved is 57.1 Mbps and at 40 MHz it is 130 Mbps. The results are similar for 802.1ax where 119 Mbps to 231 Mbps speed is achieved. Guard bands make difference in overall throughput as they can create overhead over actual data packets.

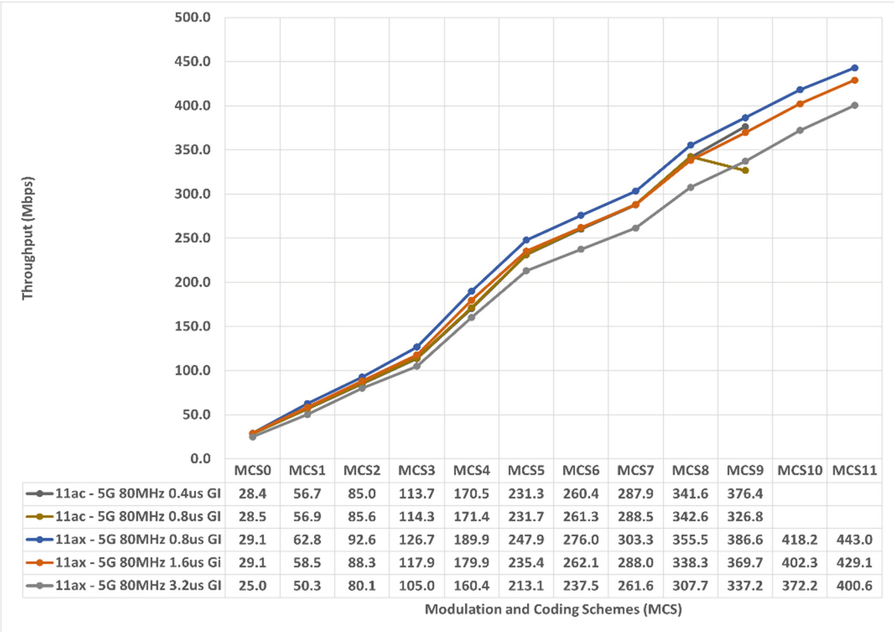


	MCS0	MCS1	MCS2	MCS3	MCS4	MCS5	MCS6	MCS7	MCS8	MCS9	MCS10	MCS11
11n - 5G 40MHz 0.4us GI	11.9	26.0	37.8	52.1	80.6	106.5	119.0	132.8				
11n - 5G 40MHz 0.8us GI	10.9	23.5	34.2	47.1	72.8	96.2	107.8	119.1				
11ac - 5G 40MHz 0.4us GI	11.9	25.9	37.8	52.1	80.5	104.2	118.5	132.5	161.1	175.1		
11ac - 5G 40MHz 0.8us GI	10.8	23.5	34.1	47.0	72.8	94.1	107.0	119.9	145.5	158.4		
11ax - 5G 40MHz 0.8us GI	12.6	29.6	42.1	59.1	88.8	118.1	135.2	152.0	181.9	200.9	224.0	246.6
11ax - 5G 40MHz 1.6us Gi	12.6	25.1	42.2	54.8	84.4	114.0	126.9	143.9	168.9	190.2	212.4	233.8
11ax - 5G 40MHz 3.2us GI	12.5	25.2	38.0	50.4	76.1	101.0	114.0	126.9	151.9	168.2	192.3	211.8

Fig. 5. Throughput vs MCS for 40 MHz bandwidth and 5 GHz band

Figure 4, 5 and 6 show Throughput against MCS for 20, 40 and 80 MHz 5 GHz band respectively. It is observed that the 5 GHz band can transfer more data compared to 2.4 GHz for all standards in the same bandwidth. Maximum throughput of 443 Mbps is achieved in 80 MHz 0.8 us Guard Interval for 802.11ax.

Maximum throughput is 376 Mbps for 802.11ac standard. Thus, for 80 MHz bandwidth in the 5 GHz spectrum, 802.11ax is 18% faster. For 20 MHz bandwidth between 2.4 and 5 GHz, the 5 GHz bands can carry more data than the 2.4 GHz band because of the denser frequency band of 5 GHz and less interference in the channel.



