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Performance Evaluation of the Giga-bit 802.11ac Based WLANs

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Abstract

Wireless local area networks based on the legacy 802.11-1997 standard brought about a new era in wireless communications, enabling users to utilize the Internet anytime, anywhere. About two decades later, the IEEE 802.11ac amendment was released that broke the Gigabit-Ethernet barrier for wireless local area networks (WLANs). This amendment introduced improvements to the first and second layers (PHY and MAC) of the standard. The very high throughput was accomplished by improving the modulation mechanism, adding more spatial streams, utilizing broader channels, exploiting beam forming techniques, and allowing for better frame aggregation. In this article, a simulation evaluation is conducted to investigate the performance of the 802.11ac considering the enhancements introduced by this amendment. The main metric used in this study is the system throughput. In addition, the average delay metric is also considered for investigation. Different simulation scenarios are considered to examine the previously mentioned features and enhancements. Results showed that the system throughput of 802.11ac increases with larger channel sizes, improved modulation schemes, and more spatial streams. The frame aggregation has indicated to be an effective mechanism for alleviating unwanted overheads, which consequently increased the overall throughput.

Keywords: 802.11ac; modulation schemes; spatial streams; frame aggregation**.**

INTRODUCTION

Wireless communication technology offers the convenience of wireless communication services and enables individuals worldwide to stay mobile. Utilizing the IEEE 802.11 wireless standards, Wireless local area networks (WLANs) have undergone ongoing development year after year (Rochim *et al*., 2020). WLANs are extensively utilized for various device types, with easy deployment options. Besides its usage in accessing the Internet, different applications use the WLANs, such as autonomous vehicles, surveillance, and audio/video delivery for real-time services. These applications involve users' mobility, which entails the probability of a high collision rate and potentially causing performance drops (Coronado *et al*., 2023).

The data rates of the original 802.11 standard have been improved by the 802.11a/b/g amendments. The IEEE 802.11n standard was established in 2009, exploiting the MIMO technology that achieved higher throughput rounding to 0.6 Gbps. The IEEE 802.11ac (IEEE, 2013) amendment has succeeded in accomplishing a very high throughput (VHT), which exceeds the Giga-bit baseline. Accomplishing this VHT level was obtained according to several enhancements such as using more spatial streams, considering broader channels, increasing the modulation, and coding schemes, utilizing the new feature of multi-user MIMO, and frame aggregation techniques (IEEE, 2013).

Additionally, two essential frame aggregation methods are proposed by the amendment to be used by the MAC layer while transmitting data frames. These two methods are known as Aggregate MAC service data unit (A-MSDU) and Aggregate MAC protocol data unit (A-MPDU). The utilization of frame aggregation methods considerably decreases the overhead by allowing multiple frames to share the physical header and inter-frame spacing during channel access. Moreover, the frame size has increased, as stated by the amendment, to enable more data packets coming from upper layers to be aggregated. The frame aggregation mechanism, however, is set to be compulsory in 802.11ac, making the MAC layer transmits all its MPDUs as aggregate MPDUs (A-MPDUs) (Gast, 2013; IEEE, 2013).

Essentially, the 802.11ac builds upon the significant advancements made in 802.11n. Various techniques are employed in 802.11ac to increase data rates by utilizing MIMO technology. Instead of dealing with a single receiver, the 802.11ac proposed the MU-MIMO mechanism, which allows the access point to send to multiple users simultaneously. This is a groundbreaking feature that sets 802.11ac apart from its predecessors (Gast, 2013).

This paper aims to evaluate the new enhancements proposed by the 802.11ac and investigate their impact on the performance. Simulation methodology is utilized to conduct this study considering several scenarios which cover the features introduced in the 802.11ac. Broader channels, elevated modulation schemes, increased spatial streams, and frame aggregation are the enhancements investigated in this paper. Throughput and average delay are the metrics used in this study for performance evaluation. The evaluated performance indicated that the 802.11ac achieved better throughput when employing the new key features.

