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Research Article

Implementation and Evaluation of WLAN 802.11ac for Residential Networks in NS-3

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Wi-Fi has been an amazingly successful technology. Its success may be attributed to the fact that, despite the significant advances made in technology over the last decade, it has remained backward compatible. 802.11ac is the latest version of the wireless LAN (WLAN) standard that is currently being adopted, and it promises to deliver very high throughput (VHT), operating at the 5 GHz band. In this paper, we report on an implementation of 802.11ac wireless LAN for residential scenario based on the 802.11ax task group scenario document. We evaluate the 802.11ac protocol performance under different operating conditions. Key features such as modulation coding set (MCS), frame aggregation, and multiple-input multiple-output (MIMO) were investigated. We also evaluate the average throughput, delay, jitter, optimum range for goodput, and effect of station (STA) density per access point (AP) in a network. ns-3, an open source network simulator with features supporting 802.11ac, was used to perform the simulation. Results obtained indicate that very high data rates are achievable. The highest data rate, the best mean delay, and mean jitter are possible under combined features of 802.11ac (MIMO and A-MPDU).

1. Introduction

The number of wireless devices is increasing at an exponential rate, and this may be attributed to the transition from static web to a dynamic web with an associated increase in the use of social networking making computing more pervasive and ubiquitous. Research conducted by the Wireless World Research Forum (WWRF) has shown that 7 billion people will be using 7 trillion wireless devices by 2020 [1]. According to [2], digital content consumption is on a steep ascent, with video content anticipated to reaching about ninety percent of global consumer traffic, in step with Cisco's 2011 Visual Networking Index Forecast. It has also been observed that internet traffic is moving rapidly from cable networks onto Wi-Fi networks. The multiplied reliance on wireless networks, the explosion of video intake, and the growing wide variety of Wi-Fi devices being used are all putting increased load on legacy 802.11 networks. As a result, users are more likely to experience deteriorated performance, choppy videos, and slower upload and download times.

5G Wi-Fi has become a solution to the digital content and wireless device challenges. With new technologies, it has made it possible to have reliable whole home coverage, 5G Wi-Fi will allow clients to stream digital content material between gadgets faster, and concurrently enable the node to join domestic and agency networks whilst able to retain battery power [3, 4]. Three main features underpin the many benefits of IEEE 802.11ac technology: video streaming, data syncing, and backup. IEEE 802.11ac is the fifth generation in Wi-Fi networking standards, and it promises to deliver speedy, great video streaming, and almost immediate data syncing and data backups to various wireless devices such as laptops, tablets, and mobile phones which are now part of our everyday lives [3].

IEEE 802.11 is the de facto standard for the widely deployed wireless local area networks (WLANs) [5]. Since its debut in 1997, data rates have increased from megabits per second (Mbps) to the upcoming gigabytes per second (Gbps), which was achieved by the cable technology [6, 7]. According to [8], a new task group (TG) was created late in 2008 within the IEEE 802 Standards Committee with the aim to create a new amendment to the 802.11-2007 standard. The new amendment, called 802.11ac, consists of new techniques to better the throughput of the legacy wireless local area networks (WLANs), allowing the Wi-Fi technology to offer cable network performance [9]. Some motives account for the very high expectancies around 802.11ac standard. The introduction of several new PHY and MAC features into WLAN with data rates that exceed 1 Gbps [10]. The features include more spatial streams through 8 × 8 multiple-input multiple-output (MIMO), offering wider channel bandwidth (up to 80 MHz Channels) and also the use of channel aggregation, for up to 160 MHz of total bandwidth [9].

In this work, using the ns-3 simulator, we verify the implementation of 802.11ac features by Andre Jonsson et al. with the further evaluation of the performance improvements in 802.11ac. Support for wider channels and MIMO in ns-3 is implemented and evaluated using many simulation scenarios. The residential scenario from the upcoming IEEE 802.11ax standard study group's scenario document was also implemented and evaluated [11, 12].

2. Related Work

The work reported in [13] demonstrated the benefits of the new features of the 802.11ac through simulations using MATLAB. The work considered the effect of employing different coding schemes. All the standard mandatory features were included in addition to a big portion of the optional features. BER calculation was measured for a frequency nonselective AWGN MIMO channel. However, only symmetrical MIMO systems were considered, 2 × 2, 3 × 3, and 4 × 4.

A comparative analysis of 802.11ac with 802.11n was carried out in [14]. Their work considered features such as extended channel bonding, downlink multiuser MIMO, beam-forming, high-definition video streaming data at high speeds, syncing and backing up, and modulation types. It was shown that on maximum throughput, the 802.11ac configured to run at 80 MHz and two single spatial streams will outperform the 802.11n with a configuration of 40 MHz running on two spatial streams.

Narayan et al. [15] also evaluated the performance differences between IEEE 802.11n and IEEE 802.11ac. They experimented for both IPv4 and IPv6. They implemented the 802.11ac network on two computers running the Windows operating system. The laptops were assigned static IP addresses and were connected wirelessly. They kept a distance of one to two meters between the stations and the access point to maintain the best signal strength. Their initial experiment evaluated the throughput metric of various application protocols such as UDP, TCP, DNS, VoIP, and Telnet traffic. Secondly, they evaluated the performance measure of the jitter of UDP, TCP, DNS, VoIP, and Telnet traffic. Also, they evaluated the delay metric for all protocols and network traffics. Lastly, they evaluated for the UDP drop rate. They concluded after evaluations that 802.11ac outperforms 802.11n for both ipv4 and ipv6. Also, the lower jitter values were measured on the ipv6 against the ivp4. The delay and drop rate metrics had also been measured and observed to be higher for the 802.11ac.

