Performance Analysis of IEEE802.11ax (Wi-Fi 6) Technology using Multi-user MIMO and Up-Link OFDMA for Dense Environment

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***Abstract*— Recently, there has been a concerted effort to upgrade the IEEE 802.11 Standard, also known as IEEE802.11ax Wi-Fi 6 technology. It was released due to its high-efficiency wireless local area network (WLAN) technologies for congested or crowded environments such as stadiums, public areas such as railway stations, theatres, and other similar venues. Wi-Fi 6 introduces new features as well as acronym. It is faster than expected, but not in the same sense that Wi-Fi has become a victim of its own popularity. Density refers to concentration, such as several users with wireless devices, and we are surrounded by access points all striving to service more data-hungry this has become our high density reality. The 802.11 families have been modified since 1997, with performance enhancements in three areas: modulation strategy, special streams, and channel bounding technique.**

Wi-Fi 6's popularity has risen dramatically as a result of its high data rate and OFDMA & MU-MIMO principles. It is currently popular due to its high performance and high data rate capabilities, as well as the fact that it cuts installation and maintenance costs, which were previously signed in Wi-Fi 5. In this study, we compare the performance of IEEE802.11ax Wi-Fi 6 to IEEE802.11ac Wi-Fi 5 in terms of throughput, data rate, modulation techniques, number of users, and other factors. Because of the usage of a new technology known as UL-OFDMA and MU-MIMO, a larger number of users can effectively utilize available bandwidth and use the same channel at the same time.

Keywords—WLAN, IEEE802.11ax, IEE802.11ac, Wi-Fi 5, Wi-Fi 6, UL-OFDMA, MU-MIMO.

I. INTRODUCTION

Wireless Local Area Network (WLAN) i.e.IEEE802.11, as well as wireless devices and apps based on WLAN, has become an integral aspect of day-to-day Internet use in recent years. As we all know, the world's population is growing at an exponential rate, so we need a solution that can scale up the number of devices and be implemented globally at a low cost and with few hardware changes while maintaining great quality of service (QoS) performance. According to a study conducted by researchers and industry, 541.6 million public wireless devices would be active globally by the end of 2021 [1]. To meet the overhead and user requirements, There is need to develop a solution that is more capable and faster. The worldwide data is likely to increase by up to tenfold from its current level [3].

The wireless local area network (WLAN) has undergone enormous evolution since the first technical approval of the IEEE 802.11 draught in 1997, with the emergence of Wi-Fi devices providing wireless access for mobile computing and internet access [1][2].

However, the distributed coordination function (DCF) of the IEEE 802.11 medium access management (MAC) protocol is inadequate for the dense state of things [5], where multiple Wi-Fi devices exist in geographically confined areas. High efficiency network are not able to deliver adequate information to destination in dense or busy Wi-Fi

environments, science server collision happens due to channel bandwidth and interference from surrounding devices, resulting in a decline in system performance [5]. As a result, with the growing density of wireless Wi-Fi device deployments, it's critical to upgrade Wi-Fi technology to improve metrics and performance parameters. It reflects user expertise, such as delay, latency, and average throughput per user, rather than focusing on increasing the height, link output of a single user [3]. In March 2014, the IEEE Standards Association (IEEE-SA) norms board endorsed IEEE 802.11ax. The goal of IEEE 802.11ax is to provide an improved user experience by increasing the average outturn per user in recurrence groups between one gigacycle and about six gigacycle [3]. The alteration used in 802.11ax compared to the previous 802.11 standard leads to development activity in the recurrence groups between one gigacycle and about six gigacycle for the physical layer (PHY) and the medium access control (MAC) sublayer [3].

In March 2014, the Wi-Fi Alliance and the IEEE association adopted IEEE 802.11ax. Its purpose is to provide a better user experience by increasing average output per user by at least fourfold in densely deployed areas. The key features are Orthogonal frequency division multiple access (OFDMA), preamble puncturing, transmission multi-user multiple-input multiple-output (UL letter MIMO), abstraction reprocess, trigger frame and OFDMA random access, power-saving with target wake time (TWT), station-to-station (S2S) operation, and backward compatibility with IEEE 802.11 devices [5].

The paper is organized as follows, the literature review and overview of 802.11ax technology is discussed part II. The Wi-Fi technology is explained in Section III, from legacy mode to 11ax high-efficiency mode. The MU-MIMO technology and operating concept are covered in Section IV, followed by a review of UL-OFDMA and the analysis of Up-Link in Section V. The experimental setup is discussed in the final part, along with the data collected.