RELATED WORK

Extensive research has been proposed in the literature that investigated the operational effectiveness of the IEEE 802.11 wireless networks. Tuifaiga *et al*. presented a study that compares the performance of IEEE 802.11ac wireless LAN in Windows and Linux Ubuntu (Tuifaiga *et al*., 2021). The study showed that IPv4 outperforms IPv6 in terms of several performance metrics. UDP has higher throughput than TCP, and Linux performs better than Windows. The theoretical limit of 1.3Gbps for 802.11ac was not reached with an 80 MHz channel size. Another study by (ElKassabi *et al*., 2022) explored the practical deployment of WiFi standards in outdoor smart city environments. The study compared the 802.11ax, 802.11ac, and 802.11n in terms of performance. The results indicated that both IEEE 802.11ax and IEEE 802.11ac outperformed the performance of the IEEE 802.11n. Surprisingly, the distance between the transmitter and receiver was the criterion which made the 802.11ac perform better when a certain distance was exceeded. De Carvalho *et al*. evaluated the performance of wireless equipment in Wi-Fi (IEEE 802.11ac) using WPA2 PTP links (de Carvalho *et al*., 2020). TCP and UDP performance metrics were measured. The 802.11ac outperformed 802.11n in terms of TCP throughput, jitter, and datagram loss. The results suggested further investigations across different standards, equipment, and environments. Alternatively, a Markovian model was presented to predict AP throughput based on network topology and demands (Stojanova *et al*., 2021). Simulations showed a 10% mean error. The model is tailored for IEEE 802.11 standards with channel bonding, providing insights for channel assignment. Guidelines for static channel bonding were derived considering node characteristics. The authors of (Natkaniec *et al*., 2023) analyzed the coexistence of 802.11ax stations with other legacy stations. The study investigated the effect on system performance caused by the BSS coloring, A-MPDU, and A-MSDU aggregations. Simulation results showed that implementing BSS coloring increased throughput by up to 43%, but legacy devices disrupted its functioning. Fukuda *et al*. focused on IEEE 802.11ax and its impact on communication performance in dense campus wireless LANs (Fukuda *et al*., 2022). They conducted experiments using multiple terminals to measure the throughput under various channel configurations and coexistence scenarios with other standards. Findings indicated that 40-MHz channel bonding improved throughput with a small number of terminals, whereas increasing the ratio of 802.11ax stations coexisting with 802.11ac stations enhanced the overall performance. The challenge of combining 802.11ad and 802.11ac interfaces in future WLAN devices was addressed by (Aggarwal *et al*., 2022). The authors proposed MuSher, an agile MPTCP scheduler that improves throughput in WLAN/Internet settings and speeds up traffic recovery.

Similarly, Chen *et al*. focused on the challenges of rate adaptation (RA) in IEEE 802.11ac networks (Chen *et al*., 2021). The authors identified limitations in current RA solutions, such as the lack of joint rate and bandwidth adaptation, scalability, and online learning capability. To overcome these limitations, they proposed an experience-driven rate adaptation (EDRA), which incorporates deep reinforcement learning. The evaluation results demonstrated that EDRA outperformed the default RAs by up to 821.4% (Intel) and 242.8% (Linux) in various scenarios. The research of (Khan *et al*., 2017) discussed the high system throughput of IEEE 802.11ac networks in a MIMO channel. It considered key MAC and PHY layer features and identified trends and trade-offs. The work in (Muhammad *et al*., 2021) presented a performance evaluation of 802.11ax (Wi-Fi 6). The research conducted empirical tests to investigate metrics such as throughput and jitter, and their relationship with parameters like payload length and environmental variables. The results showed that 802.11ax achieved higher throughput compared to its predecessor 802.11ac, and exhibited improved channel utilization due to its higher modulation and coding scheme. Confined to the 160-MHz channel, Kolahi *et al*. evaluated the performance of WLAN 802.11ac for IPv4, IPv6, UDP, and TCP protocols (Kolahi *et al*., 2023). Results indicated that the client-server setup using UDP and IPv4 achieved the highest throughput at 1124 Mbps, surpassing the results for IPv6. However, the achieved throughput is lower than the theoretical maximum of 1700 Mbps. Another study (Gupta *et al*., 2020) explored an integrated fiber-wireless network combining a 10-Gigabit passive optical network and IEEE 802.11ac WLAN. The focus was on enhancing network throughput and meeting quality of service requirements. The proposed approach incorporated a deficit dynamic bandwidth allocation algorithm at the optical line terminal to ensure improved QoS parameters. Simulation results demonstrated positive enhancements in all measured performance metrics. The authors of (Rochim *et al*., 2020) compared the performance of the sixth-generation wireless protocol IEEE 802.11ax with the previous fifth-generation protocol IEEE 802.11ac, both operating at 5 GHz. Different modulation schemes and payload sizes, as well as the number of users, were considered for comparison. Results indicated that in the case of dense stations, 802.11ax performed better than 802.11ac. However, the 802.11ax experienced a slightly longer delay response time.