Ravindranath et al. in their work [16] evaluated the superior performance of the new IEEE 802.11ac standard concerning 802.11n. They used ns-3, an open source network simulator, version (ns-3.24.1), which is appended with features to support 802.11ac. The simulation outcome shows that the new 802.11ac standard outperforms the legacy 802.11n. 802.11ac features such as channel bonding, guard interval, and MCS were analysed. The performance measures such as jitter, throughput, and delay were used for evaluation.

Jönsson et al. [17] implement the features in ns-3 to simulate and evaluate the IEEE 802.11ac standard by making changes in the existing PHY model to support wider channel bandwidth. They performed all nine-modulation coding set (MCS 0–9) values in 802.11ac and support for bit error rate calculations for higher modulations. Several simulations were run and evaluated, with the enterprise scenario as their case of interest. However, other key features of the standard such as MIMO and MU-MIMO for 802.11n and 802.11ac and also beamforming for 802.11n and 802.11ac were not implemented and evaluated.

It is however important to consider other network topologies and understudy the performance evaluation of the 802.11ac protocol in those other environments. In our paper, we investigate the performance of the 802.11ac protocol for residential environment under various network conditions.

3. 802.11 Features in NS-3

ns-3 has gained full recognition and acceptance being adopted by both industry and research community as a tool of choice for network performance and evaluation simulations. It has [19] proven to be the most reliable open-source network simulator. Some validation studies have attested to its accuracy in 802.11 models [16–18]. These reasons have informed our decision to choose the ns-3 simulator for the implementation and evaluation of this research work. ns-3 is an open source network simulator providing an extensive platform for network research and studies [15]. It aims to build a discrete simulator that offers various network models and simulation environment for varying network experiments. ns-3 is written in both C++ and Python. We use the ns-3.25 version [16] released on 24 March 2016 for the analysis in this paper.

It features the following significant changes [20]:

(i) A new traffic control framework, inspired by the Linux traffic control subsystem, has been introduced to allow experimentation with internet-aware active queue management (AQM) techniques, packet filtering, and policing. The existing network device queues were reworked, a Linux-like pfifo fast queuing discipline was added, and existing AQM queue models (CoDel and RED) were ported to the new framework. The RED queue model was extended to support Adaptive RED.

(ii) The Wi-Fi module adds additional support for 802.11n and 802.11ac modes, including better support for larger channel widths and multiple spatial streams (MIMO), and a simplified helper API for MPDU and MSDU aggregation. Two adaptive rate controls for 802.11n/ac, Ideal and MinstrelHt, have been added. Finally, backward compatibility between 802.11g access points and 802.11b stations, and between 802.11n/ac and legacy stations, has been added.

(iii) The internet module features a refactored TCP model to better support testing and to support modular congestion control classes. An RIPv2 routing protocol implementation was also added to the Internet module.

3.1. Structure of NS-3. ns-3 simulator [21] has a multilayered framework such that each layer depends on its lower layers. High-level user functions use helper functions to call lower level API functions. The high-level helper functions aim at scripting. These features are used to create interfaces and setup nodes with various devices, media propagation, applications, and protocols support. The simulator handles these functions as discrete events which it schedules using a scheduler and triggers the events at a set time. Also, many events can trigger the occurrence of many other events. The events are queued and iterated through to perform specific functions. The global Simulator::Run() is called in the main function to perform this action. However, simulations are not real-time; a simulation time is specified to start and stop the simulation by a call to Simulator::Start() and Simulator::Stop() functions, respectively. Also, when the event queue is empty, the simulation stops. Simulation results are saved in trace files which can then be analysed and optimised [22].

3.2. NS-3 Modules. ns-3 is made up of different modules for different network simulation scenarios. These modules also include many different classes that give specific features. Some of which are mandatory for a simulation. Examples of these modules are the following [23]:

(i) Node modules are the abstraction of a basic computing device. It is used to manage computing devices in the simulation. They can be created in groups for specific purposes and managed as a group using a NodeContainer.

(ii) Network modules provide methods for managing representation of computing devices in simulations.

(iii) Applications generate different traffic patterns and various data rates for varying protocol types. Packets are transmitted through sockets to other destinations. There are two subclasses, UdpEchoClientApplication and UdpEchoServerApplication, that are used for server/client application using UDP. It is set to start/stop at a given moment within the simulation time.

(iv) Channels are used to model media such as a wired cable (CsmaChannel) and wireless (WifiChannel) among others used for data transmit. Various attributes can be set for the channel such as bandwidth, frequency, speed, propagations loss, etc.

(v) NetDevice emulates the Network Interface Card (NIC) in a computer. It is installed on nodes to connect through the media for communication. CsmaNetDevice, WifiNetDevice, and PointToPointNetDevice have different features and are used on different systems. Creating a basic 802.11 model in ns-3 will consist of the nodes which will communicate. On each node is installed the NetDevice module, the protocol stack, consisting of different network protocol implementations such as UDP and TCP, and the application modules as shown in Figure 1.

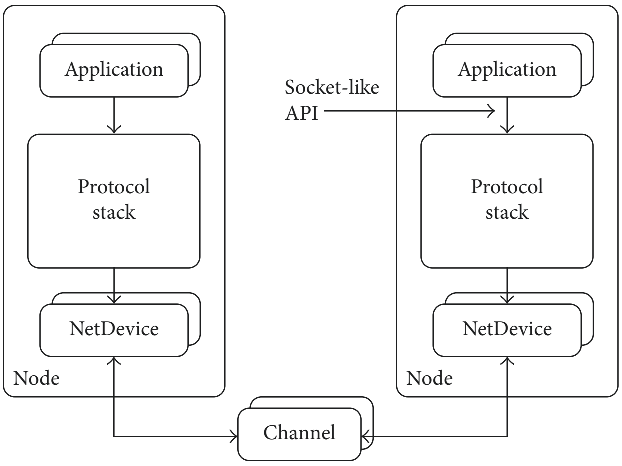

Figure 1: The basic ns-3 wireless network model.

