Impact of Beamforming and Interference on the Average Throughput of IEEE 802.11ac in a Typical Home Environment

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Summary
In this research, we carry out experiments to determine the impact of beamforming on the average throughput of IEEE 802.11ac in a residential home environment. Our results show that the beamforming provides significant gain in average throughput of IEEE 802.11ac at distances close to the router However, beamforming does not provide any significant gain in average throughput at large distances (more than 12m in our experimental test bed). Another important feature of our work is to study the co-existence of both IEEE 802.11ac and IEEE 802.11n in a typical home environment. We carry out experiments in a real home environment to quantify the impact of Co-Channel Interference (CCI) and Adjacent Channel Interfere (ACI) caused by IEEE 802.11n (at channel widths of 20MHz and 40MHz) on the average throughput of IEEE 802.11ac. We found that CCI and ACI caused with 40MHz channel width severely deteriorates the average throughput of IEEE 802.11ac compared to CCI and ACI caused with the channel width of 20MHz. Our results reveal that in a typical residential environment, IEEE 802.11ac should be deployed with IEEE 802.11n operating at channel width of 20MHz in order to get maximum benefit of high average throughput provided by IEEE 802.11ac.
Key words:
IEEE 802.11ac, IEEE 802.11n, Beamforming, Channel Width, Co-Channel Interference, Adjacent Channel Interference.

1. Introduction

Nowadays, Wireless Local area Networks (WLANs) based on IEEE 802.11 standard have become the most popular and widely deployed technologies in the world. The WLANs exist everywhere, in roads, offices, cafés, homes, etc. [1]. Millions of people around the world use WLANs from the comfort of their homes [2]. Moreover, there has been an exceptional rise in the use of wireless devices by home users for watching rich multimedia content (e.g. streaming music and movie videos etc) [1]. The popularity of youtube and netflix has also increased the use of WLANs at homes. However, the multimedia content that is demanded by home users needs high throughput. To meet this ever-increasing demand of high data rate, WLANs technologies have grown rapidly in the last decade and many standards that support high throughput have been proposed. IEEE 802.11ac is one such standard that promises to provide high data rate [1][3].

IEEE 802.11ac operates in 5GHz frequency band and has a potential to provide a data rate of 1.3Gbps with 3x3 Multiple Input Multiple Output (MIMO) system and 80MHz channel width. IEEE 802.11n, the current WLAN standard widely used by home users, operates in both 2.4GHz and 5GHz frequency band. IEEE 802.11n can also operate at any of the two channel widths of 20MHz and 40MHz [1][4][5]. However, an important aspect of utmost importance that needs to be studied is the co-existence of both IEEE 802.11ac and IEEE 802.11n in the same environment. This involves studying the effect on average throughput of IEEE 802.11ac if it is deployed in an environment that already has IEEE 802.11n networks operating in it. Home users, who are the focus of our work, are now slowly adopting IEEE 802.11ac enabled wireless routers [2]. However, with IEEE 802.11n widely deployed in homes, it is interesting to study the impact of IEEE 802.11n on the average throughput provided by IEEE 802.11ac. Another important feature of IEEE 802.11ac that requires further analysis and investigation is the advantage provided by the use of beamforming technology. This technology can play a significant role to increase the average throughput of IEEE 802.11ac [3][5].
Recently, some studies have been carried out to measure the average throughput of various IEEE 802.11 standards. The researchers utilize different techniques and factors to quantify the average throughput of various IEEE 802.11 standards in an indoor office environment. In [1] authors conduct experiments to compare average throughput obtained by IEEE 802.11n and IEEE 802.11ac with interference caused by other IEEE 802.11n (5GHz) sources in an indoor office environment. In [6] the effect of interference and channel width on the IEEE 802.11n (2.4GHz) throughput is discussed. In [7], the authors study 'near-far effect' phenomenon between non-overlapping channels of IEEE 802.11b/g, while, [8] focuses on the impact of Adjacent Channel Interference (ACI). Authors in [9] carry out experiements to measure the MIMO and channel width influence on the throughput of IEEE 802.11n (2.4GHz) and (5GHz). Authors in [10] investigate the impact of packet aggregation and Multi-User Multiple Input Multiple Output (MU-MIMO) on the throughput of IEEE 802.11ac. Similarly, in [11] experiments are performed to measure

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IEEE 802.11ac throughput under conditions of different MIMO configurations, channel width and interference at various locations. To the best of our knowledge, very limited studies exist that have quantified the impact of Co-Channel Interfernce (CCI) and ACI caused by IEEE 802.11n on the average throughput of IEEE 802.11ac in a typical home environment. In addition, as far as we know, gain in average throughput provided by the beamforming (in a residential home environment) in IEEE 802.11ac is not studied in the existing literature.

In this work, we first conduct experiments in a real home environment to quantify the average gain in throughput provided by beamforming in IEEE 802.11ac. We then carry out performance comparison of average throughput (without interference) achieved by both IEEE 802.11ac and IEEE 802.11n in a typical home environment. We then extend our work and quantify the decrease in the average throughput of IEEE 802.11ac in the presence of another IEEE 802.11n network operating in the same frequency band of 5GHz. Our main aim is to determine the impact of CCI and ACI caused by IEEE 802.11n (at channel widths of 20MHz and 40MHz) on average throughput of IEEE 802.11ac.

