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TCP Throughput Measurement and Comparison of IEEE 802.11 Legacy, IEEE 802.11n and IEEE 802.11ac Standards

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Abstract

Objectives: This paper focuses on extensive TCP throughput measurement for different IEEE 802.11 standards. TCP being the reliable protocol in the multi-network environment, we measure the TCP throughput to benchmark the performance. **Methods**: The TCP throughput measurement setup includes Ix-Charriot tool which generates traffic between the source and destination clients. To measure throughputs of IEEE 802.11 a,b,g,n, we used single clients while, for IEEE 802.11ac we did a multi-client throughput measurement. The throughput is measured upstream and downstream. **Findings**: In the evolution of IEEE 802.11 standard, the major amendments have been with respect to the data rates. In our work we are trying to analyze how the enhancements made in IEEE 802.11 standards have affected the data rates, by measuring the TCP throughput and comparing the values in every case. TCP being the reliable protocol in the multi-network environment is the preferred choice of protocol to benchmark the performance in terms of throughput. **Conclusion**: From the performance testing results we conclude that with the enhancement in the IEEE 802.11 technology, there has been tremendous improvement in the performance of the latest standards, i.e., 802.11n and 802.11ac. As the IEEE 802.11n standard uses OFDM technology rather than DSSS or FHSS, the throughput is better. This is because in OFDM multiple frequencies are used for data transmission whereas DSSS uses single frequency to transmit the data. Thus the throughputs for IEEE 802.11b/g are lower compared to IEEE 802.11n. Also in IEEE 802.11n MIMO technology is used, which enables more data transfer over larger distances.

Keywords: Measurement, Performance, Throughput, TCP

1. Introduction

IEEE 802.11 refers to the WLAN technology, i.e., communicating wirelessly over the air either by using an infrastructure like an AP (Access Point) or by ad-hoc. In the infrastructured wireless communication, the two basic components that make WLAN are: the AP and the mobile station. IEEE 802.11 thus characterizes a management protocol between the AP and the mobile station[1]. With the convenience that IEEE 802.11 has provides, the demand for internet has increased tremendously over the years, and thus we see the IEEE 802.11 products in the business markets as well as residential markets. Lot of research is going on to improve the bandwidth access and the data rates.

The theoretical max throughput values that the standards have, may not be realistic[2]. Those values depend on the experimental scenario. The objective of this work is to measure the actual throughputs using TCP traffic for different IEEE 802.11 standards (i.e. a, b, g, n, ac), analyze and compare the values. We use TCP traffic since it is a reliable protocol providing end-to-end guarantee in a multi-network environment. With the use of acknowledgment mechanism, and sliding window mech-

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anism handling both timeouts and retransmissions, TCP provides a reliable application services to the virtual connection.

2. An Overview of Enhancements in IEEE 802.11

IEEE 802.11b was the first enhancement to the 802.11 standard which provided 11 Mbps bandwidth operating in the standard 2.4 GHz frequency band. With IEEE 802.11b, IEEE 802.11a was another amendment made to the basic 802.11 standard[3]. To meet its basic and initial goal of achieving high data rate, it made use of Orthogonal Frequency Division Multiplexing (OFDM) and chose 5 GHz frequency band for operation over 2.4 GHz band, taking the advantage of having non-overlapping channels for data transmission providing 54 Mbps data rate.

IEEE 802.11g was the next enhancement made in order to bring the best of both 802.11b and 802.11a. It supported bandwidth up to 54 Mbps and operated in 2.4 GHz band, providing backward compatibility with 802.11b devices. Next major enhancement was IEEE 802.11n which made use of MIMO technology[1], which is nothing but making use of multiple antennas instead of one. It operates in 2.4 GHz as well as 5 GHz RF band and provides backward compatibility for 802.11b/g and 802.11a. With the introduction of MIMO technology, the throughput drastically improved providing up to 600 Mbps[4-7].