Buta *et al*. presented an implementation and evaluation of the sub-band MVDR algorithm for IEEE 802.11ac signals (Buta *et al*., 2020). The algorithm demonstrated a good performance and effectively directed the array of antennas as required. Additionally, it improved data transmission quality, as indicated by lower bit error rates compared to non-beamforming scenarios under the same signal-to-noise ratio conditions. On the other hand, many studies focused on the impact of frame aggregation on network operation. Karmakar *et al*. conducted a survey examining the effect on application performance caused by the concepts of high throughput WLANs (Karmakar *et al*., 2017). It covered

IEEE 802.11n and IEEE 802.11ac standards, highlighting features like frame aggregation, MIMO, and channel bonding. The survey emphasized the need for research on evaluating the performance of upper layers in HT-WLANs and developing efficient link adaptation mechanisms. The authors of (Suzuki *et al*., 2021) proposed an optimization problem to maximize throughput in IEEE 802.11 networks using frame aggregation. They introduced a scheme that determined optimal subframe sets for both A-MPDU and A-MSDU, resulting in a significant improvement in throughput. Another work by (Yazid *et al*., 2016) discussed the frame aggregation techniques and their effects on 802.11ac system performance. It also emphasized the importance of cross-layer communications between the PHY and MAC layers to optimize wireless bandwidth utilization. Simulation results demonstrated the benefits provided by the frame aggregation in improving network performance. Guo *et al*. focused on optimizing IEEE 802.11-based wireless networks, specifically for Linear Wireless Ad-hoc Networks (Guo *et al*., 2022). The study identified the impact of the linear multi-hop characteristic on frame aggregation and the RTS/CTS handshake. Based on this analysis, a variable frame aggregation method and an adaptive RTS/CTS control algorithm were proposed to improve network performance in Linear-WANETs. Simulation results validated the effectiveness of the algorithm, demonstrating the significance of adjusting frame aggregation and RTS/CTS mechanisms to enhance overall system performance. Using simulations, the authors of (Khalil *et al*., 2020) demonstrated that the 802.11ac standard could achieve throughputs of around 600 Mbit/s, approaching the data rates specified in the IEEE 802.11ac standard. The study presented the performance of hybrid frame aggregation, which achieved higher throughputs compared to A-MPDU or A-MSDU aggregations. Additionally, the study analyzed the most suitable modulation and coding schemes based on the distance between the station and the access point, finding that QPSK modulation performed better than 256-QAM for longer ranges.

MATERIALS AND METHODS

The Jemula 802.11ac simulator was used to assess the various aspects of 802.11ac (Jumela Team, 2016). It is an open-source Java library that serves as an event-driven stochastic simulation kernel for real-time systems. The simulator comprises three primary packages: kernel, statistics, and plot. Our simulation involved different channel configurations (20 MHz, 40 MHz, 80 MHz, and 160 MHz) and examined various modulation schemes, including QPSK, 16-QAM, 64-QAM, and 256-QAM. We also investigated the impact of varying the number of spatial streams (1, 2, 4, and 8). Table 1 summarizes the physical and MAC layer parameters (IEEE, 2013) as well as the frame aggregation parameters employed in the simulation. Multiple scenarios were created, with each scenario run for 20 seconds. The average values were obtained by executing every scenario for ten times to ensure the reliability and robustness of the obtained results.

Table:(1). Simulation Parameters.