Our main contributions in this work are, (i) To quantify the impact of beamforming on the average throughput of IEEE 802.11ac in a typical home environment. (ii) To determine the average throughput provided by IEEE 802.11ac compared to IEEE 802.11n (5GHz), in an indoor residential environment without interference. (iii) To measure the impact of CCI and ACI caused by IEEE 802.11n operating at 40MHz channel width on the average throughput of IEEE 802.11ac (iv) To determine the impact of CCI and ACI caused by IEEE 802.11n operating at 20MHz channel width on the average throughput of IEEE 802.11ac.

The rest of the paper is organised as follows. In section two, we present related work. In section three, we explain our experimental test bed and the equipment used to carry out the experiments. Results of our experiments are presented in section four. Finally, we conclude our work in section five.

2. Related Works

Many studies have been carried out in the current literature to measure the average throughput of IEEE 802.11 standards. In [1] authors assert that IEEE 802.11ac handles the interference caused by IEEE 802.11n (5GHz) and provides a higher throughput than IEEE 802.11n for both Line of Sight (LoS) and Non Line of Sight (NLoS) conditions. Authors in [12] determine the factors that influence the IEEE 802.11n channel width performance. They find that intelligent channel bonding decisions depend on the knowledge of transmitter's surroundings. Authors in [9] carry out experiments to measure the MIMO and channel

width influence on the throughput of IEEE 802.11n (2.4GHz) and (5GHz). In [10], the variation in throughput of IEEE 802.11ac with frame aggregation is discussed. The results presented in [11] [13] show that when the distance is increased, IEEE 802.11ac provides better performance than IEEE 802.11n in an indoor office environment. The throughput of IEEE 802.11ac increases to 700 Mbps for a 3x3 MIMO configuration [11]. Moreover, with regards to the co-channel interference, [7] finds that radios in the same channel interfere with each other even well outside their carrier sensing range. That is due to ineffective virtual carrier sensing mechanism (RTS/CTS). While [8] claims that the 'near-far effect' can happen between non-overlapping channels if the interfering transmitter is in the proximity of the receiver. This has two major effects i.e. frame corruption and channel blocking. In [14] authors explain that throughput of IEEE 802.11a was degraded due to ACI. Also, [14] discusses the impacts of CCI and ACI with regards to the deployment of IEEE 802.11 multi-hop mesh network.

We note that most of the existing studies focused only on indoor office environment. However, homes remain the most preferable place for people to use internet; for example, 86% of Australians connect to internet from home [2]. Home users these days demand high-bandwidth, to enjoy the rich multimedia content available to them. Therefore, this study has a considerable motivation to determine the average throughput of the emerging IEEE 802.11ac standard in an indoor home environment. As far we know, very limited studies exist that have studied the impact of beamforming on the average throughput of IEEE 802.11ac in a residential home environment. Also, impact of CCI and ACI caused by IEEE 802.11n (at channel widths of 20 MHz and 40MHz) on the average throughput of IEEE 802.11ac in a typical home environment is not studied in the current literature.

3. Experimental Test Bed

In this section, we explain our experimental setup in detail. We first explain the hardware and software used to carry out the experiments, followed by in depth description of the measuring environment.

3.1 Hardware and Software

To carry out experiments in this research, two wireless Access Points (APs) (Linksys WRT 1200AC and Linksys WRT 1900AC) were used [15]. Both these APs support various features of the IEEE 802.11ac standard e.g. 80MHz channel width, beamforming etc. [16][17]. WRT 1200AC supports 2x2 MIMO while WRT 1900 AC supports 3x3 MIMO. We utilize D-Link Dual Band AC1200 (DWA-182)

and Netgear AC1200 (A6200-100PAS) adapters to allow our laptops to access IEEE 802.11ac and IEEE 802.11n (5GHz) networks. However, the D-Link (DWA-182) did not support the beamforming, while Netgear (A6200-100PAS) supported
the beamforming technology [17][18]. Moreover, four laptops were also used in our experiments. InSSIDer tool [19] was used to detect current wireless networks operating in the test-bed environment, in addition to measure the Received Signal Strength Indicator (RSSI) at various positions. While, Iperf was utilized to generate traffic in all the experiments [1] [11].

3.2 Test-Bed Environment

All experiments were carried out in a typical home environment as shown in Figure 1. The test-bed environment contains four rooms and a front yard. Wooden walls separate all rooms. The rooms have various materials, for example wooden cupboards, tables, and beds. Television, electrical stove, two refrigerators, and a microwave are also present in this environment. InSSIDer tool was used to identify other networks operating in the 5GHz frequency bands. Details of existing networks in the test bed are presented in Table 1. We find that 5GHz frequency band is unused as there are no IEEE 802.11n and IEEE 802.11ac network operating in this band.

Table 1: Existing Wi-Fi Networks

SSID	Frequency Band (GHz)	Channel(s)
Trustpower_vb67	2.4	11, 7
mWireless	2.4	2, 6
Spark-tgsn3u	2.4	5
Vodstone9D10	2.4	11
Spark-ebdguc	2.4	1
John key	2.4	11
VodstoneB2A8	2.4	6
sunfamily	2.4	1

3.3 Experimental Setup

In all our experiments, Iperf was used to generate User Datagram Protocol (UDP) traffic from client to server over the Wi-Fi network for 40 seconds. The datagram size is 1472 bytes. Throughput and RSSI were measured for 10 days and seven times per each location. Finally, the average of these values were taken [1] . The experimental test bed is shown in Figure 1.Various positions for measurements are marked as A (4m), B (8m), C (12m), D (16m) and E (20m). Each position is at a different distance from router and possesses different RF characteristics. We measure throughput and RSSI at these positions. We use WRT 1900AC router as our main router (shown as R1 in figure 1). However, WRT 1200AC router (shown as R2 in figure 1) is used to cause interference (See section 4.3 for more details). Our experimental setup is shown in figure 2.