II. LITERATURE SURVEY

Remote systems have maintained and improved quality, attracting an ever-increasing number of customers. This has resulted in a significant increase in data use across all platforms. By 2019, global data traffic is predicted to grow at a rate several times faster than it was in 2014 [6].

The 'legacy' mode must be supported by higher-level protocols when the new draft for 802.11 is released. IEEE 802.11ax, with a top speed of 10 Gbit/s, was introduced in mid-2014 to improve throughput, the number of users, and channel boundaries in high-density circumstances. The first draught versions of 802.11ax, D1.0 and D2.0, were released in the summers of 2016 and 2017.

However, the Wi-Fi technology's phenomenal success in terms of preparation also poses a threat to its future expansion. There are a lot of users, as well as a lot of demanding networks and clients. Because population density is rising, this advancement in Wi-Fi technology may soon fall short of efficiently supplying the intended consumer base [4]. IEEE802.11ax makes extensive use of OFDMA technology as a mac layer convention to serve a group of clients at the same time. UL-OFDMA is a multi-user version of OFDM in which task subsets of subcarriers, referred to as resource units, are used (RU). Concurrent transmissions of data, control, and administration outlines from many customers are granted to completely different clients. The goal of UL-OFDMA is to reduce channel overhead by spreading it across multiple clients. In the 5GHz range, IEEE 802.11ax allows for channel bandwidths of 20/40/80/160(80+80), with up to nine users in the twenty megahertz band, eighteen users in the forty megahertz band, thirty-seven users in the eighty megahertz band, and seventy-four users in the one hundred sixty megahertz band [4].

The switch invites letter Up-Link communications in a brand new frame called as trigger frame (TF). A station that is the TF's accumulated collector, responds by relaying HE trigger-based physical layer protocol data unit (PPDU) information in acknowledgement frame. Because the first Wi-Fi standard, IEEE802.11, 1997, has a low data rate "legacy" of 2Mbps, the evaluation of Wi-Fi technology indicates a radical change in terms of data rate and user increase. Later, IEEE 802.11 a/b/g/n/ac was introduced, and the data rate increased to several Gbits/s in the latest 802.11ac [6]. As the data rate increased, so did the number of users supported, and bandwidth utilization became more efficient. Advanced modulation and coding algorithms, as well as a new application of Multiple-input multiple-output (MIMO) technology, are used to accomplish this high data rate [4]. Inappropriately, research into the most recent wifi technology IEEE802.11ac reveals that new modulation and coding methods must be created and implemented to improve data rate and throughput, despite the fact that increasing bandwidth and special streams is insufficient to achieve good TP [5][6].

There are designing challenges for deploying IEEE802.11ax in dense environment. The fundamental benefit of IEEE802.11ax is that it may be used in crowded / dense environments such as stadiums, train stations, outdoor public Wi-Fi, public gatherings, and exhibitions, among others [7]. Coverage is more important in these cases, as is user capacity. In such a situation, aggregate throughput is less significant than increasing overall throughput per user and optimum bandwidth usage according to use, which is also known as the relationship between total network throughput TP and network capacity [8][9]. With the new advance MIMO technology, we are able to achieve more performance and capacity as comparison to non-multiuser technology [17][18].

III. Wi-Fi Technology

A. *The 802.11 Network*

802.11 is a component of the IEEE 802 family of standards, which is designed for LAN connectivity. It defines a collection of medium access control (MAC) and physical layer (PHY) protocols for implementing Wi-Fi, or wireless LAN (WLAN) computer communication.

The IEEE802.11 Network architecture has the main component like Station (STA), Access point (AP), Basic service set (BSS), Extended service set (ESS), and Distributed system (DS).

All devices connected to the WLAN network called STA can be classified further as Client and AP. The BSS is a group of stations communicating, the BSS is made at the PHY layer for communication. A group of BSSs put together gives us the ESS. The DS, It’s the logical link that connects the AP’s in ESS.