3.3. Wi-Fi Modules. The Wi-Fi module consists of modules that offer a proper implementation of the 802.11 specifications (i.e., Mac-level). It also provides a packet-level abstraction of the PHY-level for extraordinary PHYs, adhering to the 802.11 standards as shown in Figure 2. Adding a WifiNetDevice object to ns-3 nodes, we could create 802.11-based models for both infrastructure and ad hoc networks. The nodes can be installed with some different sets of NetDevice objects, as is to computing devices with separate interfaces cards for Ethernet, Wi-Fi, Bluetooth, and so on. Using the SpectrumWifiPhy framework makes it possible to build scenarios involving co-channel interference or more than one Wi-Fi technology on a single channel. Also, it offers three 802.11 sublayers of models [24]:

(i) PHY layer models: the WifiPhy class is the implementation of the PHY layer, based on the YANS (Yet Another Network Simulator). It is mainly for modelling packet reception and energy consumption in the network.

(ii) Lower MAC models: they design capabilities including medium access (i.e., DCF, EDCA, and RTS/CTS) and sending Acks. The lower Mac level is similarly sublayered into a mac-low and a mac-middle sublayering, with media access categorised as the middle MAC sublayer.

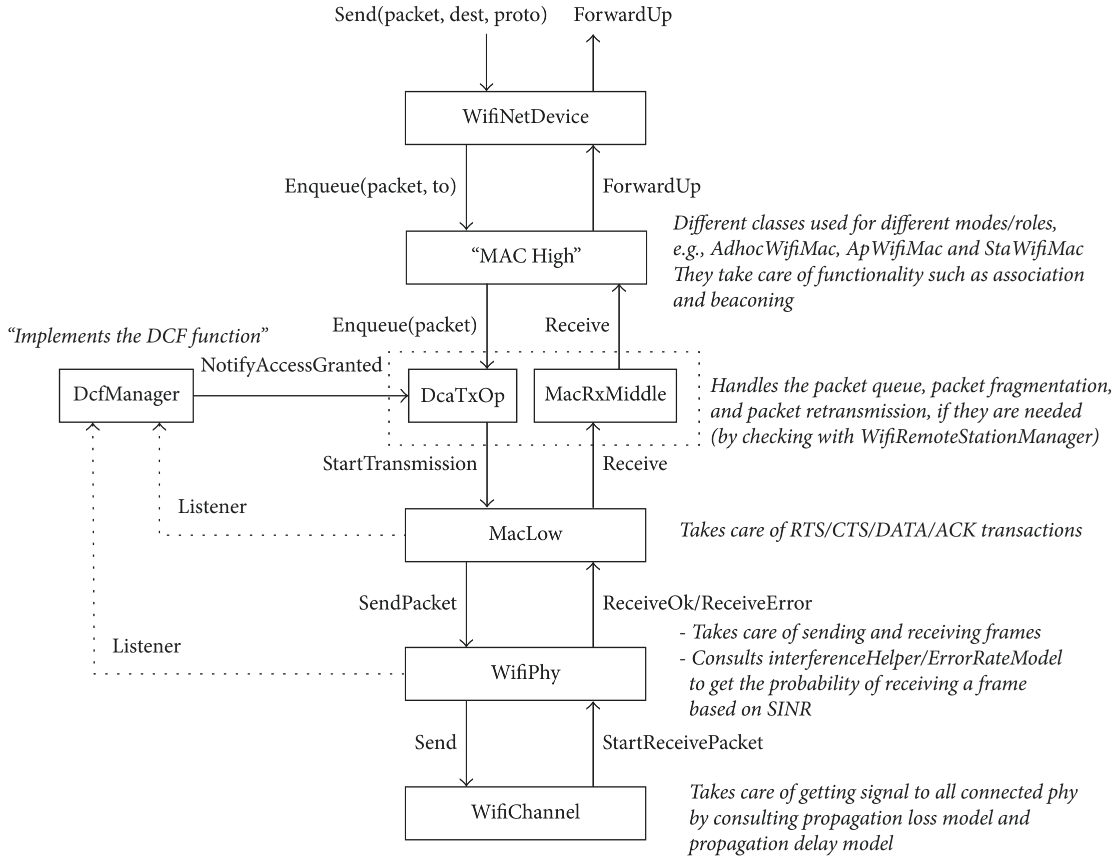

Figure 2: The Wi-Fi architecture.

(iii) DcfManager: it is an implementation of the DCF function in ns-3, together with the DcaTxop module. It grants access to the channel by processing the physical carrier sense from the WifiPhy module.

(iv) DcaTxop or EdcaTxop: it handles frames queuing. DcaTxop holds the most recent frames before it is acknowledged. Also, acquired frames from top layers are queued in a WifiMacQueue. Moreover, it handles fragmentation and retransmission. The EdcaTxop is used to assist QoS stations.

(v) MacTxMiddle and MacRxMiddle: MacTxMiddle controls frame fragmentation and appends a sequence number to the frames before transmission. MacRxMiddle reassembles the chunks of packets. However, while doing this, it discards duplicate frames by checking the sequence numbers attached to each frame fragment.