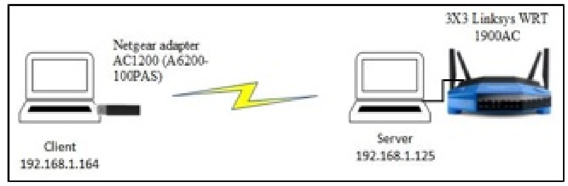

Fig. 2 Experiment Setup

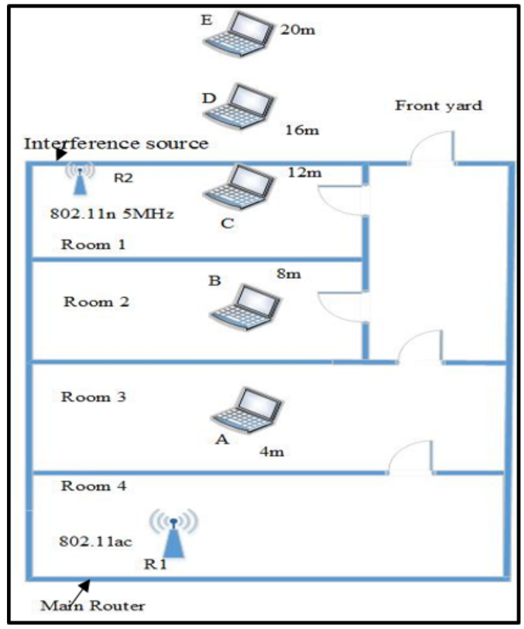

Fig. 1 Experiment Test-bed

4. Results

4.1 Impact of Beamforming on the Average Throughput of IEEE 802.11ac

We first measure the impact of beamforming on the average throughput of IEEE 802.11ac. For this purpose, we first measure RSSI at all the positions. The measurements were carried out using both Netgear A6200 (supports beamforming) and D-Link DWA-182 (no support of beamforming) adapters. Our results of RSSI are shown in figure 3. We find that at positions close to the router (A (4m) and B (8m)), Netgear provides better RSSI than D-Link. Netgear provides RSSI of -40dbm and -57dbm at positions A and B, respectively. However, D-Link provides RSSI of -49.43dbm and -60.88dbm at positions A and B, respectively. We chose two more points in our experimental test bed (A’ (2m) and B’ (6m)) to further investigate the effect of beamforming on RSSI. We find that at these two positions Netgear also provides better RSSI than D-Link. At positions A’ (2m) and B’ (6m), Netgear provides RSSI of -31.8dbm and -45.5dbm, however, D-Link provides

RSSI of -45dbm and -51.38dbm, respectively. We also note that at distance greater than 8m i.e. at points C (12m), D (16m), and E (20m) both adapters provide similar RSSI. However, RSSI of Netgear is slightly better than D-Link at point C. Our results of RSSI indicate that beamforming has no effect if distance between wireless client and router is more than 12m. This is consistent with the fact that there is not much difference in the average throughput of both adapters at points D (16m) and E (20m). However, at points A (4m), B (8m) and C (12m), Netgear provides higher average throughput than D-Link. Netgear provides an average throughput gain of 58.59%, 56.69% and 42.55% compared to D-Link at points A (4m), B (8m) and C (12m), respectively. Our results of average throughput are shown in figure 4. Table 2 summarizes all our results.

Our results in this section clearly indicate that in a typical home environment, beamforming is providing benefit to home users up to a certain distance close to wireless router (till 12m in our test bed). However, at longer distances (greater than 12m in our test bed) beamforming has no advantage for home users.

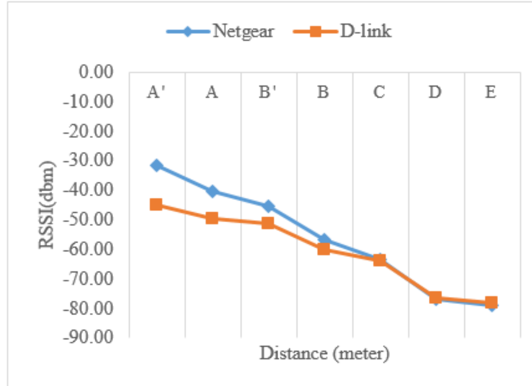

Fig. 3 RSSI (Netgear vs D-Link adapter)

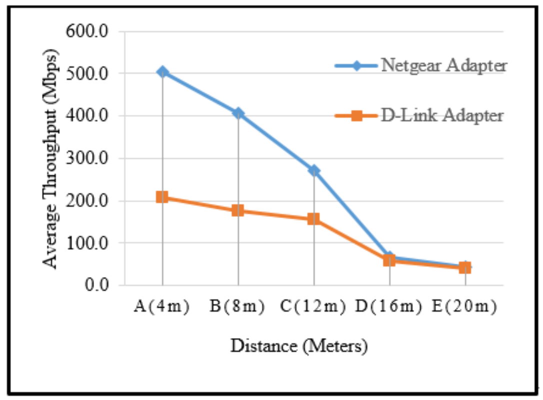

Fig. 4 Average Throughput provided by Netgear (A6200) and D-Link (DWA-182) Adapters