	MCS0	MCS1	MCS2	MCS3	MCS4	MCS5	MCS6	MCS7	MCS8	MCS9	MCS10	MCS11
11ac - 5G 80MHz 0.4us GI	28.4	56.7	85.0	113.7	170.5	231.3	260.4	287.9	341.6	376.4		
11ac - 5G 80MHz 0.8us GI	28.5	56.9	85.6	114.3	171.4	231.7	261.3	288.5	342.6	326.8		
11ax - 5G 80MHz 0.8us GI	29.1	62.8	92.6	126.7	189.9	247.9	276.0	303.3	355.5	386.6	418.2	443.0
11ax - 5G 80MHz 1.6us Gi	29.1	58.5	88.3	117.9	179.9	235.4	262.1	288.0	338.3	369.7	402.3	429.1
11ax - 5G 80MHz 3.2us GI	25.0	50.3	80.1	105.0	160.4	213.1	237.5	261.6	307.7	337.2	372.2	400.6

Fig. 6. Throughput vs MCS for 80 MHz bandwidth and 5 GHz band

Figure 7 shows how bandwidth sharing with a different station affects throughput of the network setup. From Fig. 7 it is seen that as the number of station increases throughput decreases for a single antenna. Further, 802.11ax has better efficiency for multiple stations whereas legacy protocol 802.11n struggles to keep up with the throughput.

Moreover, it supports MU-MIMO technology, which allows for the transmission of up to 8 spatial streams concurrently. Due to its higher density, the 5 GHz frequency band has greater data-carrying capacity than the 2.4 GHz band for 20 MHz bandwidth between 2.4 and 5 GHz.

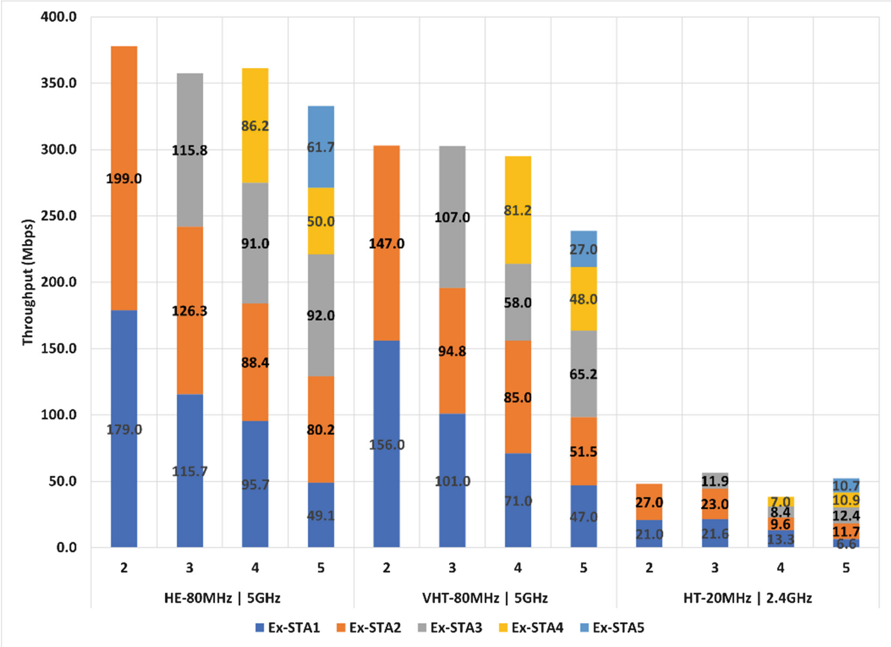


Fig. 7. Bandwidth sharing for different standard

4 Conclusion

Simulation and analysis of different Wi-Fi standards namely 802.11n, 802.11ac, and 802.11ax are carried out for 20, 40, and 80 MHz bandwidth for 2.4 and 5 GHz bands. For both bands, 20 MHz channel width does not show much improvement compared to 40 MHz and 80 MHz bandwidth. 802.11 ax standard at 2.4 GHz offers 119 Mbps and at 5 GHz it offers 122 Mbps. 2.4 GHz band offers lower throughput due to multiple reasons like lower data carrying capacity and higher interference compared to 5 GHz. The second experiment with a multi-station environment shows that as the number of station increase throughput for individual station also decrease. This is because bandwidth is shared between stations. 802.11ax performs better as it can efficiently prioritize packets, for example, it gives more priority to video calls and video streaming compared to downloading any software. In the future work range against rate, delay and jitters can be measured. The new release 802.11be popularly named Extremely High Throughput can also be simulated and its performance can be analyzed.

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