Para.	Val.
Time of slot	9 µs
CW_{min}	16
CW_{max}	1024
$Prop_{Delay}$	1 µs
T_{SIFS}	16 µs
T_{DIFS}	34 µs
MAC Header length	36 bits
Max MSDU length	2304 bytes
Max MPDU length	11454 bytes
BLK_ACK length	64 bytes
ACK length	14 bytes
Min P_ HDR Time	40 µs
Max P_HDR Time	68 µs

RESULTS AND DISCUSSION

In this study, we intended to examine how various features implemented in 802.11ac impacted the overall throughput of the system. We assess the combined throughput of the network and evaluate the effects of these features utilizing different scenarios.

Scenario 1: Channel Bandwidt:

In order to investigate the impact of using broader channels, we vary the channel bandwidth, taking the values of 20, 40, 80, 160 MHz. The payload is also varied between 500 and 2000 octets. However, other parameters are fixed to focus only on the channel bandwidth effect. Modulation is fixed at 16-QAM, one spatial stream is used, and number of stations is set to 10. As shown in Figure 1, the system throughput increases by about 10 Mbps as the channel bandwidth is doubled. The increase in throughput can be interpreted easily when considering the formula of Shannon for channel capacity. That is when the bandwidth is widened, the channel can handle more data transfer, thus increasing the throughput. Nonetheless, another factor must be considered; the SNR, which plays a crucial role in the channel capacity formula.

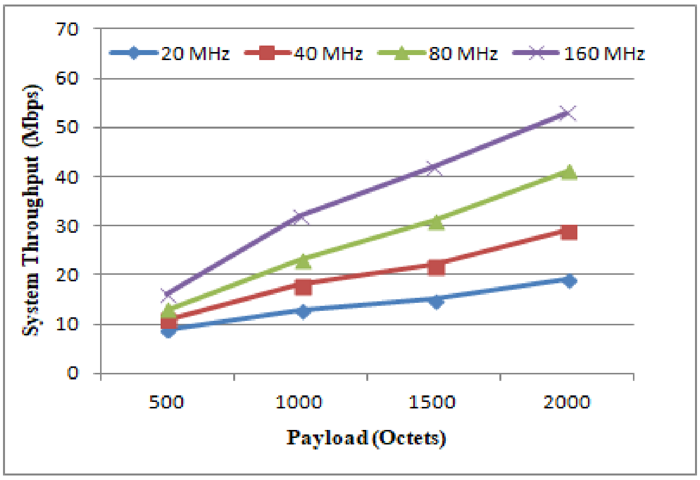

Figure: (1). Impact of channel bandwidth.

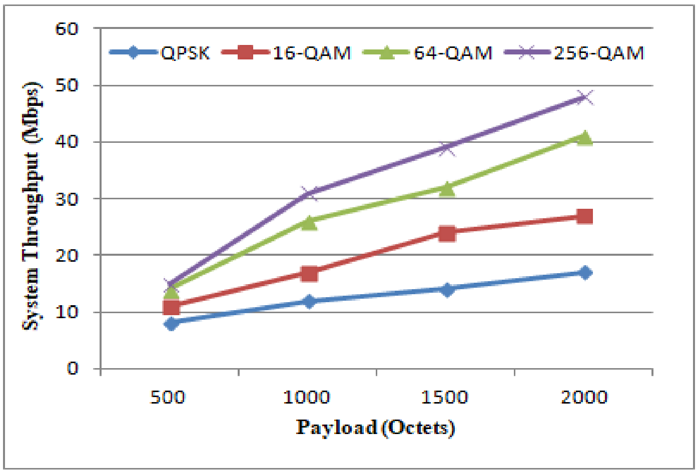

Figure: (2). Impact modulation schemes.

Scenario 2: Modulation Schemes

Modulation schemes are varied in this scenario (QPSK, 16-QAM, 64-QAM, and 256-QAM) to explore their influence on system throughput. For simplicity, we fix the spatial stream to one, the number of stations is ten, and the channel bandwidth is 40 MHz. The system throughput increases with the increase of modulation and coding schemes, as illustrated in Figure 2. It is clearly understood and expected result because as the modulation scheme increases, the number of bits per symbol increases. This leads to conveying more data bits, which consequently increases the system throughput. It is worth to mention that the 256-QAM is newly proposed by the 802.11ac, which achieved about 10 Mbps higher that of the 64-QAM.