(vi) Upper MAC models: these models are the implementation of non-time-critical strategies in Wi-Fi which include the Mac level beacon technology, probing, and associating machine states, and also a collection of algorithms for rate control. This sublayer is on occasion known as the higher Mac and includes greater software-oriented implementations versus time-crucial hardware implementations. It has three main models: ApWifiMac, StaWifiMac, and AdhocWifiMac to emulate AP and non-AP and create ad hoc networks, respectively. However, the three models belong to a parent class called RegularWifiMac. The ns3::RegularWifiMac class allows different attributes to be set such as QoS support and HtSupport for 802.11n, VhtSupported for 802.11ac, and HeSupported for 802.11ax.

(vii) Rate Control algorithm: ns-3 also provides some algorithms for rate control that is applied to the MAC layer.

4. Residential Model

Our main evaluation study is based on the residential model in the 802.11ax scenario document [25], proposed by the IEEE 802.11ax study group for simulations of new features for the 802.11ax standard. We choose this scenario to implement because it shares a lot of features with 802.11ac [17]. Implementing this scenario when testing the 802.11ac features allows us to study and evaluate its performance in dense apartments.

According to [26], greater people increasingly depend on Wi-Fi connections to satisfy their connectivity wishes inclusive of working from home, entertainment, web browsing, and e-trade. International Data Corporation predicts that 87% of wireless devices will make sales by 2017. The usage of those devices for data backup, online gaming, and video streaming among others has increased data rate

Table 1: MCS values for 802.11ac.

MCS index	Modulation type	Coding rate	20 MHz (short GI)	Channel width multiplication factor
0	BPSK	1/2	7.2	
1	QPSK	1/2	14.4	×1.0 for 20 MHz
2	QPSK	3/4	21.7	
3	16-QAM	1/2	28.9	×2.1 for 40 MHz
4	16-QAM	3/4	43.3	
5	64-QAM	2/3	57.8	×4.5 for 80 MHz
6	64-QAM	3/4	65	
7	64-QAM	5/6	72.2	×9.0 for 160 MHz
8	256-QAM	3/4	86.7	
9	256-QAM	5/6	96.3[2]	

demands in the Wi-Fi infrastructure. Advances in technology coupled with changes in cultural and social norms and practices are enabling more people to work from home and away from their offices. This requires that robust network architecture is developed to support this form of work. The proposed infrastructure is geared to support this mode of work. We evaluated the impact of different channel allocations on throughput in the residential network and the impact of active stations on throughput in such networks. Table 1 describes the MCS types, code rates, and theoretically achievable throughput for each. Table 2 describes the general simulation parameter for our experiments. Table 3 describes the parameters we implement for our PHY layer in our scenarios. Table 4 also describes parameters for the MAC layer as implemented in our scenarios: primary nonoverlapping channel of 80 MHz, no RTS/CTS, and 100% station association to access points in each apartment. We use an MPDU aggregation size of 64 kb. Finally, Table 5 outlines the parameters for the residential scenario; the environment is a multifloor building with five floors, 3 m height on each floor, as shown in Figure 3. While other residential scenarios are possible, we chose this because such tall apartment blocks are typical of urban centres and cities. On each floor of the apartment building, there are 2×10 apartments with dimensions $10\,\text{m} \times 10\,\text{m} \times 3\,\text{m}$. Above the floor level in every apartment is randomly placed stations (STAs) at a height $z = 1.5$ m. Moreover, each apartment has an access point randomly placed in the x-y plane, at the height of $z = 1.5$ m above the floor of the apartment.

5. Performance Evaluation

In this section, we present a performance evaluation of our experimental study. In Section 5.1, we describe our simulation setup, and Section 5.2 presents experimental results and discussion.

5.1. Simulation Setup. In our initial set of simulations, we compared our results to [17] to enable us validate our setup. We used the specified parameters in [17] to run our simulations as shown in Table 5. In the scenario, an access point and a station are connected in an infrastructure WLAN mode at a distance of 1 m. We tested for average throughput, jitter, and delay using UDP traffic pattern. Also, the optimum range of transmission for different MCS values was investigated at various distances. We investigated the effect of different numbers of MIMO (2×2, 3×3, and 4×4), A-MPDU for different MCSs, and channel widths and also the effect of MIMO plus A-MPDU on throughput. We then run experiments for the residential model scenario and used it to investigate the impact of number of active nodes per APs and also the impact of channel allocation in a residential network. Figure 3 shows the network topology and Tables 3–5 show the simulation parameters as specified in [25]. Initially, we specified 200 stations sending UDP packets and 100 APs in the experiment, that is, two STAs per APs in each apartment. We subsequently increased the node density for 3 STAs per AP, 4 STAs per AP, and 5 STAs per AP. The average throughput in the network was investigated. The simulation was run for both MCS 0 and MCS 7.

Table 2: Simulation parameter.

Parameter	Value
Propagation loss model	Log distance propagation loss model
Packet size	1472 bytes
Error rate model	Nist error rate model
Distance	(1,100) m, step = 10 m
Mobility model	Constant position mobility model
Rate manager	Constant rate Wi-Fi manager
Channel width	20, 40, 80, 160 MHz
MCS	MCS 0 to MCS 9
Max A-MPDU size	4692480 bytes
MIMO	2×2, 3×3, 4×4

Table 3: The PHY parameter for the residential scenario.

Parameter	Value
MCS	MCS 0 or MCS 7 for all transmissions
Guard interval	Short
AP # of TX antennas	2 or 4 for all VHT
AP # of RX antennas	2 or 4 for all VHT
STA # of TX antennas	1 or 2 for all VHT
STA # of RX antennas	1 or 2 for all VHT

5.2. Experimental Results and Discussion. In this section, we present our experimental results. Figure 4 shows the

Table 4: The MAC parameters for the residential scenario.

