# IEEE 802.11 Based Heterogeneous Networking: An Experimental Study

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**Abstract.** This paper analyses the results from an experimental study on the performance of the heterogeneous wireless networks based on IEEE 802.11a, 802.11n and 802.11ac standards in an indoor environment considering the key features of PHY layers mainly, Multiple Input Multiple Output (MIMO), Multi-User Multiple Input Multiple Output (MU-MIMO), Channel Bonding and Short-Guard Interval (SGI). The experiment is conducted for the IEEE 802.11ac standard along with the legacy protocols 802.11a/n in a heterogeneous environment. It calculates the maximum throughput of IEEE 802.11 standard amendments, compares the theoretical and experimental throughput over TCP and UDP and their efficiency. To achieve this desired goal, different tests are proposed. The result of these tests will determine the capability of each protocol and their efficiency in a heterogeneous environment.

**Keywords:** Local Area Network (LAN)
Wireless Local Area Network (WLAN)
Quality of Service (QoS) and AP (Access Point)

## 1 Introduction

The Wireless LAN (WLAN) technology have seen tremendous growth and benefits due to major changes in the world of Local Area Network (LANs), as the WLAN technology has matured and it is now the core of internet communication. In IEEE 802.11, 802.11a specifications provide up to 54 Mbps data rates [1]. However, the practical and theoretical throughput of IEEE 802.11a are 25 Mb/s and physical-layer (PHY) data rate are 54 Mb/s respectively [2]. The IEEE 802.11n standard introduced the MIMO by implementing spatial diversity, which enables it to achieve at least four times more throughput than legacy protocols [3].

The wireless network standards IEEE 802.11a/n works reliably. However, their speed does not satisfy users' demand and the throughput may not support large data files under various condition, hence, the latest amendment of IEEE 802.11ac is invented to improve transmission performance [4]. The 802.11ac is the latest WLAN standard that is rapidly being adapted due to the potential of delivering very high throughput. The throughput increase in 802.11ac are due to larger channel width


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(80/160 MHz) which support for denser modulation (256 QAM) with increased number of spatial streams for MIMO and MU-MIMO [5]. The 802.11ac is a faster, improved and more scalable version of the 802.11n with the capabilities of Gigabit Ethernet with a wider bandwidth [6].

The deployment of wireless network in 2.4 GHz frequency band over the years has started to show limitations due to number of interference issues between neighboring devices which affects the performance of entire wireless network [7]. The emerging wireless technologies which operates in 5 GHz frequency spectrum has number of advantages over 2.4 GHz in terms of non-overlapping channels with wider channel bandwidth for gaining higher throughput. However, 5 GHz wireless network technology suffers the signal attenuation at higher frequencies which results in lower range compared to 2.4 GHz network technology. The IEEE 802.11 protocols operate in multiple frequency spectrum band, some of them operate in both bands (2.4 and 5 GHz) like, 802.11n and others 802.11a/ac operates in single band (5 GHz). The 802.11 WLAN efficiency is severely compromised due to interference of other Wireless LAN technology operating in same environment and this affects the data throughput and efficiency of Wireless Network. The performance evaluation of IEEE 802.11ac has been widely explored over simulation platform, although there is not much experimental evaluation done in practical scenarios [8, 9].

The objective of this research is to test 802.11ac experimentally with legacy protocol 802.11a/n for throughput and efficiency operating in heterogeneous environment. The rest of the paper is organised as follows. Section 2, provides a brief discussion on details and problems of the IEEE 802.11 and their amendments in heterogeneous environment. Section 3, describes the design and arrangement of the experiment. It includes the network diagram, list of equipment's used and test cases for testing the throughput and efficiency. The results are discussed in Sect. 4. We conclude the presented work in Sect. 5.

## 2 Related Work

According to [10] if there are two access points placed in an indoor environment, one is an 802.11n and the other is an 802.11ac, then the signals transmitted by the 802.11ac will overlap with the signal of legacy protocol 802.11n resulting narrower channel width and hence decrementing the network throughput. Another issue stated by [11] when an 802.11n and 802.11ac are deployed in an indoor environment the Time Difference of Arrival (TDOA) of signal of 802.11ac compared to 802.11n decreases because of interference with 802.11n signal, also use of wider bandwidth with 802.11ac, thus can improve the accuracy and stability of TDOA at lower sound to noise ratio (SNR). Another interoperability issue stated by [12], that 802.11ac works only on a 5 GHz band and the 802.11n works on 2.4/5 GHz band and there is no 80 and 160 MHz channel in 802.11n. Moreover, 802.11n only works on 20 and 40 MHz, hence the backward compatibility should be checked with existing 802.11a/n devices.