Table 2: Gain in Average Throughput provided by Netgear (A6200) compared to D-Link (DWA-182) Adapter

Distance (meters)	Netgear Adapter: Average Through-put (Mbps)	Netgear Adapter: RSSI (dbm)	D-Link Adapter: Average Through-put (Mbps)	D-Link Adapter: RSSI (dbm)	Gain %
A(4m)	503.8	-40.0	208.58	-49.43	58.59
B(8m)	406.9	-57.0	176.21	-60.88	56.69
C(12m)	271.5	-66.7	155.96	-67.75	42.55
D(16m)	66.7	-77.0	65.40	-77.00	1.94
E(20m)	42.7	-80.3	40.31	-80.3	5.59

4.2 Comparison of the Average Throughput of IEEE 802.11ac and IEEE 802.11n (without interference)

In this section, we carry out experiments to compare the average throughput provided by IEEE 802.11ac and IEEE 802.11n (20MHz and 40MHz). For the rest of our experiments, we use the Netgear adapter as it supports beamforming and provides higher average throughput than D-Link adapter (see section 4.1). We first measure RSSI for both IEEE 802.11ac and IEEE 802.11n (20MHz and 40MHz). Our results of RSSI are shown in Table 3. We note that for both standards, RSSI decreases sharply as the distance between wireless client and router is increased. It can be seen from the table 3 that both standards have similar RSSI. However, IEEE 802.11n (20MHz and 40MHz) has slightly better RSSI at all positions. Our throughput results are shown in figure 5.

Table 3: Average Throughput and RSSI of IEEE 802.11ac, IEEE 802.11n (40MHz) and IEEE 802.11n (20MHz)

Distance (meters)	IEEE 802.11ac: Average Throughput (Mbps)	IEEE 802.11ac: Average RSSI (dbm)	IEEE 802.11n (40MHz): Average Throughput (Mbps)	IEEE 802.11n (40MHz): Average RSSI (dbm)	IEEE 802.11n (20MHz): Average Throughput (Mbps)	IEEE 802.11n (20MHz): Average RSSI (dbm)	Gain Provided by IEEE 802.11ac (%): Compared to IEEE 802.11n (40MHz)	Gain Provided by IEEE 802.11ac (%): Compared to IEEE 802.11n (20MHz)
A (4m)	503.83	-40	249.59	-38.5	121.78	-36.5	50%	75.82%
B (8m)	406.86	-56	212.76	-54	115.73	-51.57	47.7%	71.55%
C (12m)	271.47	-66.67	119.79	-67.22	67.23	-69.8	55.87%	75.23%
D (16m)	66.67	-78	36.31	-76.4	28.52	-77.5	45.53%	57%
E (20m)	42.68	-80.25	25.29	-79.2	18.8	-79.1	40.74%	56%

It can be seen from the figure 5 that IEEE 802.11ac provides much higher throughput than IEEE 802.11n (40MHz and 20MHz) at all positions e.g. at point A (4m from the router) IEEE 802.11ac, IEEE 802.11n (40MHz) and IEEE 802.11n (20MHz) provide throughput of 503.83Mbps, 249.59Mbps and 121.78Mbps, respectively. IEEE 802.11ac provides a gain of 50%, 47.7%, 55.87%, 45.53% and 40.74% compared to IEEE 802.11n (40MHz) at positions A (4m), B(8m), C(12m), D(16m) and E(20m), respectively. The gain in average throughput provided by IEEE 802.11ac compared to IEEE 802.11n (20MHz and 40MHz) is shown in table 3. This high throughput of IEEE 802.11ac is due to the use of 256 Quadrature Amplitude Modulation (QAM) (especially at points close to router), higher channel width of 80MHz coupled with the use of beamforming and MIMO. We also note that IEEE 802.11n (40MHz) is providing higher throughput than IEEE 802.11n (20MHz). This again shows the advantage of using higher channel width. We find that the throughput is not constant and has high degree of variation at all points. This is observed in all our experiments and is due to the rapid changes of the used modulation and coding scheme due to packet loss, which are caused by the multipath effect present in the residential home environment. Our results of average throughput and peak throughput provided by IEEE 802.11ac at all points are shown in figure 6. We summarize our results in table 3. Our results in this section clearly show that in a residential home environment that is free from any interference in 5GHz frequency band, IEEE 802.11ac provides much higher throughput than IEEE 802.11n. However, it will be interesting to see the impact on the average throughput of IEEE 802.11ac in a more realistic scenario where interference from another IEEE 802.11n network is present in the environment. We present our results for such a realistic scenario in the next section.