B. *Legacy Network (802.11- a/b/g)*

The 802.11b standard was the first widely adopted WLAN Wi-Fi standard, followed by 802.11 a/g. The specifications are as followed:

- 802.11b –
  802.11b operates on the 2.4GHz frequency band, with a maximum data rate of 11mbps and a range of up to 150 feet. Microwaves, for example, operate in the 2.4GHz spectrum and may create interference.
- 802.11a –
  It only operates in the 5GHz frequency spectrum, making it less susceptible to interference. For generating the wireless signal, orthogonal frequency division multiple access was employed, resulting in a data rate improvement of up to 54mbps. The consequence of using a high carrier frequency is that IEEE802.11a has a less range than 802.11b/g.
- 802.11g –
  It's more like a hybrid of 802.11a and b. 802.11g networks use OFDM technology to enable a maximum rate of 54mbps while operating in the 2.4GHz range. It supports backward compatibility with 802.11b devices, which means that devices that support 802.11b can connect to an 802.11g network and continue to operate at 802.11b speeds.

C. *High Efficiency (HE) Network (802.11-AX)*

The IEEE802.11ax system, popularly known as Wi-Fi6, is the most recent IEEE802.11 technology. It was created with the goal of providing excellent performance in congested situations. It's also compatible with the Internet of Things (IoT). The following are some of the key characteristics of 802.11ax networks:

1. Works in both the 2.4GHz and 5GHz frequency bands.
2. 160MHz channel width in addition to 80, 40, and 20MHz.
3. The technology of orthogonal frequency division multiple access (OFDMA).
4. MU-MIMO communication for both uplink and downlink.
5. 1024 QAM modulation technique.
6. BSS coloring, for identifying home wi-fi network.
7. Target Wake Time for efficient power savings.

The efficient power-saving capability of the devices connected to the network is one of the most significant elements of any dense network. Target Wake Time was introduced to address this issue.

The purpose of this study is to demonstrate how UL-OFDMA and MU-MIMO can help boost overall TP while also increasing network capacity by scheduling each station's transmission..

In the Wireshark sniffer capture, the Very high throughput (VHT) capabilities and VHT information section lists all the VHT specific features offered by a device.

D. MCS Rate Mapping

The Modulation Coding Scheme (MCS) index is a statistic based on a few factors of a Wi-Fi connection between two stations that is used to estimate your Wi-Fi connection's likely information rate.

When connecting your remote getaway or any wireless device to the router AP, the MCS value describes the SS spatial streams present, the modulation techniques, and the MCS rate that's possible. Hardware design, physical parameters, and neighboring impedances will all influence the true MCS. If a remote or Wi-Fi connection cannot be maintained, i.e. there are too many CRC errors on the interface, the MCS Streams can be disabled, which will reduce the data rate (by picking a more suitable balancing type/coding rate) but at the cost of a slower information rate. The MCS, on the other hand, will show the information rate of the remote or Wi-Fi connection. For 11ax, we have an MCS rate of 0-11 and a maximum throughput of 1201MB/s with 0.8us GI, can be calculated using eq (1).
Formula used to calculate data rate:-

$$\text{Data Rate} = \frac{\overset{\text{Number of Data Subcarriers}}{N_{SD}} * \overset{\text{Number of Coded Bits per Subcarrier per Stream}}{N_{BPSCS}} * \overset{\text{Coding}}{R} * \overset{\text{Number of Spatial Streams}}{N_{SS}}}{\underset{\text{OFDM Symbol Duration}}{T_{DFT}} + \underset{\text{Guard Interval Duration}}{T_{GI}}} \quad \text{.....eq.(1)}$$

The modulation type dictates how data is transmitted over the air, whereas the coding scheme specifies the type of coding necessary. In the beginning, BPSK modulation was used to transfer data, but today, 802.11ax uses the QAM modulation technology, which is commonly 1024 QAM. The coding rate expresses how many percentages of data are transmitted.

