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Performance Analysis of IEEE 80.11ac Wireless Local Area Networks

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Abstract: The introduction of the IEEE 802.11 standard in late 1990s sparked a whole new promising area in wireless communications, allowing computer users to have untethered access to the Internet. Recently, the IEEE 802.11ac amendment for wireless local area networks (WLANs) has been released that achieves very high throughput (VHT) to approximately 6.933 Gbps. Enhancements to the physical and MAC layers are introduced in the IEEE 802.11ac amendment. These enhancements include exploiting wider channel bandwidths, enhancing modulation and coding schemes, using explicit beamforming, and increasing spatial streams along with the breakthrough of multi-user multi-input multi-output (MU-MIMO). This paper presents a performance analysis in terms of throughput of IEEE 802.11ac. Simulation is conducted to examine different features defined in the 802.11ac amendment. We calculate the aggregate system throughput of several proposed simulation scenarios. Results show that 802.11ac system throughput increases with the enhancement of channel size, modulation schemes, and spatial streams.

Keywords: 802.11ac, modulation schemes, MU-MIMO, performance analysis, spatial streams.

I. INTRODUCTION

Since their emergence in 1997, wireless local area networks (WLANs) based on IEEE 802.11 standard have become progressively more popular in the networking universe. Urged by the explosive growth in multimedia applications, 802.11a/b/g amendments have elevated the data rates of the legacy 802.11 by enhancing the functionality of physical and MAC layers. Utilizing the multiple-input multiple-output (MIMO) technology, IEEE 802.11n has been standardized in 2009 to provide high throughput (HT) that expands up to 600 Mbps. The IEEE 802.11ac [1] is an amendment that has broken the Gigabit-Ethernet barrier by achieving very high throughput (VHT) with data rate of up to 6.933 Gbps in bands below 6 GHz. The VHT has been achieved through utilizing wider bandwidths, higher order modulation and coding schemes (MCS) such as 256-QAM, downlink multi-user multiple-input multiple-output (MU-MIMO) transmissions, and explicit beamforming. Unlike 802.11n that can operate in both 2.4 and 5 GHz bands, 802.11ac works only in the 5 GHz band [1]. The 5 GHz band is less susceptible to interference and provides more non-overlapping channels.

Conceptually, 802.11ac builds up on the top of all breakthrough advancements of 802.11n. Different techniques are used to increase data rate in 802.11ac through exploiting MIMO technology. In order to improve efficiency, 802.11ac takes advantage of the major new MAC features developed in 802.11n, with one exception. Instead of using MIMO only to increase the number of data streams sent to a single receiver, the 802.11ac amendment is breaking a new ground of a multi-user MIMO (MU-MIMO) that allows an access point to transmit to multiple receivers at the same time [3].

The 802.11ac extends the frame size from 8000 bytes to 11454 bytes, which increases the ability to aggregate frames from upper layers. Moreover, frame aggregation is mandatorily employed in 802.11ac which states that all MAC protocol data units (MPDU) must be sent as an aggregate MPDU (A-MPDU) [1], [3]. In this paper, we study the significant features introduced by the IEEE 802.11ac amendment to investigate how these features can affect the system performance.

The rest of this paper is organized as follows. Section II provides an overview of the major enhancements defined in the IEEE 802.11ac amendment. Related work is also summarized in section II. Simulation techniques and setup along with simulation parameters are presented in section III. Results and discussions are reported in section IV. We draw a conclusion to our work in section V.

II. BACKGROUND AND RELATED WORK

A. Overview of 802.11ac

Following the success accomplished by introducing IEEE 802.11n in 2009 [4], the IEEE 802.11 task group AC has introduced a new standard that achieves a very high throughput. The 802.11ac amendment has enhanced all features defined in 802.11n along with other new features.

Using channel bonding technique and in addition to 20 and 40 MHz channels, the 802.11ac amendment defines two wider channel bandwidths: a mandatory 80 MHz channel and an optional 160 MHz channel. The 80 MHz channels are

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two adjacent 40 MHz channels, whereas 160 MHz channels are specified as two 80 MHz channels which can be contiguous or noncontiguous. Wider channels imply achieving higher throughput than that achieved by 802.11n [1]-[4]. As a result of the advancements and accuracy in digital processing, 802.11ac extends the modulation and coding schemes (MCS) to 256 quadrature amplitude modulation (256-QAM). This leap from 64-QAM in 802.11n to 256-QAM with coding rates 3/4 and 5/6 in 802.11ac, allows transmitting eight information bits per hertz which ensues increasing system throughput. Nonetheless, 256-QAM requires higher signal-to-noise ratio (SNR) as to maintain a lower bit-error probability [2].