The problem can be elaborated with the help of the following examples. In a heterogeneous environment consisting of two access points namely AP-1 and AP-2 working on different protocols, when the clients boot up, it sees the signal from AP-1 stronger than AP-2 and gets connected. But in another case, the AP-1 offers 54 Mbps of data rate at −35 dBm and AP-2 offers 64 Mbps at −45 dBm. In this case the client has to make a decision whether it should connect to the access point which offers higher data rate or connect to a slower network with stronger signal. In both of these cases, the clients have to spend more power since the slower network would transmit the data with lower data rate and it has to send more number of frames to transfer particular data, which would consume more power. On the other hand, if the clients connect to the other access point, which offer higher data rate but with lower signal strength, it again has to spend more power, in such case the decision has to be made by the clients' algorithm whether to spend more power to connect the weak but fast network or strong but slow network.

This paper intends to study the problem stated above and to check the behaviour of TCP and UDP protocols in terms of their theoretical data rate, practical data rate and efficiency while connecting to a particular heterogeneous wireless network. Thus, our contribution is to build a test bed and set of tests to determine the capability of each protocol (IEEE 802.11a/n/ac) and their efficiency in a heterogeneous environment with off-the-shelf equipment and indoor heterogeneous environment. The results obtained by the tests performed will be useful in understanding protocols in wireless networks.

## 3 Design of Experiment

The test-bed is described in Fig. 1, followed by the details of equipment used for test-bed. In order to investigate the performance in terms of data throughput of wired and wireless hosts against the advertised data rates by implementing test cases provided in Table 1.

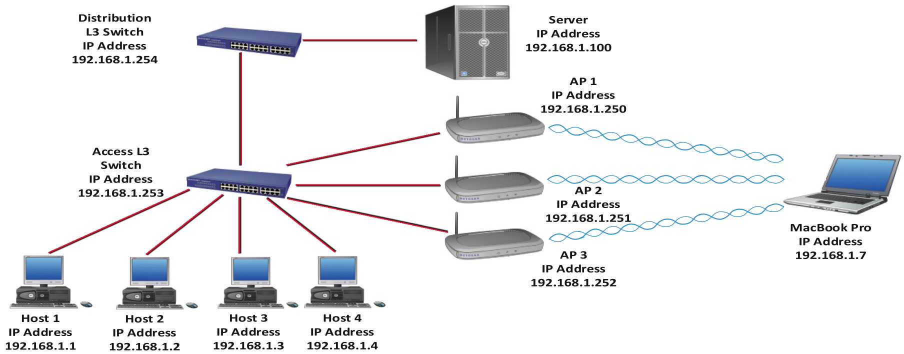


**Fig. 1.** Network diagram for experiment

**Distribution Layer Switch:** The distribution switch (Cisco 3560) consists of 12 fibre gigabit Ethernet and 2 copper gigabit ports. The IP traffic generator used on a server which acts as a host connected to the gigabit port on distribution switch. Fibre optic port are providing the downlink connection from the distribution switch to access the layer switch. Both 802.11n and 802.11ac supports the data rates up to 600 Mbps and 867 Mbps.

**Table 1.** Test cases used for experiment.

| Test | Test cases |
|---|---|
| 1 | Wired |
| 2 | 802.11a 5 GHz 20 MHz |
| 3 | 802.11n 5 GHz 20 MHz, 1 Stream and SGI=ON |
| 4 | 802.11n 5 GHz 20 MHz, 2 Stream and SGI=ON |
| 5 | 802.11n 5 GHz 40 MHz, 1 Stream and SGI=ON |
| 6 | 802.11n 5 GHz 40 MHz, 2 Stream and SGI=ON |
| 7 | 802.11ac 5 GHz 20 MHz, 3 Stream and SGI=ON |
| 8 | 802.11ac 5 GHz 40 MHz, 3 Stream and SGI=ON |
| 9 | 802.11ac 5 GHz 80 MHz, 3 Stream and SGI=ON |

**Access Layer Switch:** Cisco 3560 switch used as an access layer switch consists of 12 copper gigabit Ethernet ports. This switch is used to terminate all access points and host connections.