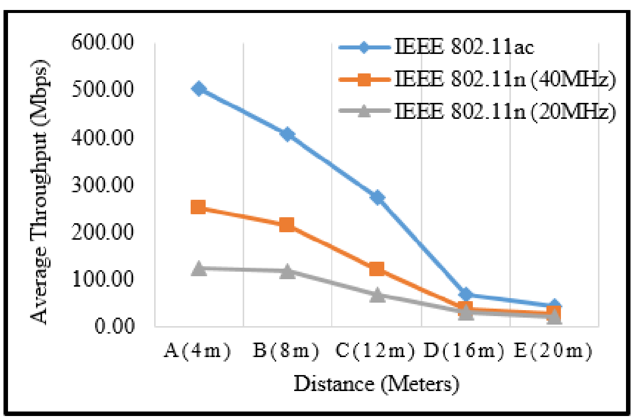

Fig. 5 Average Throughput of IEEE 802.11ac, IEEE 802.11n (40MHz) and IEEE 802.11n (20MHz)

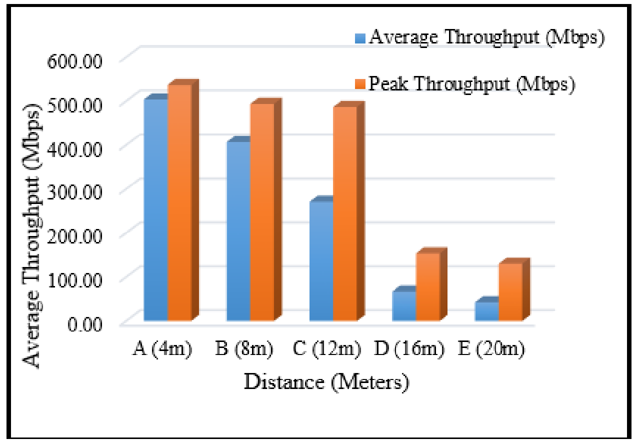

Fig. 6 Average Throughput Vs Peak Throughput provided by IEEE 802.11ac

Table 4: Average Throughput of IEEE 802.11ac without any interference and with Co-Channel Interference, Adjacent Channel Interference caused by IEEE 802.11n (40MHz)

Distance (meters)	Without Inference		Co-Channel Interference by IEEE 802.11 n (40MHz)		Adjacent Channel Interference by IEEE 802.11n (40MHz)		Decrease in Average Throughput of IEEE 802.11ac (%)	
	Average Throughput (Mbps)	Average RSSI (dbm)	Average Throughput (Mbps)	Average RSSI (dbm)	Average Throughput (Mbps)	Average RSSI (dbm)	With Co-Channel Interference	With Adjacent Channel Interference
A(4m)	503.83	-40	367.71	-43.5	403.94	-41.5	27%	20%
B(8m)	406.86	-62	330	-62.4	341	-63	19%	16%
C(12m)	271.47	-66.67	235.37	-70	254.32	-67	13%	6%
D(16m)	66.67	-78	59.92	-78	59.12	-78	10%	11%
E(20m)	42.68	-80.25	34.02	-81	36.92	-81.33	20%	13%

4.3 Impact of the Co-Channel and Adjacent Channel Interference caused by IEEE 802.11n on the Average Throughput of IEEE 802.11ac

Our results presented in the last section are free from any interference in the 5GHz frequency band. In this section, our purpose is to emulate a scenario when a home user that uses IEEE 802.11ac faces interference from a neighbouring user's IEEE 802.11n network. This is a very realistic scenario as IEEE 802.11n is already widely deployed at homes and co-existence of both the standards needs to be investigated. More specifically, we want to quantify the impact of CCI and ACI caused by IEEE 802.11n on the average throughput of IEEE 802.11ac. For this purpose, we setup an IEEE 802.11n network in our experimental test bed using a WRT 1200AC router. This wireless router (shown as R2 in figure 1) is located at a distance of 12m from the router that is operating on IEEE 802.11ac network (shown as R1 in figure 1). Moreover, a HP laptop was connected to router (R2) as second server, while Toshiba laptop equipped with another Netgear (A6200) adapter was used to generate UDP traffic for creating interference. We are also interested to observe the impact of changing channel width in IEEE 802.11n ((20MHz and 40MHz) on the average throughput of IEEE 802.11ac. For this purpose, experiments are carried out to investigate and quantify the impact of CCI and ACI at both channel widths of 20MHz and 40MHz. Our experimental results are explained in the section below.

4.3.1 Impact of Co-Channel Interference (CCI) caused by IEEE 802.11n (40MHz)

We first assess the impact of CCI caused by IEEE 802.11n with 40MHz channel width on the average throughput of IEEE 802.11ac. For this purpose, we configured router (R2) to use IEEE 802.11n with channel width of 40MHz. Router (R1) is configured to use IEEE 802.11ac with a channel width of 80MHz. To cause CCI, the R2 is forced to operate in the

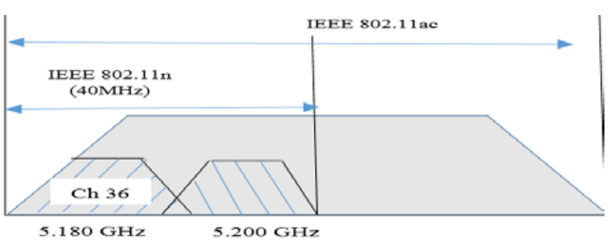

Fig. 7 IEEE 802.11ac and IEEE 802.11n (40MHz) Co-Channel Interference

same primary channel 36 as router (R1). This scenario is shown in figure 7. We note that this interference affects the RSSI (given in table 4) of IEEE 802.11ac. It can be seen from table 4 that the RSSI with interference deteriorates as compared to the RSSI without interference at all positions. Our results of average throughput of the IEEE 802.11ac with CCI caused by IEEE 802.11n (40MHz) are shown in figure 8. For comparison, the throughput of IEEE 802.11ac without interference is also shown in figure 8. We note that, there is a significant impact to the average throughput of IEEE 802.11ac at all positons. The average throughput of IEEE 802.11ac declines by 27%, 19%, 13%, 10% and 20% at points A(4m), B(8m), C(12m), D(16m) and E(20m), respectively compared to average throughput of IEEE 802.11ac without interference. This reduction in average throughput of IEEE 802.11ac is because of the fact that CCI caused by IEEE 802.11n reduces the available spectrum, which leads to channel access delays and collisions in transmissions [7].