Scenario 3: Spatial Streams

To evaluate the impact of spatial streams on system throughput, we varied the number of spatial streams with values 1, 2, 4, and 8 and plotted it against the payload size. We fixed the number of stations to 10, the modulation scheme is 16-QAM, and we used the 40 MHz channel. The system throughput is increased significantly with the increase of spatial streams, as depicted in Figure 3.

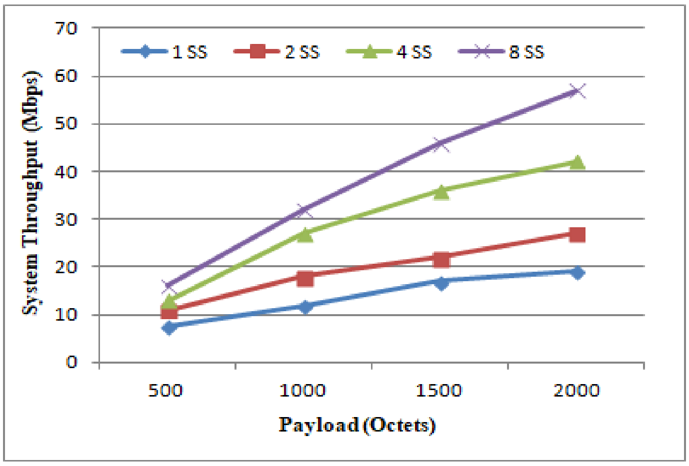

Figure: (3). Impact of spatial streams (SS).

It is clearly seen that the throughput is increased more than threefold when considering 8 spatial streams rather than 1 spatial stream. This is a great enhancement of the 802.11ac.

Scenario 4: MCS impact on average delay

Modulation and coding schemes are varied in this scenario to investigate the average delay in delivering data packets. Payload is fixed to 1500 octets, 20 MHz and 40 MHz channels are considered with spatial streams is set to 1. The average delay experienced by data transmission is decreased as the modulation and coding scheme increases, as shown in Figure 4. This decrement is observed in both channel bandwidths (20 and 40 MHz). However, the 40 MHz channel experiences a higher average delay than the 20 MHz channel. This can be attributed to the higher number of packets transmitted in case of using a wider channel.

Scenario 5: Impact of Frame Aggregation

The impact of employing the aggregate MPDUs is the aim of this scenario. We vary the number of the 2000 octets MPDUs that are aggregated into an A-MPDU. The 100 Mbps and 150 Mbps physical rates are used. The number of stations is fixed to 12 stations. The 40 MHz channel, along with 16-QAM is utilized. According to the results depicted in Figure 5, as the number of aggregated MPDUs increases, the throughput also increases. This can be taken as an evidence of the efficiency of frame aggregation mechanisms. This increase in throughput can be attributed to the reduction in the amount of overheads entailed by the MAC and PHY layers. However, after aggregating 64 or more MPDUs, the throughput reaches a plateau and no significant increase is observed. We argue that when dealing with larger frames, higher physical rates are needed to accomplish better enhancements in system throughput.

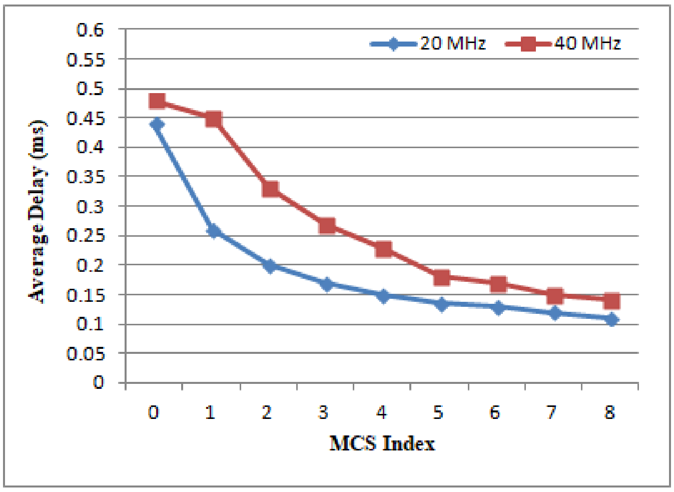

Figure: (4). Impact of MCS on average delay.