Parameter	Value
Access protocol parameters	EDCA with default parameters according to traffic class.
Center frequency, BSS BW, and primary channels	Operating channel: 2.4 GHz: random assignment of three 20 MHz nonoverlapping channels 5 GHz: random assignment of three or five 80 MHz nonoverlapping channels, with random selection of primary channel per operating channel.
Aggregation	A-MPDU/64 MPDU aggregation size/BA window size, no A-MSDU, with immediate BA.
Max # of retries	Max retries: 10.
RTS/CTS threshold	No RTS/CTS.
Association	X% of STAs in an apartment is associated to the AP in the apartment; 100−X% of the STAs are not associated ($X = 100$).
Management	Each AP is independently managed.

Table 5: Parameters for the residential scenario.

Parameter	Value
Environment description	Multifloored building: a building of five floors, 2 × 10 apartments on each floor, each of 3 m height, room dimensions: 10 m × 10 m × 3 m
AP location	Each apartment has an AP randomly placed in xy-locations, at a height $z = 1.5$ m above the apartment floor
AP type	100 VHT APs per building VHT = 11ac in 5 GHz
STA location	Each apartment has a STA randomly placed in xy-locations, at a height $z = 1.5$ m above the apartment floor
Number of STA and STA type	2 VHT STAs per apartment VHT = 11ac (TBD) in 5 GHz
Channel model and penetration losses	Fading model: TGac channel model D NLOS for all the links Pathloss model: $\mathrm{PL}(d) = 40.05 + 20 * \log 10(\mathrm{fc}/2.4) + 20 * \log 10(\min(d,5)) + (d > 5) * 35 * \log 10(d/5) + 18.3 * F((F+2)/(F+1) - 0.46) + 5 * W$ $d = \max(\text{3D distance (m)}, 1)$ $fc = \text{frequency (GHz)}$ $F = \text{number of floors traversed}$ W = number of walls traversed in x-direction plus number of walls traversed in y-direction "Shadowing: log-normal with 5 dB standard deviation, iid across all links."

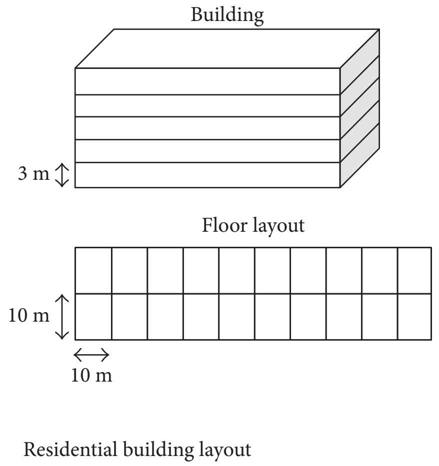

Figure 3: Residential network topology.

throughput result obtained for the channel width of 80 MHz; our results are plotted against the results obtained in [17] for throughput. As can be observed, there is very close agreement between the two set of results. Figure 5 shows the result obtained at the same channel width with A-MPDU enabled. Our results are again plotted against those of [17], and we observe very close agreement in the achievable data rates. Figures 6 and 7 show the result obtained for only MIMO, only A-MPDU, and for both MIMO and A-MPDU enabled. A channel width of 80 MHz and 160 MHz was used, respectively. The data rate is low without the new PHY/MAC features. MIMO by itself does not increase the throughput much. When only A-MPDU was enabled, data rate increases much more. However, the best achievable throughput was under the combined features of MIMO and A-MPDU. At a channel width of 80 MHz and MIMO (4 × 4), data rate was almost 1 Gbps. At a channel width of 160 MHz, we observed throughput over 1 Gbps. Figure 8 shows one of the results obtained for the range of transmission for different MCS values (in this case, MCS 3). A short guard interval (SGI) is used. Also, it shows the results for the different channel width in 802.11ac. The signal coverage deteriorates for large channel sizes and higher MCS values. At the lowest frequency (20 MHz), the signal becomes totally dead at 60 m. Figure 9

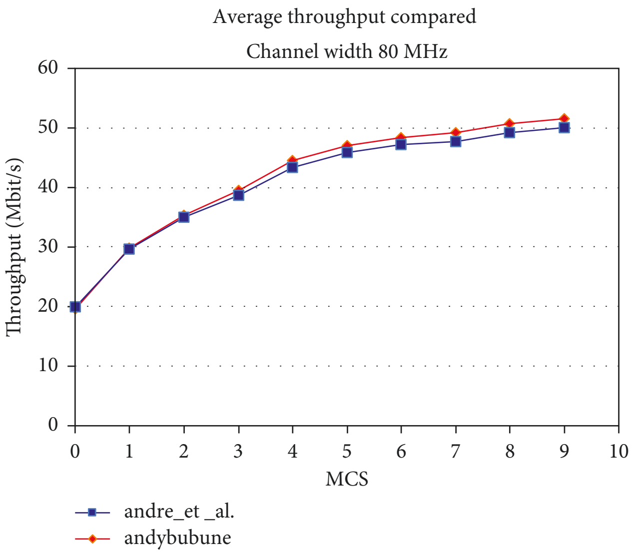

Figure 4: Throughput versus MCS: average throughput compared.