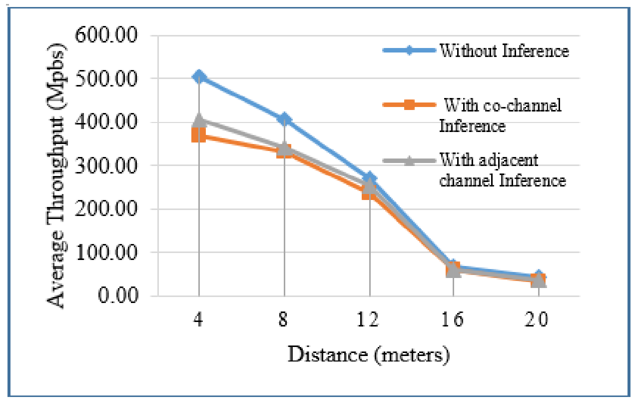

Fig. 8 Average throughput of IEEE 802.11ac without and with Co-Channel and Adjacent Channel interference by IEEE 802.11n (40MHz)

4.3.2 Impact of Adjacent Channel Interference (ACI) caused by IEEE 802.11n (40MHz)

In this subsection, we determine the effect of ACI caused by IEEE 802.11n (40MHz) on the average throughput of IEEE 802.11ac. For this purpose, we configured router (R2) of IEEE 802.11n with channel width of 40MHz to operate on channel 149. Router (R1) is operating on channel 36. This scenario is shown in figure 9. We observe that the RSSI deteriorates at all the positions (see table 4). Our results of average throughput of the IEEE 802.11ac with ACI caused by IEEE 802.11n (40MHz) are shown in figure 8. For comparison, the throughput of IEEE 802.11ac without interference is also shown in figure 8.

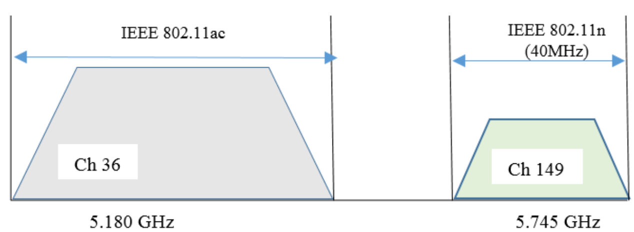

Fig. 9 IEEE 802.11ac and IEEE 802.11n (5GHz) Adjacent Channel Interference

We again note that, there is a substantial interference impact to the average throughput of IEEE 802.11ac. The average throughput of IEEE 802.11ac drops by 20%, 16%, 6%, 11% and 13% at locations A(4m), B(8m), C(12m), D(16m) and E(20m) respectively, compared to average throughput of IEEE 802.11ac without interference. This decrease in throughput is due to the phenomenon called as the “near-far effect” which states that the interference can also be present between two non-overlapping channels if the interfering transmitter (which is router (R2) in our experimental test bed) is in the proximity of the receiver (which is client of router (R1) in our experimental test bed). This leads to channel blocking due to spurious carrier detection and corruption of frames due to interference noise [7].

4.3.3 Impact of Co-Channel Interference (CCI) caused by IEEE 802.11n (20MHz)

In third scenario, we measure the impact of CCI caused by IEEE 802.11n operating at the channel width of 20MHz on the average throughput of IEEE 802.11ac. We configured the router (R2) to operate IEEE 802.11n (20MHz) in the same primary channel (36) as the main router R1. This scenario is presented in figure 10. We note decrease in RSSI of IEEE 802.11ac with interference compared to RSSI without interference. The results of RSSI are shown in table 5. In addition, it can be seen from figure 11 and table 5 that there is a minor impact of this interference on the average throughput of IEEE 802.11ac. The average throughput of IEEE 802.11ac decreases by 2.8%, 1.5%, 5%, 7.9% and 10.8% at points A(4m), B(8m), C(12m), D(16m) and E(20m) respectively, compared to average throughput of IEEE 802.11ac without interference. Our results presented in table 4 and table 5, show that IEEE 802.11ac provides higher throughput in the presence of CCI caused by IEEE 802.11n operating at 20MHz compared to CCI caused by IEEE 802.11n operating at 40MHz. This is because at 20MHz the overlapping of both routers (R1 and R2) is restricted to only the primary channel.