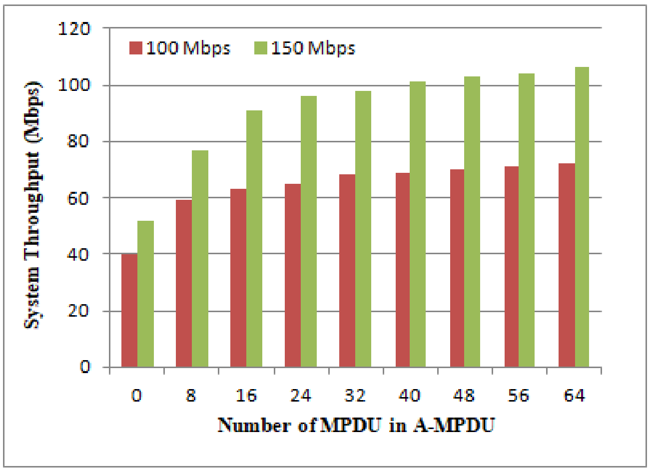

Figure: (5). Impact of Aggregate MPDU.

CONCLUSION

This study analyzed various aspects of the IEEE 802.11ac amendment. Our simulation scenarios focused on exploring wider channel bandwidths, modulation schemes, and multiple spatial streams, which are critical features of the amendment. The results demonstrated that these features significantly increase the system throughput, thereby improving overall performance. Additionally, we assessed the average delay as a metric to gain insights into the impact on data packet transmission. Based on simulation findings, it has been demonstrated that frame aggregation is a valuable approach for improving channel utilization. By reducing overhead, frame aggregation enhances the efficiency of the MAC protocol. However, it is essential to carefully consider the relationship between frame sizes and the physical data rate to ensure optimal performance.

Duality of interest: The authors declare that they have no duality of interest associated with this manuscript.

Author contributions: Ashraf Bourawy brought up the research topic and conducted the simulation scenarios. In addition, Abdalmunam contributed in setting up the simulation scenarios and parameters. Abdalmunam Abdalla surveyed the literature and wrote the introduction and related work. Ashraf Bourawy extracted the results and wrote the results and discussion part. Both authors contributed to the last version of the manuscript.

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REFERENCES

Aggarwal, S., Saha, S. K., Khan, I., Pathak, R., Koutsonikolas, D., & Widmer, J. (2022). Musher: An agile multipath-tcp scheduler for dual-band 802.11 ad/ac wireless lans. *IEEE/ACM Transactions on Networking*, *30*(4), 1879-1894.

Buta, R., Codau, C., Pastrav, A., Palade, T., Dolea, P., & Puschita, E. (2020, November). Performance evaluation of sub-band MVDR beamforming for IEEE 802.11 ac wideband signals. In *2020 International Symposium on Electronics and Telecommunications (ISETC)* (pp. 1-4). IEEE.

Chen, S. C., Li, C. Y., & Chiu, C. H. (2021, May). An experience driven design for IEEE 802.11 ac rate adaptation based on reinforcement learning. In *IEEE INFOCOM 2021-IEEE Conference on Computer Communications* (pp. 1-10). IEEE.

Coronado, E., Valero, V., Cambronero, M. E., & Orozco-Barbosa, L. (2023). Modelling, simulation and performance evaluation of the IEEE 802.11 e protocol with station mobility. *PeerJ Computer Science*, *9*, e1457.

De Carvalho, J. A. P., Pacheco, C. F. R., Reis, A. D., & Veiga, H. (2020). Performance Evaluation of IEEE 802.11 ac WPA2 Laboratory Links. *KnE Engineering*, 182-194.

ElKassabi, I., & Abdrabou, A. (2022, October). An Experimental Comparative Performance Study of Different WiFi Standards for Smart Cities Outdoor Environments. In *2022 IEEE 13th Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON)* (pp. 0450-0455). IEEE.