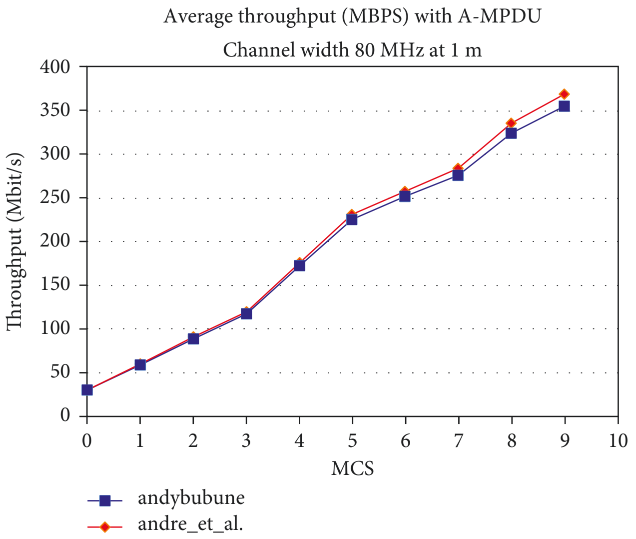

Figure 5: Throughput versus MCS: average throughput (MBPS) with A-MPDU.

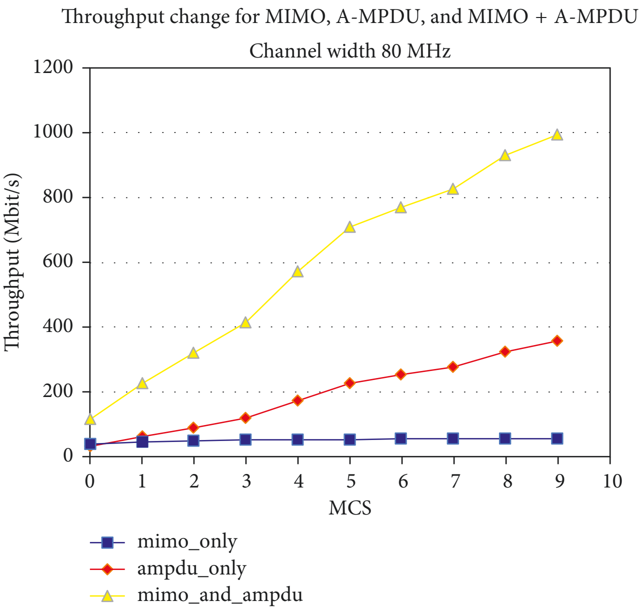

Figure 6: Throughput versus MCS: throughput change for MIMO, A-MPDU, and MIMO + A-MPDU for 80 MHz.

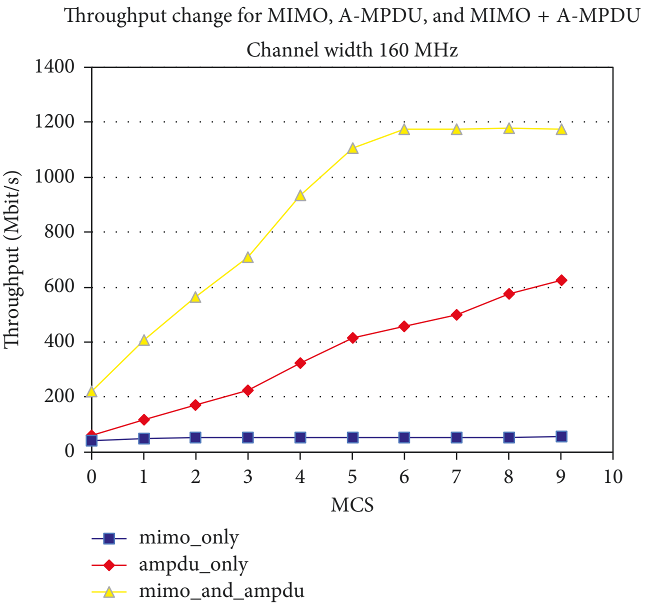

Figure 7: Throughput versus MCS: throughput change for MIMO, A-MPDU, and MIMO + A-MPDU for 160 MHz.

gives a detailed result of a channel width of 20 MHz as shown in Figure 8 earlier; the best transmission range is within 50 m. Signal strength begins to drop after 50 m and is totally lost at 60 m. This is due to the short wavelength of high frequencies and interference. In Figures 10 and 11, the results present the mean delay for three categories: no features enabled, MIMO enabled, and both MIMO and A-MPDU enabled. The channel width was set to 80 MHz and 160 MHz, respectively, and for all MCS values. Similarly, Figures 12 and 13 present the result for the mean jitter. The mean delay was highest for low MCS values when frame aggregation (A-MPDU) was enabled. However, it drops drastically for higher MCS values. With no features set, the mean delay was comparatively high for all MCS values. Combining A-MPDU and MIMO gave us the best mean delay and was negligible at the highest MCS. The mean jitter was rather highest for A-MPDU at lower MCS values. However, the mean jitter was low when both MIMO and A-MPDU features were enabled. It becomes negligible at the highest MCS. When all features were disabled, the lowest jitter was recorded for lower MCS values; however, it remained almost same for all other MCS values. MIMO and A-MPDU together performed best for the mean jitter. Generally, we observed that larger channel width minimized delay and jitter in the network.

Figures 14 and 15 show the result obtained for two scenarios for the impact of different node densities on the throughput in the residential environment, when no features

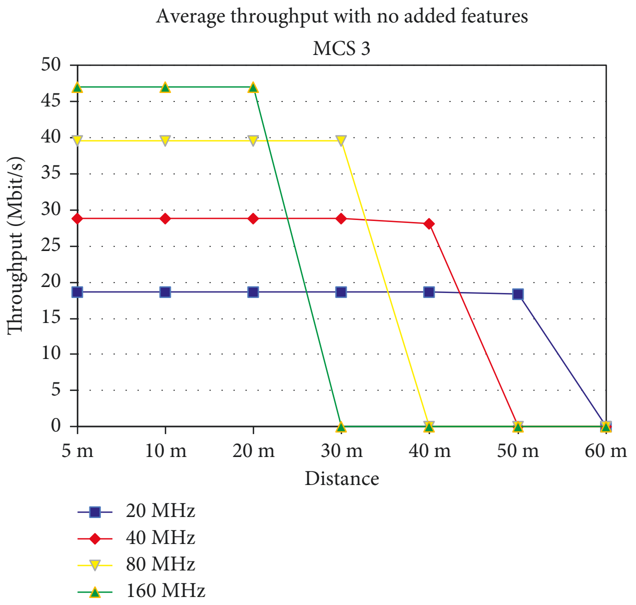

Figure 8: Throughput versus distance: average throughput with no added features.