The latest Wi-Fi technology is the IEEE 802.11ac which supports up to 1.3 Gbps data rates and operates only in 5 GHz band. Another special feature that plays major role in offering higher data rates is the provision of wider operating channels of 80 MHz to 160 MHz.

The introduction of MIMO-OFDM (Multiple Input Multiple Output - Orthogonal Frequency Division Multiplexing) led to new IEEE 802.11n, which showed better performance in wireless LAN with respect to throughput and range. Throughputs of about 100 Mbps can be achieved only with two spatial streams. This is almost four times that of IEEE 802.11a/g. Also the range increases by three times with the use of MIMO-OFDM in IEEE 802.11n than compared to IEEE 802.11a/b/g. Realizing the capabilities and effectiveness of MIMO-OFDM, many organizations have chosen this as the best solution for future wireless technology[8-9].

Through series of experiments and thorough analysis it was seen that the TCP station in 802.11 WLAN, the connections are not consistent or sporadic, while most of the traffic generated by the TCP connections is saved by the access point10. A saturated equivalent model is used to explain the interactions between the transport layers and the MAC layer. Also a detailed study to understand the results of the performance evaluation IEEE 802.11 WLAN standards is done. The details of the study reveal that in TCP flows, the throughput is independent of the number of streams and it could be modeled as aggregate of multiple streams. Whereas, for UDP streams, n times better throughput for n number of streams could be obtained.

3. Performance Test-bed Setup

For throughput testing we use a traffic generator tool named Ix-Charriot. This is a GUI based tool that is capable of generating any traffic (i.e. UDP or TCP). This software tool runs on the control station from where the traffic is fired. The test bed set up, includes Win-XP laptops as clients, a dual radio access point, i.e., it operates in both 2.4 GHz as well as 5 GHz band and a control station that runs the traffic. We conduct the experiment in anechoic chamber to avoid interferences. The experiments are conducted for single clients as well as multiple clients.

3.1 Legacy Performance Testing

To start with we did the performance test for the legacy clients, i.e., 802.11a/b/g. For legacy we have done with single client. The set-up is as shown in Figure 1.

3.2 Performance Testing for 802.11n

With the same AP and client platform we perform the throughput test for 802.11n clients in 20 MHz as well as 40 MHz operating bandwidth for single clients' scenario. The set-up is as shown in Figure 2.

3.3 Performance Testing for 802.11ac

The throughput performance for 802.11ac clients is done on the same platform with 80 MHz channel bandwidth. For 802.11ac we do the setup for multi-client (10, 20 and 30) as shown in Figure 3.

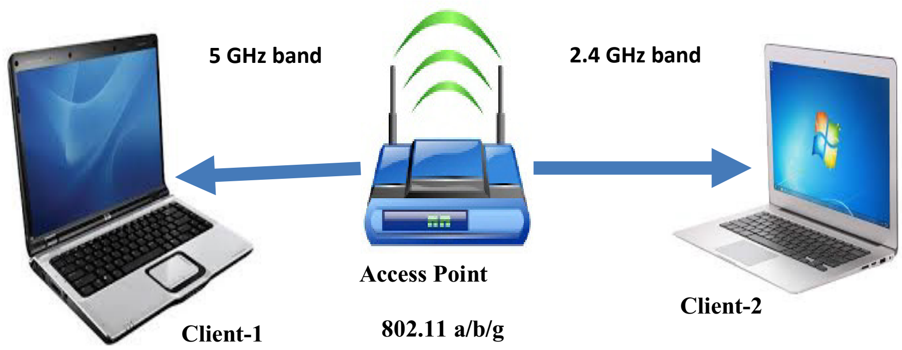

Figure 1. Test bed setup for legacy performance testing.