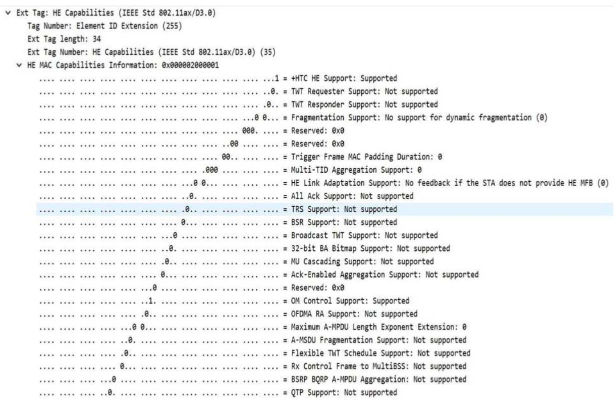
```
v Ext Tag: HE Capabilities (IEEE Std 802.11ax/D3.0)
    Tag Number: Element ID Extension (255)
    Ext Tag length: 34
    Ext Tag Number: HE Capabilities (IEEE Std 802.11ax/D3.0) (35)
  v HE MAC Capabilities Information: 0x000002000001
      .... .... .... .... .... .... .... .... .... .... .... ...1 = +HTC HE Support: Supported
      .... .... .... .... .... .... .... .... .... .... .... ..0. = TWT Requester Support: Not supported
      .... .... .... .... .... .... .... .... .... .... .... .0.. = TWT Responder Support: Not supported
      .... .... .... .... .... .... .... .... .... .... ...0 0... = Fragmentation Support: No support for dynamic fragmentation (0)
      .... .... .... .... .... .... .... .... .... .... 000. .... = Reserved: 0x0
      .... .... .... .... .... .... .... .... .... ..00 .... .... = Reserved: 0x0
      .... .... .... .... .... .... .... .... .... 00.. .... .... = Trigger Frame MAC Padding Duration: 0
      .... .... .... .... .... .... .... .... .000 .... .... .... = Multi-TID Aggregation Support: 0
      .... .... .... .... .... .... .... ...0 0... .... .... .... = HE Link Adaptation Support: No feedback if the STA does not provide HE MFB (0)
      .... .... .... .... .... .... .... ..0. .... .... .... .... = All Ack Support: Not supported
      .... .... .... .... .... .... .... .0.. .... .... .... .... = TRS Support: Not supported
      .... .... .... .... .... .... .... 0... .... .... .... .... = BSR Support: Not supported
      .... .... .... .... .... .... ...0 .... .... .... .... .... = Broadcast TWT Support: Not supported
      .... .... .... .... .... .... ..0. .... .... .... .... .... = 32-bit BA Bitmap Support: Not supported
      .... .... .... .... .... .... .0.. .... .... .... .... .... = MU Cascading Support: Not supported
      .... .... .... .... .... .... 0... .... .... .... .... .... = Ack-Enabled Aggregation Support: Not supported
      .... .... .... .... .... ...0 .... .... .... .... .... .... = Reserved: 0x0
      .... .... .... .... .... ..1. .... .... .... .... .... .... = OM Control Support: Supported
      .... .... .... .... .... .0.. .... .... .... .... .... .... = OFDMA RA Support: Not supported
      .... .... .... .... ...0 0... .... .... .... .... .... .... = Maximum A-MPDU Length Exponent Extension: 0
      .... .... .... .... ..0. .... .... .... .... .... .... .... = A-MSDU Fragmentation Support: Not supported
      .... .... .... .... .0.. .... .... .... .... .... .... .... = Flexible TWT Schedule Support: Not supported
      .... .... .... .... 0... .... .... .... .... .... .... .... = Rx Control Frame to MultiBSS: Not supported
      .... .... .... ...0 .... .... .... .... .... .... .... .... = BSRP BQRP A-MPDU Aggregation: Not supported
      .... .... .... ..0. .... .... .... .... .... .... .... .... = QTP Support: Not supported
```

Figure 1. HE Capabilities Sniffer Trace

Figure 1 depicts the sniffer transfer of HE PHY capabilities, where the mode of operation and supported datarate are displayed under the HE MAC Capabilities Information. By collecting data frames using the Wireshark network program, the respective MCS rate may be verified. In figure 1, the tag length is 34 which shows the HE capabilities having tag number 35. Along with Rx LDPC enable feature, earlier in VHT band this feature is not supported so it was disable. It also supports the STBC feature, in which multiple antennas is used to send the same data to destination. For UL-OFDMA feature we have to keep MU-MIMO feature disable that's why MIMO configuration bits are not set here. And according to standard MCS rate that can be supported by HE band is 0-11 so we can validate this from figure 1 and figure 3.

IV. MULTI-USER MIMO

Multi-user MIMO employs multiple antennas on both the transmitter and receiver sides to achieve multi-path propagation, which improves the system's overall performance. Multiple users can communicate with each other via MU-MIMO, which allows them to send data over one or more antennas. Figure 2 illustrates the Down-Link and Up-Link MU-MIMO concept.