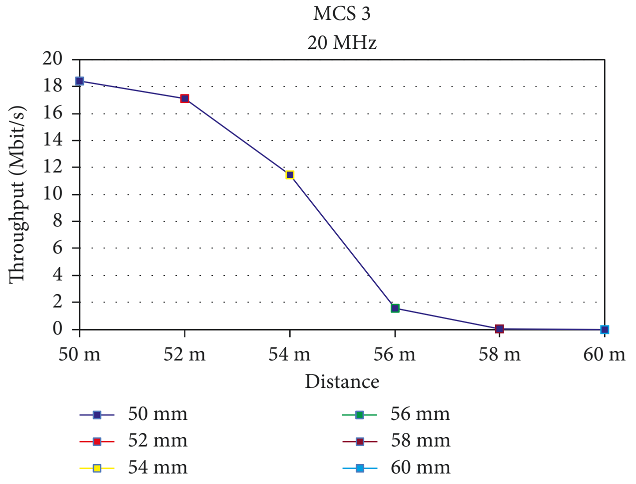

Figure 9: Throughput versus distance.

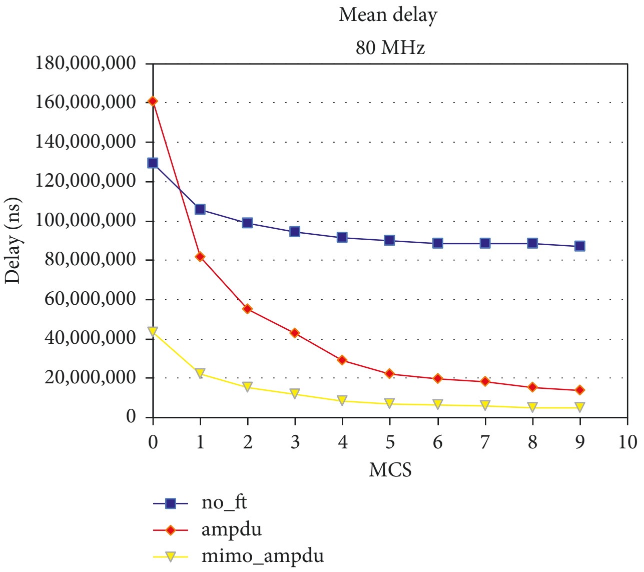

Figure 10: Delay versus MCS for 80 MHz.

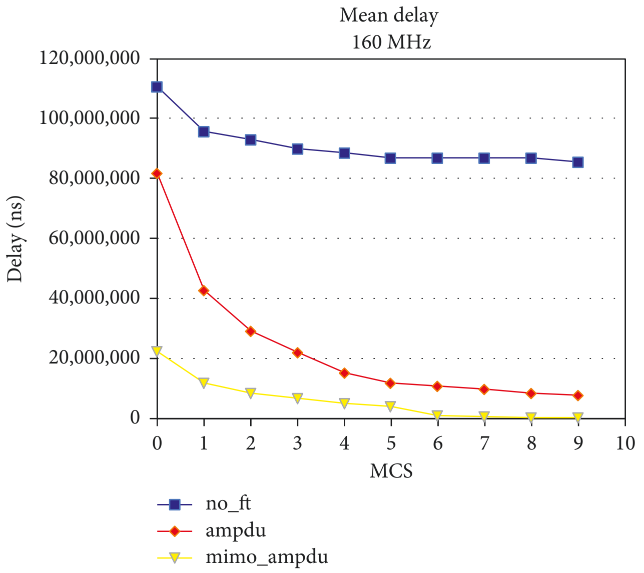

Figure 11: Delay versus MCS for 160 MHz.

set and when combined features of A-MPDU and MIMO is configured, respectively. The result is depicted as a boxplot of the average throughput against different node densities within the network. Node density was increased: two nodes per AP, three nodes per AP, four nodes per AP, and five nodes per AP, that is, 200, 300, 400, and 500 active stations in the network, respectively. The simulation is run for different scenarios, and the result is presented as shown in Figures 14 and 15. The results indicate a boxplot of the average throughput against the various node densities within the network. In Figure 14, we obtained average throughputs of 23.98, 15.66, 11.99, and 9.027 Mbps for the various node densities of 200, 300, 400, and 500 nodes, respectively, when no features were used. In Figure 15, we obtained average throughputs of 435.63, 258.60, 368.32, and 107.05 Mbps for the different node densities of 200, 300, 400, and 500 nodes, respectively, for combined features of MIMO and A-MPDU. The average throughput drops across the network as node density is increased. However, we see that even at this high node density (i.e., 500 nodes), the 802.11ac protocol performs well with about 70% of the nodes in scenario 1 and 60% of the nodes in scenario 2, sending an appreciable amount of data. It demonstrates the protocol's capacity for very high throughput in dense environment, that is, support for large numbers of active stations in a network. It makes this protocol suitable for densely populated home residences.