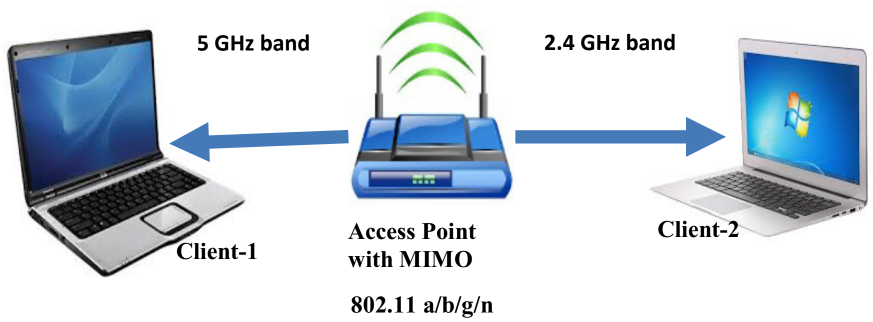

Figure 2. Test bed setup for legacy performance testing.

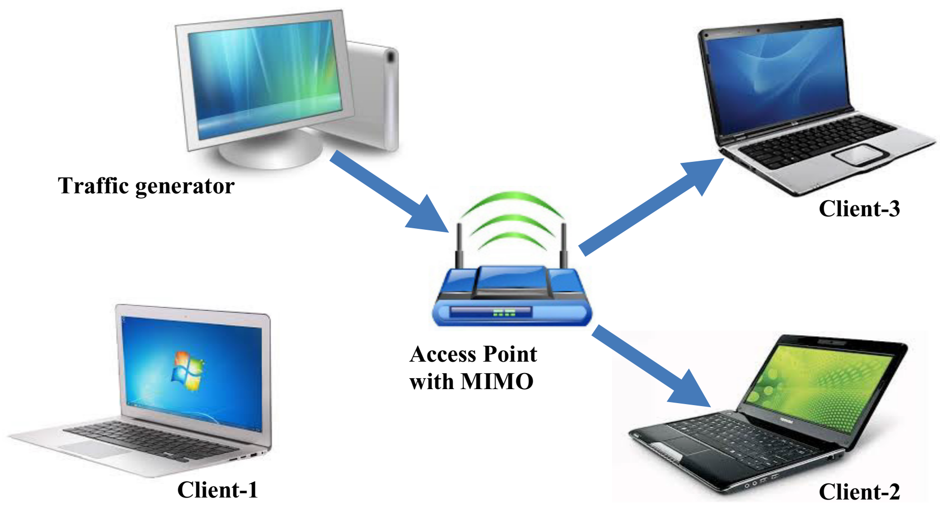

Figure 3. Test bed setup for legacy performance testing.

4. Results and Analysis

Below tabular column Table 1 is for legacy performance test results. In the 5 GHz band legacy we test for mode 'a' using channel 159 and multiple streams of traffic. And in 2.4 GHz band we test for 'bg' mode using channel 3. From the statistics we see that with the link rate 54 Mbps, in mode 'bg' for two stream uplink traffic, average throughput is 27.8 Mbps as seen in Figure 4. While in the downlink traffic, the throughput is 21.7 Mbps as seen in Figure 5. And in mode 'a' for two stream uplink traffic, the average throughput is 28.3 Mbps, as seen in Figure 6, while for downlink traffic it is 22.3 Mbps, as seen in Figure 7.

Table 1. Throughput values for legacy i.e. a/b/g clients

Mode	Direction	Channel	Client	Observed Throughput (Mbps)
bg	Uplink	3	Win XP	27.8
bg	Downlink	3	Win XP	21.7
a	Uplink	149	Win XP	28.3
a	Downlink	149	Win XP	22.3

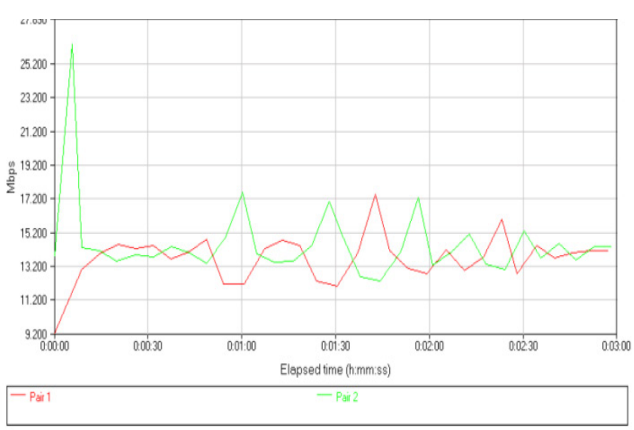

Figure 4. Throughput graph for bg mode, 20 MHz, Uplink.