The time interval between transmitted symbols is defined as Guard Interval (GI). In particular, this GI is required to preclude the inter-symbol interference (ISI) problem. Like IEEE 802.11n, IEEE 802.11ac can use a guard interval of 400 ns instead of 800 ns employed in legacy 802.11a/b/g. The short guard interval (SGI) can effectively reduce the idle time in data transmission which consequently increases the throughput of the system. However, in dense networks with heavy traffic, the SGI option may cause more interference leading to degradation in the system throughput [5].

Beamforming is a technique used to optimize communications between access points (APs) and stations to respond to interference [3]. IEEE 802.11ac uses explicit beamforming in which both transmitter and receiver contribute in estimating channel conditions. In explicit beamforming, the beamformer sends a null data packet (NDP) that includes the addresses of targeted nodes. The beamformee measures the channel and sends back this information to the beamformer. Consequently, the beamformer can accurately direct each beam to the target receiver [6].

The IEEE 802.11ac has increased the number of spatial streams (SS) up to eight SS at the access point compared to four spatial streams specified by 802.11n. These spatial streams can be used to transmit to multiple nodes simultaneously. More importantly, multi-user MIMO (MU-MIMO) is the breakthrough of 802.11ac. Using MU-MIMO, an AP can transmit packets concurrently to multiple clients in the same frequency spectrum at the same time (spatial reuse). However, to employ the MU-MIMO efficiently, the IEEE 802.11ac specifies that the maximum number of simultaneous beams directed to different nodes is four [3], [6]. That is, the maximum number of concurrent receivers of a MU-MIMO is four. Moreover, the maximum number of spatial streams inside each beam to a specific node is four. This means that each particular receiver can have no more than four spatial streams.

Aggregate MAC service data unit (A-MSDU) and aggregate MAC protocol data unit (A-MPDU) are two frame aggregation techniques that enhance the MAC layer in the IEEE 802.11ac amendment. The maximum size of an A-MSDU is increased to 11454 bytes instead of 8000 bytes in 802.11n. On the other hand, the maximum size of a single A-MPDU is 1 MB. In contrast to 802.11n, all frames sent by 802.11ac devices must be in an A-MPDU format. The frame aggregation reduces the overhead and thus increases the system throughput [3], [5].

B. Related Work

Many research activities have been conducted to evaluate the performance of the IEEE 802.11ac amendment. In [2], a theoretical model is proposed to examine the throughput of PHY and MAC layers of the 802.11ac. Simulation results are relatively close to the results of the theoretical model. The authors of [5] provide a survey on the impact of physical and MAC enhancements on transport and application layer protocols. A comparison between 802.11n and 802.11ac is also considered in [5]. In addition, the authors specify some challenges for 802.11ac in order to support higher layers protocols. Alternatively, examining the channel sounding technique used in explicit estimating of channel conditions is reported in [6]. An extended request-to-send/clear-to-send is proposed and integrated with the explicit compressed feedback. A review of physical layer characteristics is presented in [7]. A testbed based on 802.11n chips is used to evaluate the performance of MU-MIMO. Considering other approaches, a measurement-based method is introduced in [8] to evaluate the performance of 802.11ac in an indoor environment. The claim is that 802.11ac works better in indoor environment because of less interference and high channel quality. Based on [9], the authors of [10] proposed a theoretical model to study the performance of the IEEE 802.11ac distributed coordination function (DCF) of the MAC layer in presence of hidden nodes. The paper concludes that using legacy RTS/CTS handshake mechanism has some shortcomings that need to be addressed to cope with the new 802.11ac features. In [11], a performance analysis of energy efficiency and interference in 802.11ac is presented. The authors proclaim that more energy is consumed when utilizing wider channel bandwidths, whereas the addition of more spatial streams is energy efficient. The authors of [12] have examined the MAC enhancements for downlink MU-MIMO transmission. Basically, the authors introduce a mechanism of enhancing the transmission opportunity (TXOP) and the backoff procedure. A frame aggregation scheme for 802.11ac is proposed in [13]. The performance of the network is studied under non-saturated conditions. Their discussions show that queue length and number of active nodes have a significant influence on the system performance.