One of the primary features of Wi-Fi 6 is Multi-User MIMO (MU-MIMO). Though Single-User MIMO (SU-MIMO) gets close in terms of per-user throughput due to multi-stream transmission, its advantages are limited by the fact that most clients only support one or two spatial streams. Even if a switch AP can support 4 or 8 spatial streams, it can only send 2 spatial streams to monitor the tolerant client. MU-MIMO allows a multi-antenna router-AP to interact with several clients at the same time, increasing system throughput [12].

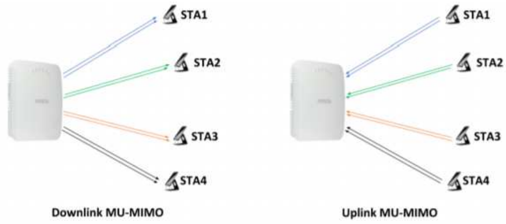

Figure 2. DL/UL MIMO Operation

There are two types of MU-MIMO transmissions: fractional transfer and full transmission capacity speed. The complete Transmission capacity approach is comparable to 802.11ac MU-MIMO operation, in which MU-MIMO streams sent to clients span the entire channel. If the channel bandwidth is 20 MHz, for example, MU-MIMO transmission uses a 242-tone Resources unit to effectively retain the entire channel [12]. When OFDMA and Multiuser-MIMO must be used at the same time, i.e., when clients are multiplexed in both the recurrence and time domains, the fractional transmission capacity mode is used. The lowest RU estimate allowed in this circumstance is 106 tones. For example, if the transmission transfer speed is 20 MHz, a total of 106 tone RUs can be assigned to two different clients for a single MU-MIMO stream. Set the MU Beamformer subfield of the HE PHY Capabilities Data field in its HE Capabilities component to 1 for an AP signal back for MU-MIMO. An MU beamformer is also an SU beamformer, hence the SU Beamformer subfield must be set to 1. In the unlikely event that the router AP supports four or more spatial streams [17].

V. ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS (OFDMA)

OFDM is a digital modulation technology that uses several overlapping orthogonal sub-carriers to transport multiple messages simultaneously. The multiuser version of the OFDM method is known as OFDMA. Subgroups of subcarriers are assigned to several stations using OFDMA to offer multiple channel access.

A Resource Unit is a keyword in comprehending OFDMA technology (RU). RU is a collection of 78.125kHz bandwidth subcarriers (tones) utilized in Uplink and Downlink transmissions in 802.11ax technology. The algorithm for calculating the number of tones based on the channel's bandwidth is:

$$\textit{Number of tones} = \textit{Bandwidth (in MHz)} \div 0.078125\ \textit{MHz} \quad \text{...eq. (2).}$$

So according to eq. (2) the 20MHz channel can be divided into 256 tones, 40MHz channel in 512, and 80MHz channel in 1024 tones.

Some of these tones are used as guard bands to protect from interference. Hence we finally have RU tones of 26, 52, 106, 242, and 996 that can be used.

A. UL-OFDMA

1) UL OFDMA Overview

- The router sends the trigger frame out as a broadcast message to all linked stations.
- In parallel, STAs (clients) broadcasted in the Basic Trigger frame transfer their data UL-uplink to the router AP.
- When the AP receives the data frames, it sends an ACK signal to the clients, which is known as a Multi-STA Block Ack frame.