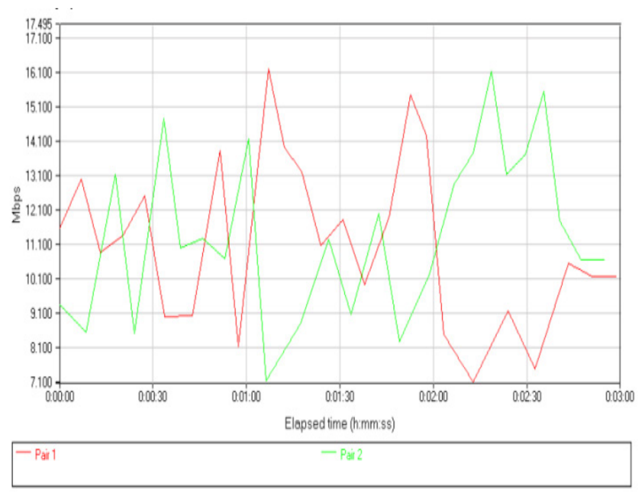

Figure 5. Throughput graph for bg mode, 20 MHz, Downlink.

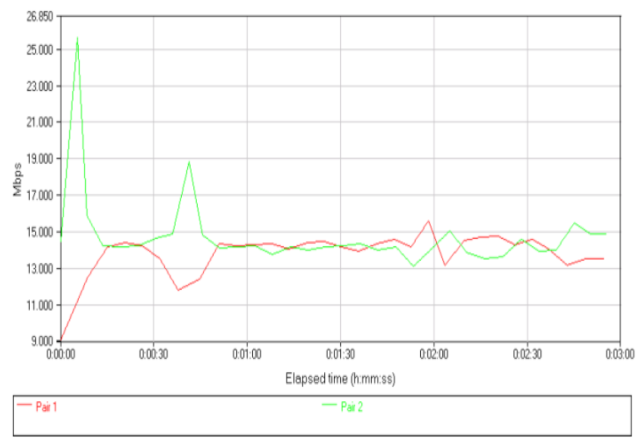

Figure 6. Throughput graph for a mode, 20 MHz, Uplink.

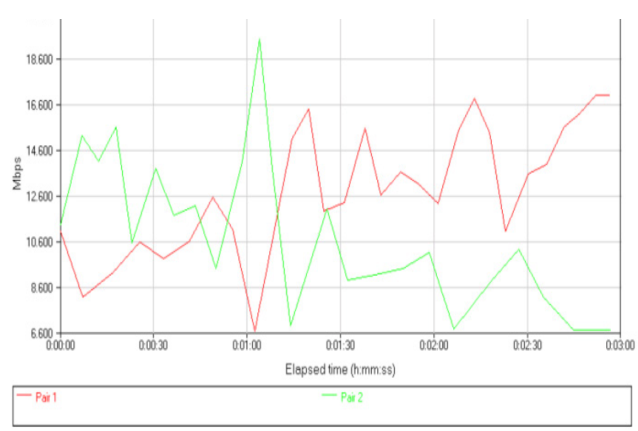

Figure 7. Throughput graph for a mode, 20 MHz, Downlink.

From the Figures below showing the graphs for the throughputs, we can see two colored graphs. They represent two flows. The X-axis is the elapsed time, in this case two minutes, and here the readings are taken for every 20 seconds. While the Y-axis represents the data-rates in Mbps. And the values in the tabular column signify the highest throughput attained. The dips in the graph are because, for every 60 seconds the AP refreshes its scan for devices, during which the transmission drops.