III. SIMULATION SETUP

In order to evaluate different features of 802.11ac, we have used the Jemula 802.11ac simulator [14]. The Jemula 802.11ac kernel is an open source JAVA library that constitutes a kernel for event-driven stochastic simulation that is prepared to simulate real-time systems. The simulation core consists of three main packages called kernel, statistics,

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and plot [14]. We consider simulating different channels, namely: 20 MHz, 40 MHz, 80 MHz, and 160 MHz. Different modulation schemes are studied which are: Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation: 16-QAM, 64-QAM, and 256-QAM. In addition, we consider varying the number of spatial streams for the values 1, 2, 4 and 8. Physical and MAC layers parameters used in our simulation are summarized in Table I. Several scenarios have been constructed where each scenario is run for 20 seconds. Each scenario is run for 10 times and we have calculated the average values to obtain stable results.

IV. RESULTS AND DISCUSSIONS

Our aim is to study the effect of different features introduced in 802.11ac on system throughput. We calculate the aggregate throughput for the network for the following different scenarios.

A. The Effect of Channel Bandwidth on Throughput

In this scenario, we study the impact of wider channel bandwidths on throughput as a function of packet size. The modulation scheme is fixed to 16-QAM. For simplicity, number of spatial streams is set to 1 SS. Number of stations in this scenario is set to 10 stations. Fig. 1 illustrates that as the channel bandwidth is doubled, the aggregate throughput is increased by approximately 10 Mbps. This is due to the ability of using more bandwidth to transmit data bits, which increases the data rate. However, this increase is constrained by the signal-to-noise ratio (SNR) of the channel. The consideration of the effect of SNR is not addressed in this paper.

TABLE I PHY AND MAC PARAMETERS

Parameter	Value	Parameter	Value
Slot time	9 µs	CW_{min}	16
L_{macH}	34 bits	CW_{max}	1024
$T_{VHT\text{-}STF}$	4 µs	$T_{SY\ MS}$	3.6 µs
$T_{VHT\text{-}SIG\text{-}A}$	8 µs	$T_{L\text{-}SIG}$	4 µs
$T_{VHT\text{-}SIG\text{-}B}$	4 µs	$T_{SY\ ML}$	4 µs
$T_{VHT\text{-}LTF}$	4 µs	$N_{service}$	16 bits
T_{DIFS}	34 µs	T_{STF}	8 µs
T_{SIFS}	16 µs	T_{LTF}	8 µs
$Prop_{Delay}$	1 µs	N_{tail}	6 bits

B. The effect of modulation schemes on throughput

We consider the effect of different modulation schemes in this scenario. The number of stations is fixed to 10 stations. We set the number of spatial streams to 1. In addition, we vary the packet size for the values: 500, 100, 1500, and 2000 octets. As shown in Fig. 2, the system throughput increases with higher order modulation schemes. This is due to the number of bits transmitted per symbol. The new 256-QAM introduced in 802.11ac achieves higher throughput of about 10 Mbps than that achieved using 64-QAM with packet size of 2000 bytes. As mentioned in scenario A, however, the higher modulation scheme requires high SNR to achieve this elevation in throughput.

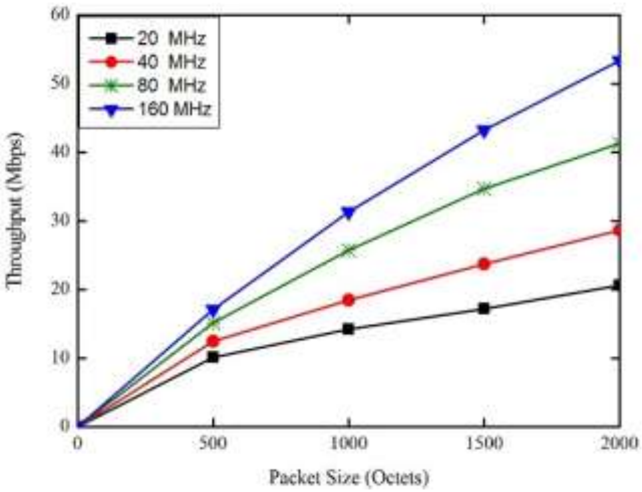

Fig. 1. The effect of wider channel bandwidths on throughput for various packet sizes