**Access Point 1:** The AIR-AP-1242AG-E-K9 access point was used to test 802.11a. It supports the 802.11a/b/g/n. In this experiment to measure the throughput for 802.11a, the other data rates 802.11b/g/n were disabled to make sure that the client should stay connected to the 802.11a.

**Access Point 2:** The AIR-AP126N-E-K9 access point was used to test 802.11n. This access point supports 2.4 GHz and 5 GHz bands.

**Access Point 3:** The Asus RT-AC66U access point was used to test 802.11ac. This access point supports 2.4 GHz and 5 GHz bands with 3 external dual-band detachable antennas.

**JPerf:** This software tool is used to measure the throughput and performance of network by varying the parameters such as payload, protocol, etc., it was carried out using Jperf's graphical interface (open source software). It accounts for parameters such as bandwidth, delay and jitter amongst others.

**Host/Servers:** The host machine used as client and client-acting server used the configuration of Windows 7 Service Pack 1 64- bit with AMD Athlon dual core processors is running at 2.20 GHz with 8 GB RAM. All hosts consist of two network adapters namely, Linksys wireless adapter connected to wireless infrastructure for 802.11n and ASUS Wireless adapter for 802.11ac on-board network card that provided connectivity to the wired network.

**USB Wireless Adaptor:** The external USB wireless adapters used for wireless connectivity are Cisco-Linksys WUSB600N and ASUS dual band USB-AC56.

**Mac Book:** A Mac Book Pro with 2.5 GHz Intel i5 processor with 4 GB of RAM used for the range test.

**Wi-Fi Scanner:** It is a convenient tool for gathering information like signal strength, noise, SNR and data rates.

## 4 Results

The throughput test is designed to test the throughput of all the protocols (IEEE 802.11a/n/ac) as mentioned in the earlier section. This results in a large number of outcomes but only the necessary number of outcomes are considered in this paper. The omitted outcomes are mainly with the protocols tested with the setting Short-Guard Interval (SGI=OFF), because this setting in the access points only affect the throughput results by 10%.

### 4.1 Averages

All the outcomes obtained from the experiment are summarised in Table 2. The wired test also called Ethernet, which shows the maximum throughput with the increased number of hosts and found much higher value than any wireless protocols tested in this experiment. The TCP is found to perform better than UDP on wired network while UDP outruns TCP on wireless network. The reason behind this is TCP negotiate the connection between source and destination and it adjusts the contention window or buffer size according to the capacity of the media, while UDP does not have any such property and sends the data across the link without knowing the capacity of the media which connects the source and destination [13, 14].

**Table 2.** Comparison of average against number of hosts for TCP and UDP.

| Protocol/Host | TCP | | | | UDP | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 Host | 2 Host | 3 Host | 4 Host | 1 Host | 2 Host | 3 Host | 4 Host |
| Wired | 687.8 | 850.8 | 855 | 837 | 131.5 | 244.5 | 421.9 | 532.1 |
| a 5G 20M 1 Stream ON | 23.25 | 20.7 | 19.59 | 18.17 | 25.83 | 26.33 | 26.61 | 22.81 |
| n 5G 20M 1 Stream ON | 44.23 | 50.05 | 52.64 | 44.00 | 59.22 | 61.33 | 61.39 | 60.73 |
| n 5G 20M 2 Stream ON | 67.75 | 75.14 | 90.96 | 91.79 | 113.9 | 114.5 | 114.8 | 113.6 |
| n 5G 40M 1 Stream ON | 74.46 | 91.44 | 94.09 | 94.41 | 116.5 | 117.5 | 117.5 | 117.19 |
| n 5G 40M 2 Stream ON | 114.7 | 122.8 | 134.9 | 144.2 | 180.6 | 196.7 | 192.8 | 188.5 |
| ac 5G 20M 3 Stream ON | 76.15 | 93.45 | 104.2 | 96.27 | 108.2 | 111.9 | 114.6 | 108.08 |
| ac 5G 40M 3 Stream ON | 106.8 | 145.5 | 160.8 | 170.1 | 125.5 | 201.5 | 209.1 | 215.5 |
| ac 5G 80M 3 Stream ON | 110.4 | 175.2 | 189.3 | 217.3 | 117.6 | 199.2 | 215.9 | 223.5 |

In the case of 802.11a the performance decreases as the number of host increases. The main reason behind this is a collision, as every host looks for a free channel to transmit. If the channel is free for the DIFS interval it can transmit, otherwise the transmission is interrupted by a random back off timer. The method of identifying the collision and to avoid it, causes the drop in the throughput of 802.11a with a number of host increases. The maximum throughput recorded by 802.11a on TCP is 23.25 Mbps and on UDP is 26.61 Mbps but as the number of hosts increasing the throughput drop can be seen in the Table 2. This affects the performance of the network. While designing the network the number of hosts connected to a given access point must be considered.