6. Conclusion

In this work, we did analyze the performance of key features of 802.11ac running various simulations. We presented our findings on aggregation schemes, modulation schemes, and

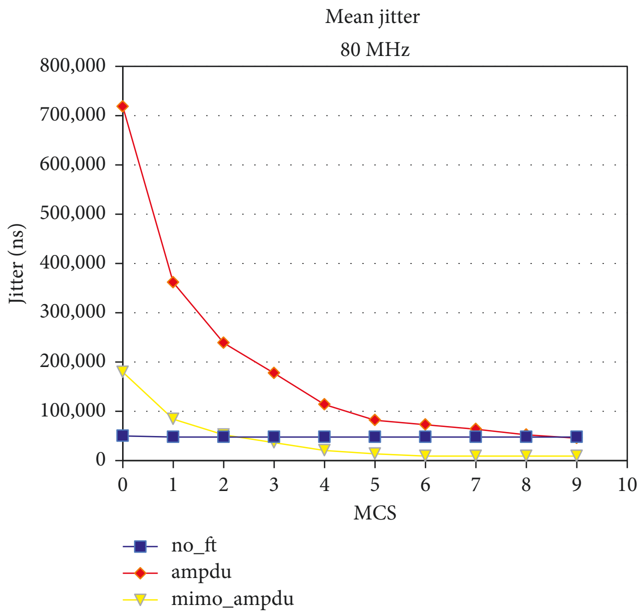

Figure 12: Jitter versus MCS for 80 MHz.

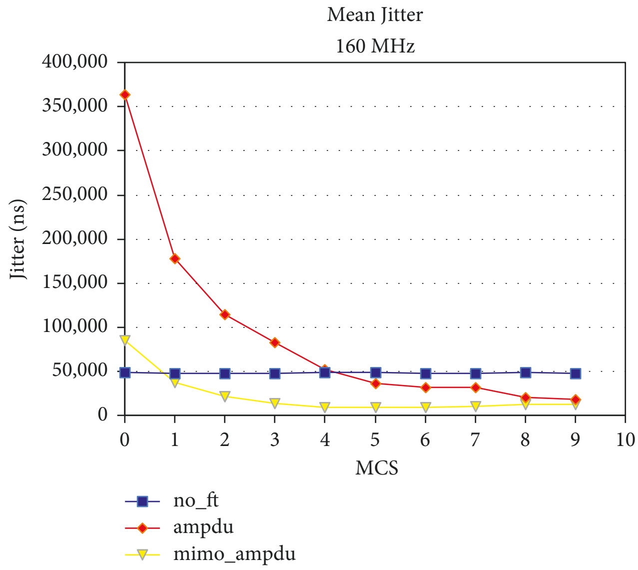

Figure 13: Jitter versus MCS for 160 MHz.

MIMO as they affect the range of transmission, throughput, jitter, and delay of networks. We found that the very high throughputs are achievable when different features are combined. Also, the 802.11ac protocol is resilient for large node densities. Also, the combination of this features (A-MPDU and MIMO) also minimized delay and jitter in the network. There still remain scenarios not discussed. We seek to further study the performance of the standard in residential environments for various conditions.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

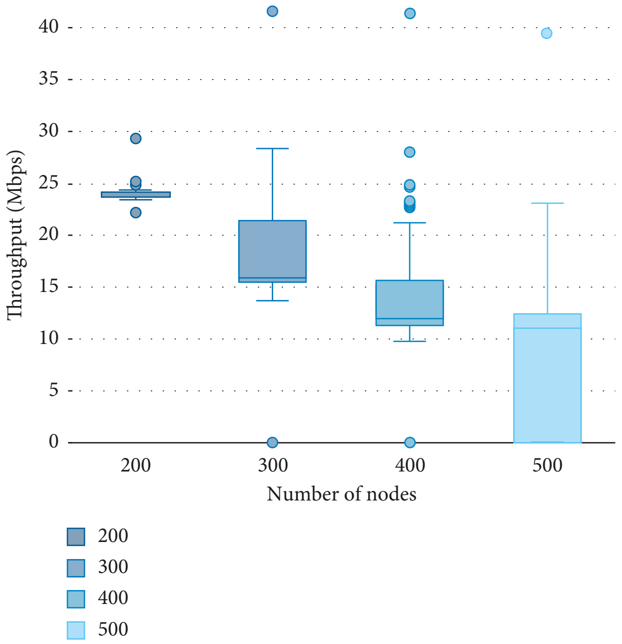

Figure 14: Throughput versus number of nodes for no features.

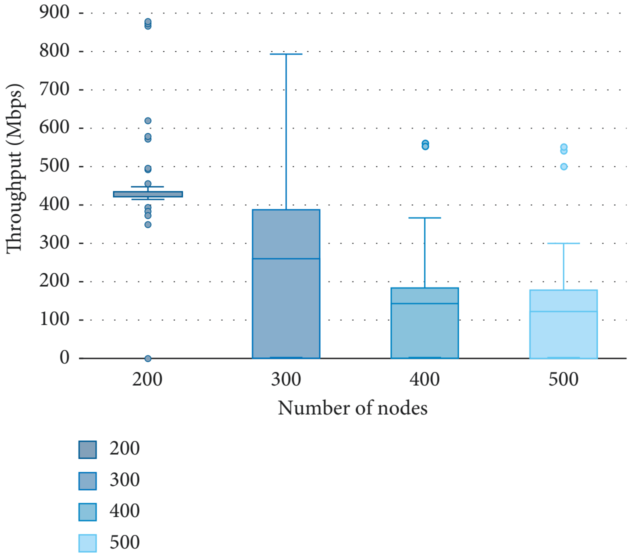

Figure 15: Throughput versus number of nodes for MIMO plus A-MPDU.

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