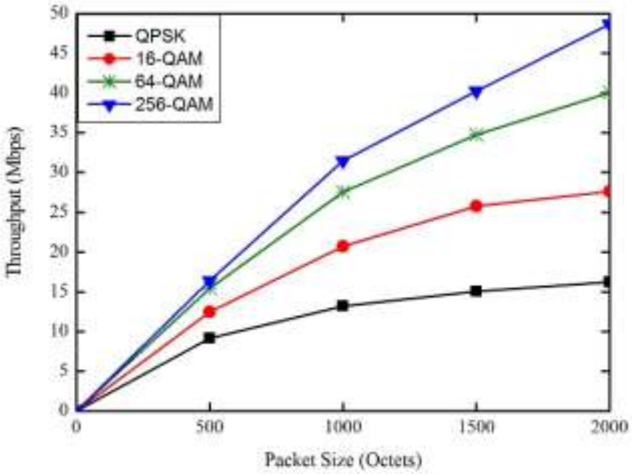

Fig. 2. The effect of modulation schemes on throughput for various packet sizes

C. The effect of multiple spatial streams on throughput

We examine the effect of number of spatial streams on throughput as a function of packet size. The number of stations is fixed to 10. The modulation used in this scenario is 16-QAM with 40 MHz channel. The number of streams is set to 1, 2, 4, and 8. As illustrated in Fig. 3, when the number of spatial streams is doubled, the throughput is increased. For instance, at payload of 2000 bytes, the 8 SS outperforms the 4 SS with a factor of about 10.

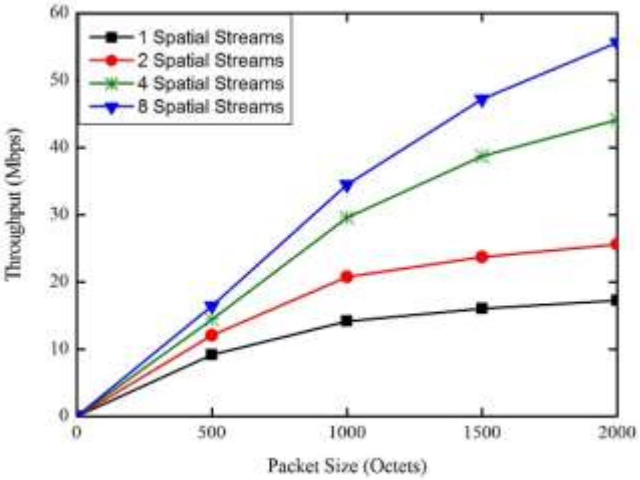

Fig. 3. The effect of number of spatial streams on throughput for various packet sizes

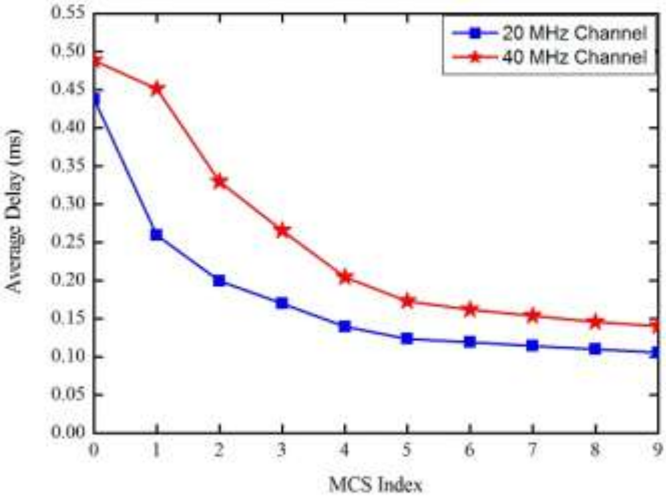

Fig. 4. The effect of modulation and coding schemes (MSC) on the average delay for 20 and 40 MHz channels

D. The effect of MCS on average delay

In this scenario we evaluate the average delay for packet transmission against different MSC. The number of stations is set to 10, where the number of SS is set to 1. We us to channel bandwidths: 20 MHz and 40 MHz. The packet size is set to 1500 bytes. The average delay in both channel sizes decreases with higher order of modulation and coding schemes, as depicted in Fig. 4. However, the 20 MHz channel encounters higher average delay than the 40 MHz channel.

V. CONCLUSION

This paper examined different characteristics of the IEEE 802.11ac amendment. Wider channel bandwidths, modulation schemes, multiple spatial streams were the key features investigated in our simulation scenarios. As shown in the results, these features increase the system throughput and thus, enhance the system performance. In addition, we evaluated the average delay as a system performance metric just to give an insight on how the transmission of data packets is affected. Despite the throughput is an important performance metric, other factors such as channel access fairness and link adaptation mechanism must be considered for further analysis. In our future work, we aim at studying the effect of MAC frame aggregation techniques on system performance.

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