The 5 GHz spectrum has very little interference during the test which helps 802.11n to achieve the higher throughput in 5 GHz frequency spectrum. The 802.11n is tested with 20 MHz and 40 MHz channel bandwidth with 1 and 2 streams. The maximum throughput achieved on 802.11n 20 MHz single stream is 52.64 Mbps, while with multiple stream it is 91.79 Mbps. This denotes that the multiple stream performs better and gives the maximum throughput. On the other hand, the throughput achieved on 802.11n 40 MHz channel bandwidth is almost double the throughput of 802.11n with 20 MHz channel bandwidth; the maximum throughput achieved on 802.11n 40 MHz single stream and multiple stream is 94.41 Mbps and 144.2 Mbps respectively. The same results are observed with 802.11n 5 GHz frequency with 20/40 MHz channel bandwidth using UDP. It can be safely concluded that the channel bonding feature in 802.11n increases the performance.

The recent amendment of IEEE is 802.11ac and it works on 5 GHz frequency with 20/40/80 MHz channel bandwidths. The access point used for this test supports 866 Mbps data rate with three spatial streams and due to limited number of external network adapter (i.e., 4) test results are constrained. The 802.11ac test on a 20 MHz channel bandwidth shows the throughput drop after 4 hosts transmitting simultaneously. However, with the channel bonding (i.e., 40 MHz and 80 MHz) the throughput increases as the new hosts are connected and this nature is observed on both TCP and UDP. The maximum throughput achieved with 4 hosts transmitting simultaneously using 80 MHz channel bandwidth on TCP is 217.38 Mbps and on UDP is 223.54 Mbps. It can also be seen that with 40 MHz channel bandwidth the 802.11ac with 4 hosts transmitting simultaneously generate the throughput of 170.1 Mbps on TCP, while 802.11ac with 80 MHz bandwidth with 4 hosts transmitting simultaneously and generate the throughput of 217.38 Mbps. The Figs. (2, 3, 4 and 5) below shows the graphical representation of the results with various test case scenarios.