Table 2 shows the results for performance throughput for 'bgn' mode operating in channel 6 in 2.4 GHz and 'an' mode operating in channel 149 in 5 GHz. And we take the results for both 20 MHz as well as 40 MHz channel bandwidth. Here we observe that overall in 40 MHz bandwidth we get better throughputs than compared to 20 MHz channel bandwidth. The use of MIMO technology and OFDM multiplexing scheme are the main reason for having improved throughputs. Also using wider operating bandwidth helps increase in data rates.

Figure 8 and Figure 15 show the performance graphs for IEEE 802.11n. Here we use four flows. In Figure 8 and Figure 10, the frequent dips in the graph are due to the refreshing of the AP after every 60 seconds. And in Figure 9, the sudden fall of the graph could be due to inconsistent TCP connection. However in Figure 12 we see that there is a drop twice.

In Figure 13, we see the throughput graph to be consistent throughout. Similarly in Figure 14, throughput is consistent but there is also drop twice periodically. In Figure 15 and Figure 14 for one particular stream we see the throughput shooting up to maximum value.

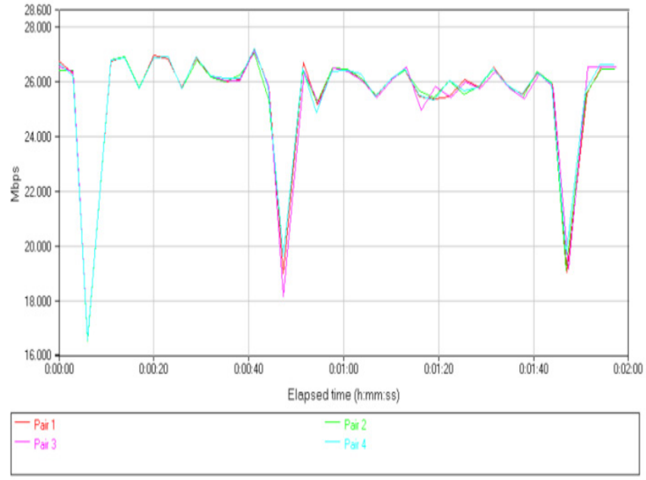

Figure 8. Throughput graph for bgn mode, 20MHz, Uplink.

For 802.11ac performance, we do multi-client throughput testing. The throughput values with TCP traffic won't reach the ideal value of 1.3 Gbps. Anyway, from Table 3 we can see that with 10 clients we get highest throughput of 725 Mbps for uplink and 651 Mbps for downlink. As we increase the number of clients the throughput drops gradually.

Table 2. Throughput values for legacy i.e., a/b/g/n clients

Mode	Direction	Bandwidth (MHz)	Channel	Observed Throughput (Mbps)
bgn	Uplink	20	6	100.7
bgn	Downlink	20	6	65.8
bgn	Uplink	40	6	188.1
bgn	Downlink	40	6	118.3
an	Uplink	20	149	97.6
an	Downlink	20	149	101.8
an	Uplink	40	149	170.9
an	Downlink	40	149	154.4

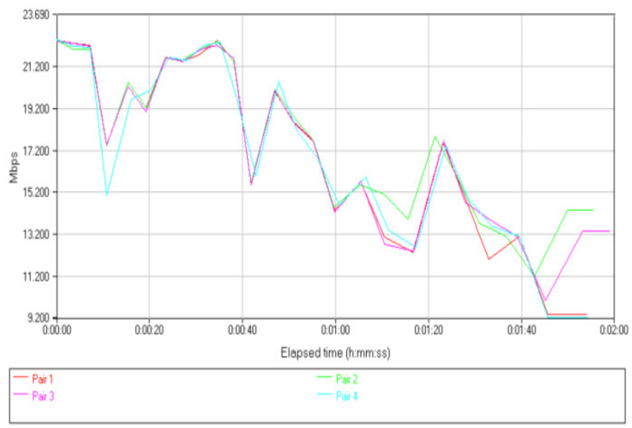

Figure 9. Throughput graph for bgn mode, 20 MHz, Downlink.