2) Basic Tigger Frame

- The Tigger frame is a new frame that will be monitored during the UL-Transmission, which is the communication from connected clients to the backside of the access point. This is a new control frame that has been added to the 11ax technology.
- Basic Trigger frame consists of:
    - Header MAC
    - CIF (comman information field)
    - Info User field

```
IEEE 802.11 Trigger, Flags: ........
    Type/Subtype: Trigger (0x0012)
  > Frame Control Field: 0x2400
    .000 0100 0101 0101 = Duration: 1109 microseconds
    Receiver address: Broadcast (ff:ff:ff:ff:ff:ff)
    Transmitter address: 42:50:43:23:fb:d1 (42:50:43:23:fb:d1)
  > Common Info
  v User Info
    v User Info: 0x3220f82020
        .... .... .... .... .... .... .... 0000 0010 0000 = AID12: 0x020
        .... .... .... .... .... .... ...0 .... .... .... = RU Allocation Region: Not used for 20, 40 or 80MHz
        .... .... .... .... .... 1000 001. .... .... .... = RU Allocation: 65 (484 tones)
        .... .... .... .... ...1 .... .... .... .... .... = Coding Type: LDPC
        .... .... .... ...0 111. .... .... .... .... .... = MCS: 0x7
        .... .... .... ..0. .... .... .... .... .... .... = DCM: False
        .... .... ...0 00.. .... .... .... .... .... .... = Starting Spatial Stream: 1
        .... .... 001. .... .... .... .... .... .... .... = Number Of Spatial Streams: 2
        .011 0010 .... .... .... .... .... .... .... .... = Target RSSI: -60dBm
        0... .... .... .... .... .... .... .... .... .... = Reserved: 0x0
    > Basic Trigger Dependent User Info: 0x04
    v User Info: 0x3220f84021
        .... .... .... .... .... .... .... 0000 0010 0001 = AID12: 0x021
        .... .... .... .... .... .... ...0 .... .... .... = RU Allocation Region: Not used for 20, 40 or 80MHz
        .... .... .... .... .... 1000 010. .... .... .... = RU Allocation: 66 (484 tones)
        .... .... .... .... ...1 .... .... .... .... .... = Coding Type: LDPC
        .... .... .... ...0 111. .... .... .... .... .... = MCS: 0x7
        .... .... .... ..0. .... .... .... .... .... .... = DCM: False
        .... .... ...0 00.. .... .... .... .... .... .... = Starting Spatial Stream: 1
        .... .... 001. .... .... .... .... .... .... .... = Number Of Spatial Streams: 2
        .011 0010 .... .... .... .... .... .... .... .... = Target RSSI: -60dBm
        0... .... .... .... .... .... .... .... .... .... = Reserved: 0x0
    > Basic Trigger Dependent User Info: 0x04
```

Figure 3. Basic Trigger frame Capture

1st Info User field:

Station (Wi-Fi DevicesSTA) with identifier id called assoc_id 0x020 has been assigned resource unit number 65 and it should use LDPC coding type with MCS7 and 2 spatial streams.

2nd Info User field:

The resource unit number 66 has been assigned to Station (Wi-Fi Devices STA) with assoc id 0x021, and it shall utilize LDPC coding form with MCS7 and 2 spatial streams.

Based on the RU Allocation Map, one client uses a 484-Resource Unite tone (RU-65) in the lower half and a 484 tone RU (RU-66) in the upper half in an 80MHz Bandwidth.

Multi-STA Block Ack:

We conduct UDP data traffic and send ACK to Wi-Fi devices connected to a Router Access point when the router access point has decoded the uplink data frame.

Multi-Station Block Acknowledgement, Multi-STA Block Ack is a new Block Acknowledgement frame used by AP. All stations in the network will receive the Multi STA Block ACK.

VI. Exprimental Setup and Results

The most recent and advanced WLAN standard, 802.11ax (Wi-Fi 6), has come and been launched in the market with its specifications; for analysis and performance testing, we will need to set up at least two clients and can be extended up to eight clients. Because OFDMA and MIMO both enable at least two stations, testing for single, two, four, and eight stations is carried out. Previous wifi standards were primarily concerned with speed, whereas 802.11ax is more concerned with efficiency and the number of users who may connect at the same time while making efficient use of the channel [13].

In the experimental setup four stations are connected to the router access point (AP) are shown in the figure 4. Each of the four stations is connected to a wifi router, and the arrangement is aligned to provide optimal baseline throughput for each station. The iPerf tool, which is a network analysis tool, is used to determine throughput.

Figure 4. Four station setups for OFDMA and MIMO testing

In an application like IoT, where low power consumption and high data rates are required, the UL-

OFDMA technique comes in handy because it efficiently handles all clients by allocating appropriate resources. Because the linked device will use bandwidth and transfer data as needed, there will be power savings. This can be used in automotive applications that require high speed and throughput.

A. Analysis of throughput for maximum MCS rate

In the aforementioned example, we've used the 5GHz frequency range because it's compatible with both 11ax and 11ac. 2.4GHz and 5GHz are the two frequency bands available here. MCS 11ax, which is set to auto by default, supports the maximum MCS rate. Throughput was improved by about 25% to 27% in the 5GHz frequency spectrum. There we have used 1024-QAM that is also another feature of 11ax technology. All graphs for all conceivable situations are included in the results section.

B. Results

The frequency used is 5GHz, and the band is HE-20 and HE-80. The figures 5 shows, a single station connected at a time. Both TCP and UDP traffic are measured for throughput.