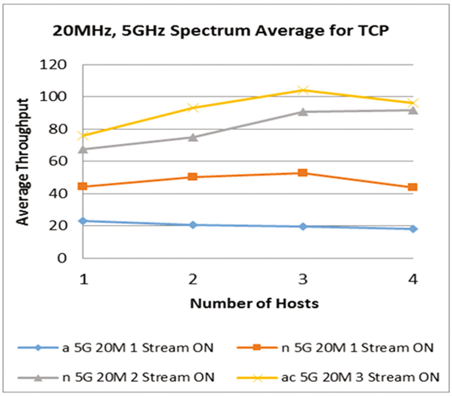


**Fig. 2.** 5 GHz, 20 MHz, Average for TCP

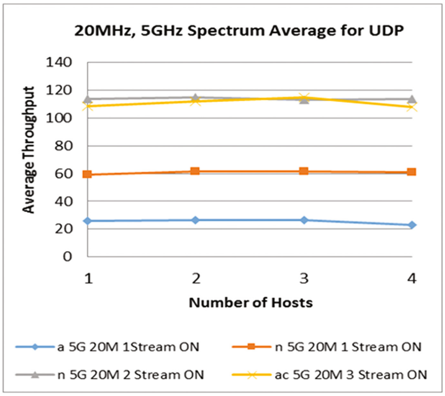


**Fig. 3.** 5 GHz, 20 MHz, Average for UDP

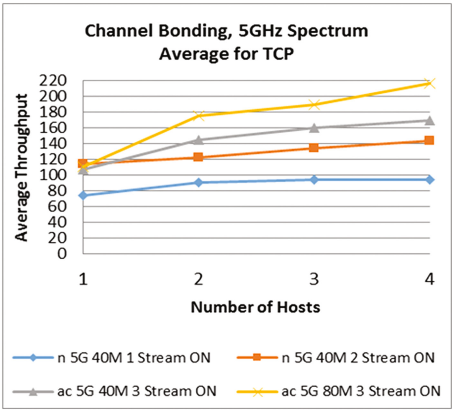


**Fig. 4.** 5 GHz, Channel Bonding for TCP

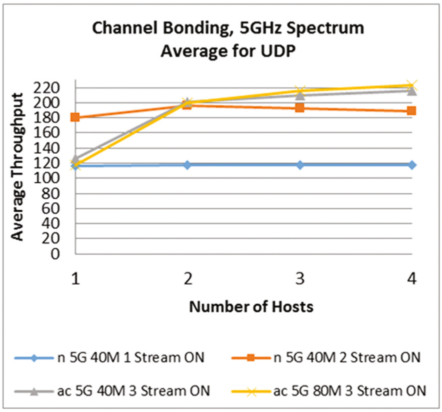


**Fig. 5.** 5 GHz, Channel Bonding for UDP

## 4.2 Efficiency of Protocols

This section analyses the results from the previous sections and the efficiency of protocols are tested. Every protocol offers different data rates, hence to compare all the protocols data rate, throughput and efficiency on the same scale, we calculate Efficiency (E) as follows:

$$E = \left( \frac{Average\ throughput\ obtained\ from\ 10\ runs}{Maximum\ data\ rate\ offered\ by\ that\ protocol} \right) \times 100 \quad (1)$$

### 4.2.1 TCP and UDP Efficiency

The graph below shows that the efficiency of TCP on the protocols tested. The highest efficiency achieved by wired network is about 85%. The efficiency is tested by simultaneously transmitting 3 streams of data from the host to the server. We found that after connecting 3 hosts this efficiency and throughput drops. In a wired network, the throughput and efficiency increases as new hosts are added till a certain limit. When comparing the wired network with the wireless network the efficiency drops are seen in wireless network as new hosts are connected. In case of 802.11a, the first host connecting gives the highest throughput but as soon as new hosts are added, the throughput drops. The wired network is full duplex and the wireless network is half-duplex. However, the wireless network also has to handle collision detection; hence, the efficiency of the wireless network decreases as new hosts are connected. 802.11a with one host shows the efficiency of 43.055% and as the number of hosts increases, it drops to 33.648% at 4 hosts. But in case of 802.11n and 802.11ac, the throughput increases as new hosts are added till certain limit. Thus, it is safely concluded that the 802.11n and 802.11ac are better than 802.11a. The 802.11n and 802.11ac behaves like wired network in terms of throughput and efficiency because it has a feature called MIMO and MU-MIMO respectively. This new feature introduced in wireless network protocols has improved their throughput and range capacity. The multiple antennas with multiple spatial streams to transmit and receive the wireless signal, boosts performance and efficiency.

The 802.11n in 5 GHz spectrum with 20 MHz channel bandwidth and 1 stream shows the efficiency 35.09%, while with 2 streams the efficiency is 30.59%. Since the 5 GHz band is fairly empty as compared to 2.4 GHz the efficiency of the 802.11n should be more and multiple streams should improve the efficiency than single stream, but in the test it is observed that the efficiency is worst with multiple streams as compared to single stream. Similarly, in case of 802.11n in 5 GHz with 40 MHz channel bandwidth the efficiency on 1 stream and 2 streams is 62.94% and 48.06% respectively. The 802.11n with channel bonding gives the highest data rate but worst efficiency. Since the channel bonding with multiple streams makes the 802.11n work on full potential and not using the complete spectrum, which results in 1 stream performing better than 2 streams.

The 802.11ac in 5 GHz spectrum with 20 MHz channel width with 3 streams shows the efficiency 12.03%, while other variants 40 MHz and 80 MHz show 19.64% and 25.10% efficiency respectively. Due to the limited resources in terms of equipment, further tests are not being performed. The 802.11ac with all variants shows the similar characteristics; as new hosts are added the throughput and efficiency increases. In the case of 802.11ac with 20 MHz, the 1 host efficiency is 8.79% and increasing linearly till the 3 hosts delivering 12.03%. The data rates achieved by the 802.11ac and all their variants are better than 802.11n but in terms of efficiency the 802.11ac fails to keep up with 802.11n protocol. The Fig. 6 shows the graphical representation of TCP protocol efficiency.