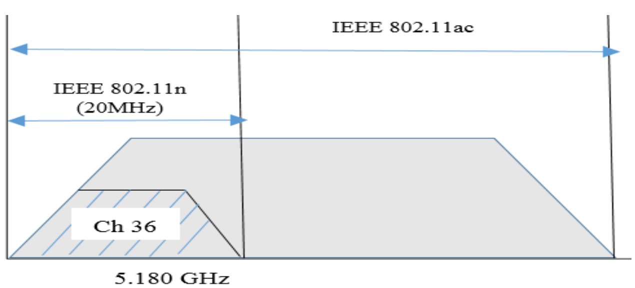

Fig. 10 IEEE 802.11ac and IEEE 802.11n (20MHz) Co-Channel Interference

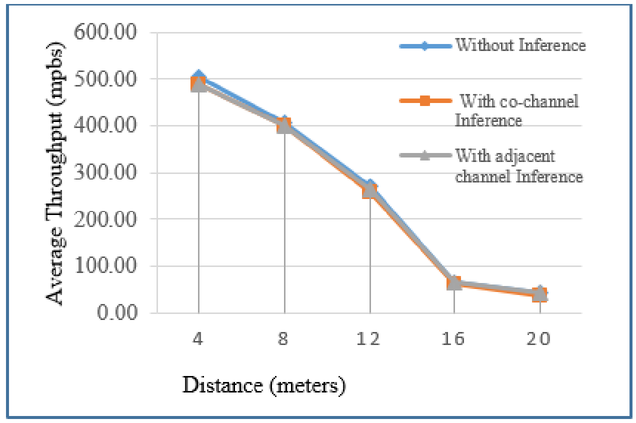

Fig. 11 Average throughput of IEEE 802.11ac without and with Co-Channel and Adjacent Channel interference by IEEE 802.11n (20MHz)Table 5: Average Throughput of IEEE 802.11ac with Co-Channel Interference and Adjacent Channel Interference caused by IEEE 802.11n (20MHz)

Table 6: Average Throughput of IEEE 802.11ac with Co-Channel Interference and Adjacent Channel Interference caused by IEEE 802.11n (20MHz)

Distance (meters)	Without Inference		Co-Channel Interference by IEEE 802.11 n (20MHz)		Adjacent Channel Interference by IEEE 802.11n (20MHz)		Decrease in Average Throughput of IEEE 802.11ac (%)	
	Average Throughput (Mbps)	RSSI (dbm)	Average Throughput (Mbps)	RSSI (dbm)	Average Throughput (Mbps)	RSSI (dbm)	With Co-Channel Interference	With Adjacent Channel Interference
A (4m)	503.83	-40	489.38	-41	489.28	-40.5	2.8%	2.9%
B (8m)	406.86	-62	400.65	-62.86	401.32	-62.9	1.5%	1.3%
C (12m)	271.47	-66.67	256.94	-69	265.59	-70	5%	2.1%
D (16m)	66.67	-78	61.36	-79.17	65.47	-78.2	7.9%	1.7%
E (20m)	42.68	-80.25	38	-81.5	42.68	-80.5	10.8%	0%

4.3.4 Impact of Adjacent Channel Interference (ACI) caused by IEEE 802.11n (20MHz)

In the last experiment, we configured the interfering router (R2) to operate IEEE 802.11n (20MHz) in different primary channel (149) than the router (R1). Router (R1) is configured to use IEEE 802.11ac with a channel width of 80MHz and is operating at the channel 36. This scenario is depicted in figure 12. Our results of RSSI are presented in table 5. It can be seen from table 5 that the RSSI with interference is very similar to RSSI without interference. The ACI has minor impact on the RSSI. We also observe that ACI caused by IEEE 802.11n (20MHz) has very little impact on the average throughput of IEEE 802.11ac. The average throughput of IEEE 802.11ac decreases by 2.9%, 1.3%, 2.1%, 1.7% and 0% at locations A(4m), B(8m), C(12m), D(16m) and E(20m) respectively, compared to the average throughput of IEEE 802.11ac without interference. The near-far effect phenomenon is not observed with 20MHz channel width. This is because at 20MHz low power is radiated by IEEE 802.11n. This low power does not lead to spurious carrier detection and corruption of frames [7][8]. Our results of average throughput of IEEE 802.11ac are shown in figure 11 and table 5.

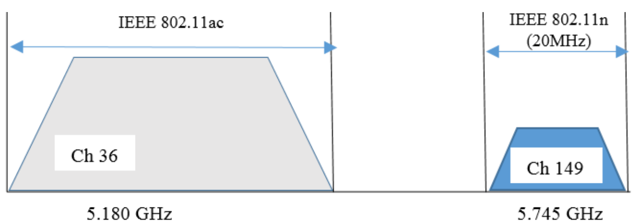

Fig. 12 IEEE 802.11ac and IEEE 802.11n (5GHz) Adjacent Channel Interference

5. Conclusion

Our study is focused on the usage of IEEE 802.11ac by the home users. We have studied the impact of beamforming on the average throughput of IEEE 802.11ac and co-existence of IEEE 802.11ac with IEEE 802.11n in a typical home environment. Our results show that the beamforming technology is beneficial to home users only close to the router. However, beamforming does not provide any significant gain in average throughput at large distances (more than 12m in our test bed). We found in our research that in the absence of any interference, IEEE 802.11ac provides much higher throughput than IEEE 802.11n in a residential home environment. This gain in throughput is because of higher channel width of 80MHz and use of higher modulation scheme of 256 QAM. With regards to the co-existence of both standards, we studied the effect of CCI and ACI caused by IEEE 802.11n at both channel widths of 20MHz and 40MHz. We found that if IEEE 802.11ac is deployed with IEEE 802.11n (40MHz) then both CCI and ACI caused by IEEE 802.11n significantly impacts the average throughput of IEEE 802.11ac. However, our experimental results show that IEEE 802.11ac co-exists well with IEEE 802.11n (20MHz) as CCI and ACI caused by it has minor impact on the average throughput of IEEE 802.11ac. We also note that unlike IEEE 802.11n (40MHz), ACI caused by IEEE 802.11n (20MHz) does not cause the 'near-far effect". We conclude that channel width of IEEE 802.11n is an important factor that must be taken into account when IEEE 802.11ac is deployed in a home environment where both IEEE 802.11n and IEEE 802.11ac co-exist simultaneously.