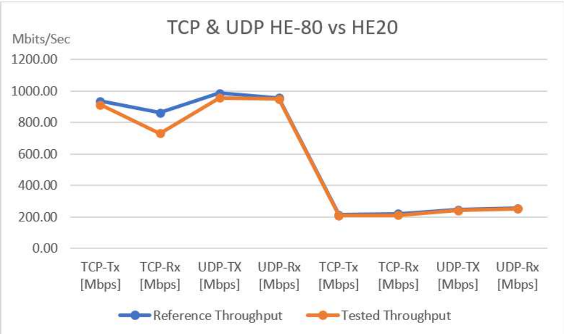

Figure 5. Throughput for Single station TCP& UDP traffic

The flow control mechanism in TCP traffic limits the rate of transmission, resulting in lower throughput than the advertise window divided by the network round-trip time, whereas UDP has no such restriction. This is the most common cause of low throughput in TCP-RX mode traffic.

The maximum throughput achieved by the Wi-Fi client connection can be shown in Figure 5. For baseline throughput, we've only connected one device. For both TCP and UDP, the operational bands are HE 80 and HE 20. TX and RX both carry data transmission to and from the client.

TCP Tx has a maximum throughput of 913MB, whereas TCP Rx has a maximum throughput of 739MB.

In the same way, UDP Tx is 957MB, and UDP Rx is 949MB. When comparing TCP with UDP, UDP has higher throughput. We receive greater TP in UDP traffic because packet-based transmission is used, and no dedicated link is established between the source and destination.

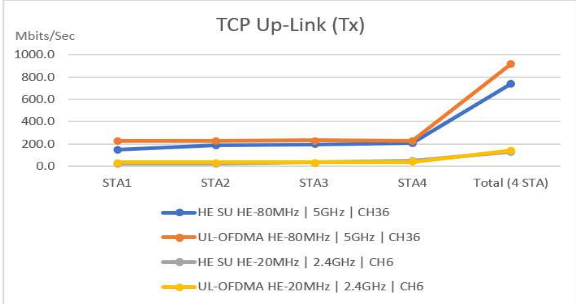

Figure 6. UL-OFDMA Throughput for Four station TCP traffic

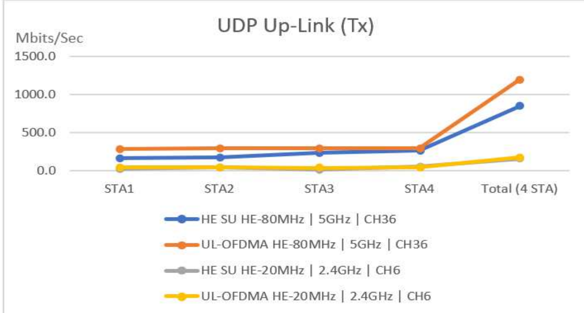

Figure 7. UL-OFDMA Throughput for Four station UDP traffic

For OFDMA testing, we'll need at least two client devices. Figures 6 and 7 depicts the outcomes for four clients connected in network. The first is HE SU, which is non-OFDMA based, and the second is HE MU, which converts the PPDU format to HE-MU while simultaneously increasing throughput. The main reason behind the increase in TP is that OFDMA is enabled which will use RU allocation for dividing the existing channel bandwidth. Here we have an MCS index is up to 11 so we can achieve this much TP as compared to normal operation.

The setup is properly oriented to attain maximum throughput to baseline throughput like that all clients are set and configured before actual OFDMA testing. Following that, we run high-capacity traffic for both TCP and UDP, Tx is here Uplink Transmission in OFDMA mode, and we've observed the suitable data frame in sniffer Wireshark to ensure proper operation.

TCP and UDP configuration values are 900MB bandwidth and 300MB bandwidth, respectively. The graph shows that the throughput for HE-SU increased to 744MB in the 5GHz band, while the throughput for OFDMA increased to 918MB for TCP.

Similarly, HE-SU in the 5GHz band provided 852MB throughput for UDP traffic, but OFDMA provided 1193MB throughput for UDP.