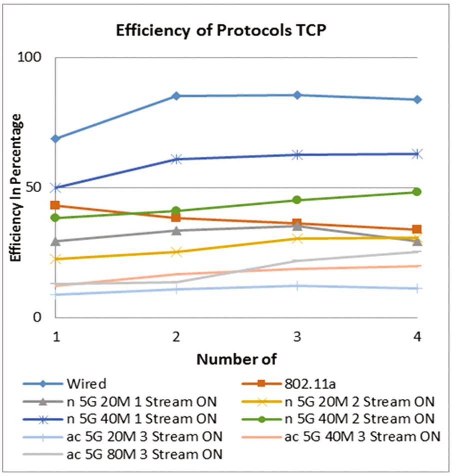


**Fig. 6.** Efficiency of TCP protocol

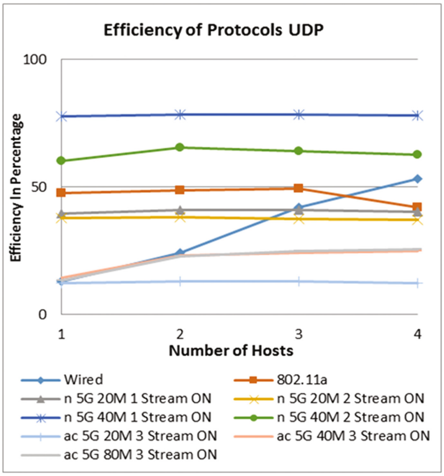


**Fig. 7.** Efficiency of UDP protocol

The Fig. 7 above shows the graphical representation of UDP protocol efficiency. The UDP efficiency of the 802.11a is 49.27%. The throughput and efficiency increases till a certain host, then it drops down. With UDP all wireless protocols and their variations show better efficiency than TCP. The reason behind this is that UDP operates without overhead for setting up the connection and acknowledgement and UDP is a best effort delivery protocol, which makes it faster than TCP. The all variants of 802.11n shows similar behavior as TCP, increasing throughput till certain point and then decreases with a constant rate. The wired network on a UDP performs poorer than TCP and the peak value of UDP is not even close to the value with one host on the TCP; for a wired network on a UDP efficiency of 1 host is 13.11%, while the maximum efficiency noted is 53.2%.

The 802.11n in 5 GHz spectrum with 20 MHz channel width with 1 stream, shows the maximum efficiency of 40.48% and with 2 streams it shows 37.96%. It can be seen here that 1 stream performs better than 2 streams. The same phenomenon is observed with 802.11n with channel bonding the maximum efficiency with 1 stream is 78.38%, while with 2 streams it is 65.52%. The main cause of that the 802.11n gives best throughput with channel bonding and multiple spatial streams but not utilizing the spectrum completely.

The 802.11ac in 5 GHz spectrum with 20 MHz channel bandwidth with 3 streams shows the maximum efficiency of 13.24%, while the other variants 40 MHz and 80 MHz shows 24.88% and 25.81% respectively. The efficiency increases as the number of hosts increases till a certain limit but it drops after that. The 802.11ac with 20 MHz channel starts with 1 host at 12.50% and reaches peak value at 13.24% at host 3. In case of 802.11ac with channel bonding, the throughput and efficiency increases till the last host. The 802.11ac and all variants give maximum throughput but they show less efficiency than any variant of the 802.11n.

UDP outruns TCP in terms of throughput and efficiency but it is not as reliable as TCP. The single stream performs better than the multiple streams but multiple streams give a better throughput. The 802.11n with channel bonding has a better efficiency than all the variants of the 802.11ac.

## 5 Conclusion

This paper included test scenarios which are designed for the 802.11ac to compare throughput performance and their efficiency with the legacy protocols (802.11a/n) in 2.4 and 5 GHz frequency spectrum. The throughput test outcomes show that the theoretical throughputs are never achieved during this experiment. On the platform of TCP and UDP the advertised throughputs of protocols are never reached; TCP shows 50% and UDP shows 65% of the actual advertised data rate of the protocol. The short guard interval (i.e.400 ns), boosts the data rate by 8–12%. It can be clearly concluded that wired network are still better than the wireless network in terms of data rate and efficiency. The increment in the throughput of the 802.11n and the 802.11ac with new features like, short guard interval, channel bonding, MIMO and MU-MIMO helps the wireless networks to achieve data rate and throughput close to the wired networks. The validation of this paper could serve as proof of content, of newer approaches or tests that could be designed to prove either one to be better.

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