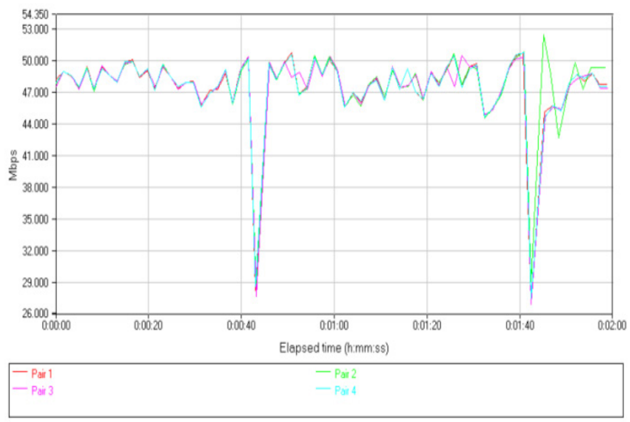

Figure 10. Throughput graph for bgn mode, 40MHz, Uplink.

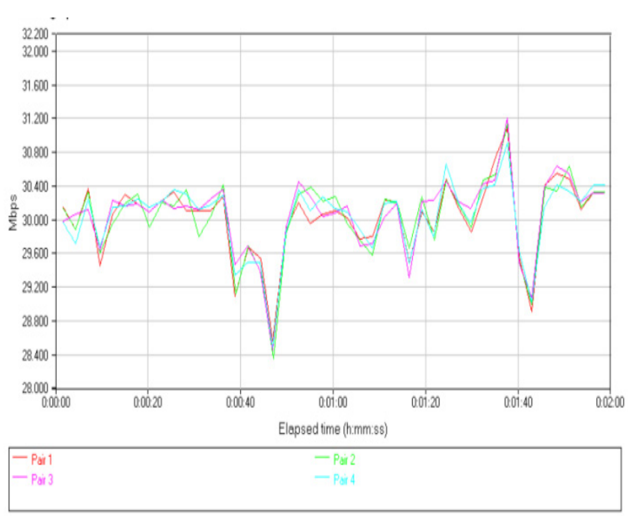

Figure 11. Throughput graph for bgn mode, 40MHz, Downlink.

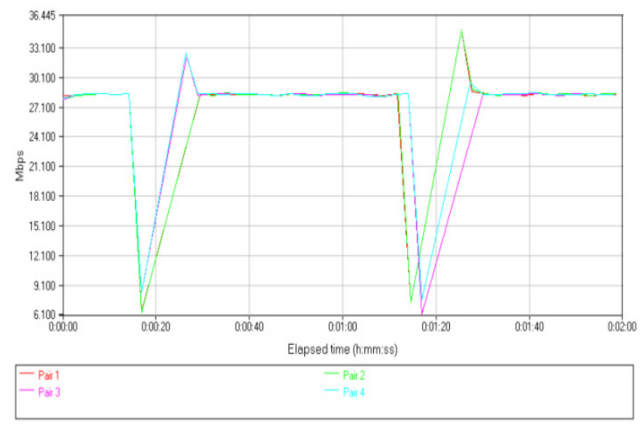

Figure 12. Throughput graph for an mode, 20 MHz, Uplink.

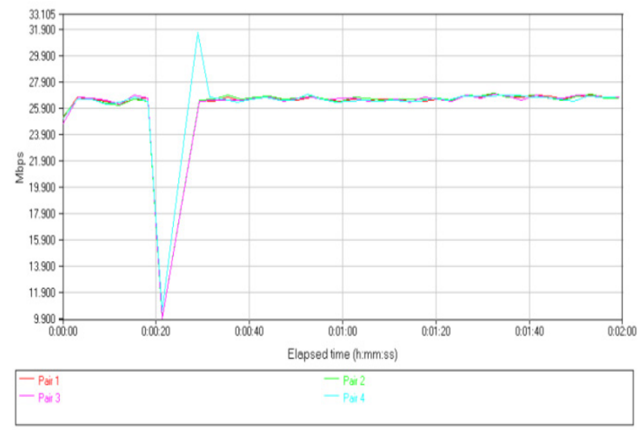

Figure 13. Throughput graph for a mode, 20MHz, Downlink.