References

[1] Zawar Shah, Siddarth Rau and Adeel Baig, "Throughput Comparison of IEEE 802.11ac and IEEE 802.11n in an Indoor Environment with Interference," in International Telecommunication Netwroks and Applications conference (ITNAC), Sydney, Australia, 2015, pp. 196-201.
[2] Acma, "Report 1- Australians' digital lives," Australian Communication and Media Authority, 2015.
[3] Steven J. Vaughan-Nicholas, "Gigabit Wi-Fi is on its Way," IEEE Computer, vol. 43, no. 11, pp. 11-14, Nov, 2010.
[4] Zawar Shah, Ashutosh Kolhe and Omer Mubarak, "IEEE 802.11ac Vs IEEE 802.11n: Throughput Camprison in Multiple Indoor Environments," International Journal of Computer Science and Information Secuirty (IJCSIS), vol. 14, no. 4, 2016.
[5] Shaneel Narayan, Chandimal Jayawardena, Jiaxin Wang and Weizhi Ma, "Perfomance Test of IEEE 802.11ac Wireless Devices," in International Conference on Computer Communication and Informatics (ICCC), Coimbatore, India, 2015, pp. 1-6.
[6] Sandra Fiehe, Janne Riihijärvi and Petri Mähönen, "Experimental Study on Performance of IEEE 802.11 n and Impact of Interferers on the 2.4 GHz ISM Band." Proceedings of the 6th International Wireless Communications and Mobile Computing Conference, Caen, France, 2010, pp. 47-51.
[7] Paul Fuxjager, Danilo Valerio and Fabio Ricciato, "The Myth of Non-Overlapping Channels: Interference Measurements in IEEE 802.11," in Fourth Annual Conference on Wireless on Demand Network Systems and Services, Tyrol, Austria, 2007, pp. 1-8.
[8] Jens Nachtigall, Anatolij Zubow and Jens-Peter Redlich, "The Impact of Adjacent Channel Interference in Multi-Radio Systems using IEEE 802.11," in International Wireless Communications and Mobile Computing Conference, Crete, Greece, 2008, pp. 874-881.
[9] Y.A.S Dama, R. A. Abd-Alhameed, SMR Jone, D Zhou and M.b.Child, "Experimental Throughput Analysis for 802.11 n System and MIMO Indoor Propagation Prediction," in International Symposium on Electromagnetic Compatibility, California, USA, 2011, pp. 833-836.
[10] Boris Bellalta, Jaume Barcelo, Dirk Staehle, Alexey Vinel and Miquel Oliver, "On the Performance of Packet Aggregation in IEEE 802.11ac MU-MIMO WLANs," IEEE Communications Letters, vol. 16, no. 10, pp. 1588-1591, October, 2012.
[11] Oladunni Femijemilohu and Stuart Walker, "Empirical Performance Evaluation of Enhanced Throughput Schemes of IEEE802. 11 Technology in Wireless Area Networks," International Journal of Wireless & Mobile Networks (IJWMN), Vol. 5, No. 4, pp.171-185, August, 2013.

[12] Lara Deek, Eduard Garcia-Villegas, Elizabeth Belding, Sung-Ju Lee and Kevin Almeroth, “The Impact of Channel Bonding on 802.11n Network Management,” in Seventh Cnnference on Emerging Networking Experiments and Technologies, Tokyo, Japan, 2011, p. 11.
[13] Mihaela-Diana Dianu, Janne Riihijärvi and Marina Petrova, “Measurement-Based Study of the Performance of IEEE 802.11ac in an Indoor Environment,” in In IEEE International Conference on Communications (ICC), Sydney, Australia, 2014, pp. 5771-5776.
[14] Vangelis Angelakis, Stefanos Papadakis, Vasilios A. Siris and Apostolos Traganitis, “Adjacent Channel Interference in 802.11a Is Harmful: Testbed Validation of a Simple Quantification Model,” IEEE Communications Magazine, vol. 49, no. 3, pp. 160-166, March, 2011.
[15] Linksys,“http://www.businesswire.com/news/home/20150105005502/en/Linksys-Expands-WRT-Product-Family-2x2-Wireless,” 2016. [Online]. Available: http://www.linksys.com/us/p/P-WRT1900ACS/.
[16] K. Sohl, “Business Wire,” 2015. [Online]. Available: http://www.businesswire.com/news/home/20150105005502/en/Linksys-Expands-WRT-Product-Family-2x2-Wireless.
[17] D-Link, “D-Link Wireless Dual Band AC1200 Mbps USB Wi-Fi Network Adapter (DWA-182),” 2016. [Online].Available:https://www.amazon.com/dp/B0099XFRIY.
[18] Netgear, “NETGEAR AC1200 WiFi USB 2.0 Adapter - AC Dual Band (A6200-100PAS),” 2016. [Online]. Available: https://www.amazon.com/NETGEAR-AC1200-WiFi-USB-Adapter
[19] Metageek, “inSSIDer,” 2016. [Online]. Available: http://www.metageek.com/products/inssider/.