Fukuda, Y., Hatase, T., Satoh, A., Nakamura, Y., & Wada, S. (2022, April). Characterizing the basic performance of IEEE 802.11 ax using actual hardware measurements. In *NOMS 2022-2022 IEEE/IFIP Network Operations and Management Symposium* (pp. 1-4). IEEE.

Gast, M. (2012). *802.11 n: a survival guide*. " O'Reilly Media, Inc.".

Guo, Y., & Li, Z. (2022). Adaptive Frame Aggregation and Rts/Cts Joint Optimization for Ieee 802.11 ac Based Linear-Wanets. *Cts Joint Optimization for Ieee, 802*.

Gupta, A., Goel, H., Bohara, V. A., & Srivastava, A. (2020, December). Performance evaluation of integrated XG-PON and IEEE 802.11 ac based EDCA networks. In *2020 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS)* (pp. 1-6). IEEE.

IEEE. (2013). IEEE Standard for Information technology--Telecommunications and information exchange between systems—Local and metropolitan area networks--Specific requirements--

Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications--Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz. *IEEE Std 802.11ac(TM)-2013 (Amendment to IEEE Std 802.11-2012, as amended by IEEE Std 802.11ae-2012, IEEE Std 802.11aa-2012, and IEEE Std 802.11ad-2012)*, 1-425. doi:10.1109/IEEESTD.2013.7797535

Jemula Team. (2016). Jemula 802.11ac simulator. Retrieved from https://sourceforge.net/projects/hewsimulator/

Karmakar, R., Chakraborty, S., & Chattopadhyay, S. (2017). Impact of IEEE 802.11 n/ac PHY/MAC high throughput enhancements over transport/application layer protocols-a survey. *arXiv preprint arXiv:1702.03257*.

Khalil, N., & Najid, A. (2020). Performance analysis of 802.11 ac with frame aggregation using NS3. *International Journal of Electrical and Computer Engineering*, *10*(5), 5368.

Khan, G. Z., Gonzalez, R., Park, E. C., & Wu, X. W. (2017, February). Analysis of very high throughput (VHT) at MAC and PHY layers under MIMO channel in IEEE 802.11 ac WLAN. In *2017 19th International Conference on Advanced Communication Technology (ICACT)* (pp. 877-888). IEEE.

Kolahi, S. S., Shaheen, T., Aderson, E., Aljadani, R., & Ceyddique, A. (2023, January). IEEE 802.11 ac WLAN Analysis in 160Mhz Channel. In *2023 International Conference on Information Networking (ICOIN)* (pp. 190-193). IEEE.

Muhammad, S., Zhao, J., & Refai, H. H. (2021, March). An empirical analysis of IEEE 802.11 ax. In *2020 International Conference on Communications, Signal Processing, and their Applications (ICCSPA)* (pp. 1-6). IEEE.

Natkaniec, M., & Bieryt, N. (2023). An Analysis of the Mixed IEEE 802.11 ax Wireless Networks in the 5 GHz Band. *Sensors*, *23*(10), 4964.

Rochim, A. F., Harijadi, B., Purbanugraha, Y. P., Fuad, S., & Nugroho, K. A. (2020, February). Performance comparison of wireless protocol IEEE 802.11 ax vs 802.11 ac. In *2020 international conference on smart technology and applications (ICoSTA)* (pp. 1-5). IEEE.

Stojanova, M., Begin, T., & Busson, A. (2021). A Markov model for performance evaluation of channel bonding in IEEE 802.11. *Ad Hoc Networks*, *115*, 102449.

Suzuki, K., & Yamazaki, S. (2021). Throughput maximization based on optimized frame-aggregation levels for IEEE 802.11 WLANs. *IEEE Communications Letters*, *25*(5), 1725-1728.

Tuifaiga, A. A., Ram, P. A., & Kolahi, S. S. (2021, December). Performance comparison of IPv6 in 802.11 ac WLAN in Windows and Linux environment. In *TENCON 2021-2021 IEEE Region 10 Conference (TENCON)* (pp. 799-804). IEEE.

Yazid, M., Bouallouche-Medjkoune, L., & Aïssani, D. (2016, September). Performance Study of Frame Aggregation Mechanisms in the New Generation WiFi. In *VECoS* (pp. 85-92).