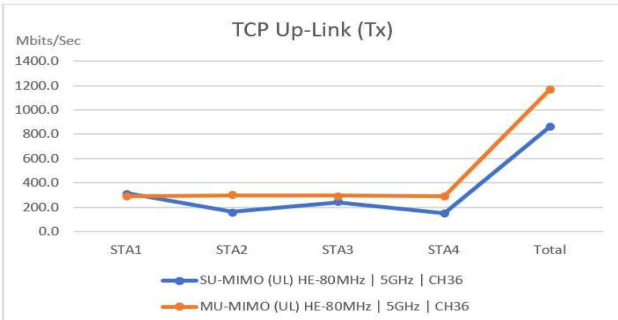

Figure 8. MU-MIMO Throughput for Four station TCP traffic

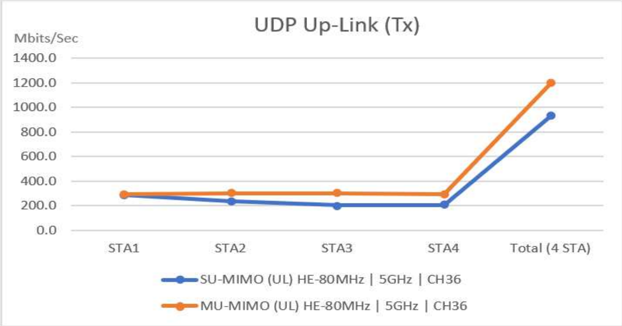

Figure 9. MU-MIMO Throughput for Four station UDP traffic

We'll need at least two client devices to test MU-MIMO because the term implies multi-user operation. The first is MIMO SU, which is non-MIMO based, and the second is HE MU, which converts the PPDU format to HE-MU and dramatically increases throughput, similar to OFDMA.

The setup has properly oriented the setup to get maximum throughput to baseline throughput so that all clients are set and configured before actual MIMO testing. The MU-MIMO uses a dedicated channel for each user and allocates all RU to a single user. That leads to maximum data transfer to one client at a time and TP increased drastically. Figures 8 and 9 show the TP number graph for TCP and UDP traffic respectively, where 4 clients are connected and auto MCS is kept i.e. MCS11.

Table 1. Throughput Numbers for MU-MIMO 4 Station connected

UL MU-MIMO		TCP Tx				
TP TYPE	Mode	STA1	STA2	STA3	STA4	Total (Mbit/s)
SU-MIMO (UL)	HE-80MHz | 5GHz | CH36	313.0	160.0	240.0	153.0	866.0
MU-MIMO (UL)	HE-80MHz | 5GHz | CH36	290.0	297.0	295.0	289.0	1171.0
UL MU-MIMO		UDP Tx				
SU-MIMO (UL)	HE-80MHz | 5GHz | CH36	286.0	236.0	203.0	205.0	930.0
MU-MIMO (UL)	HE-80MHz | 5GHz | CH36	296.0	301.0	302.0	296.0	1195.0

Following that, we performed high-capacity traffic for both TCP and UDP, Tx is here Uplink Transmission in MU-MIMO mode, and we observed the proper data frame in the sniffer Wireshark to ensure proper operation. 1.5GB bandwidth and 0.5GB bandwidth for TCP and UDP are the configuration values utilized here. The graph shows that the throughput for HE-SU, increased to 866MB in the 5GHz band, while the throughput for MIMO is increased to 1.17GB for TCP. From the Table 1, we can conclude that we have achieve the approximately 30% more throughput than single user.

Similarly, HE-SU in the 5GHz band provided 930MB throughput for UDP traffic, whereas MIMO provided 1.19GB throughput for UDP.

V. CONCLUSION

This research examines the performance of IEEE802.11ax based on throughput, modulation scheme, special streams, and channel bounding technique. The UL-OFDMA feature is confirmed, and throughput is measured for four clients. MIMO testing is also done. Wi-Fi 6 employs the new and complicated OFDMA access technology, which results in increased capacity in packed environments with high station density, such as train stations and stadiums.

The usage of OFDMA results in increased efficiency, while MIMO results in increased capacity. The new features UL-OFDMA and MU-MIMO have a substantial impact on throughput numbers. The OFDMA technique divides the overall bandwidth into small subcarriers termed RU, allowing for more efficient bandwidth utilization. We can get up to 1.19GB throughput using UDP, which is a 30 percent increase over conventional 11ac operation.

Similarly, we have successfully tested MU-MIMO with the four clients and can reach around baseline throughput. The use of 1024QAM results in improved performance.

In the future, we will use this methodology for performance measuring and improvement for Wi-Fi 6E technology which has a 6GHz frequency band. In many real-time open environment cases, this technology is likely to perform poorly, and we will continue to investigate alternative approaches to enhance throughput as part of our future work.

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