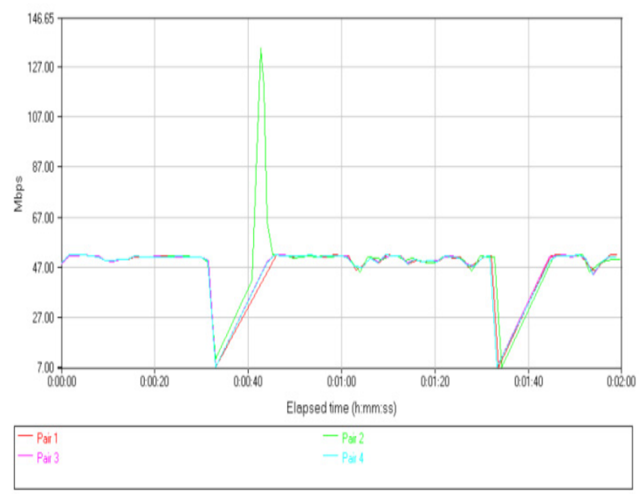

Figure 14. Throughput graph for a mode, 40MHz, Uplink.

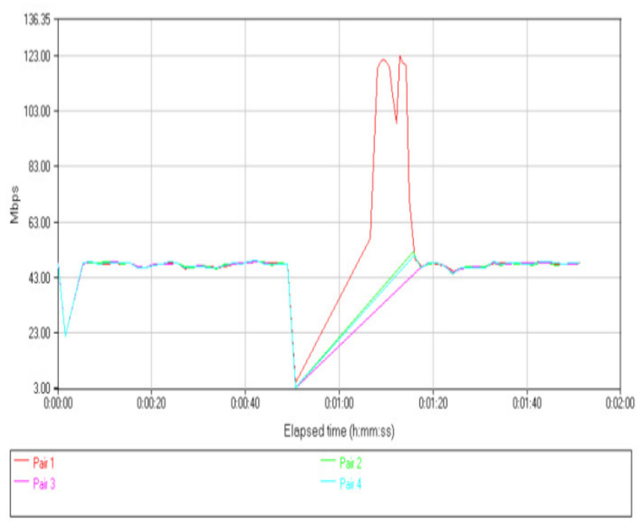

Figure 15. Throughput graph for a mode, 40MHz, Downlink.

Table 3. Throughput values for legacy i.e., a/b/g/n clients

Mode	No of Clients	Uplink Throughput (Mbps)	Downlink Throughput (Mbps)	Phy Rate
a/n/ac	1	484	521	1300
a/n/ac	10	725	651	1300
a/n/ac	20	713	632	1300
a/n/ac	30	705	618	1300

5. Conclusion

In this paper through the experiments we have measured the actual throughput for TCP traffic in different IEEE 802.11 standards. With the enhancement in the IEEE 802.11 technology, we observe that there has been tremendous improvement in the performance of the latest standards, i.e. 802.11n and 802.11ac.

As the IEEE 802.11n standard uses OFDM technology rather than DSSS or FHSS, the throughput is better. This is because in OFDM multiple frequencies are used for data transmission whereas DSSS uses single frequency to transmit the data. Thus the throughputs for IEEE 802.11b/g are lower compared to IEEE 802.11n. Also in IEEE 802.11n MIMO technology is used, which enables more data transfer over larger distances.

In IEEE 802.11ac, the channel bandwidth was almost doubled from 40 MHz to 80 MHz or 160 MHz which improves the speed drastically. With the use of 256 quadrature amplitude modulation, there is improvement in speed. And compared to IEEE 802.11n which provides 4 spatial streams, IEEE 802.11ac is capable of providing eight spatial streams which again leads to higher throughput.

6. Future Scope

The performance evaluation for other latest standards could be done. Also for different traffic streams like voice, video and best effort performance comparison and analysis could be done.

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