WIRELESS EVOLUTION: IEEE 802.11N, 802.11AC, AND 802.11AX PERFORMANCE COMPARISON

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ABSTRACT

The widespread adoption of IEEE 802.11 WLANs is attributed to their inherent mobility, flexibility, and cost-effectiveness. Within the IEEE 802 working group, a dedicated task group is diligently advancing WLAN technologies, particularly tailored for dense network scenarios. Amidst these advancements, the 802.11ac protocols have emerged as a preferred choice, delivering superior data transfer rates compared to the preceding 802.11n standard. Significantly, the sixth-generation wireless protocol, IEEE 802.11ax, has been introduced, showcasing enhanced performance capabilities that outpace its fifth-generation predecessor, 802.11ac.In this pioneering investigation, we engage in an in-depth simulation-based scrutiny of prominentWLAN protocols—namely, IEEE 802.11n, IEEE 802.11ac, and the cutting-edge IEEE 802.11ax. Our exhaustive analyses traverse a spectrum of critical metrics, encompassing throughput, coverage, spectral efficiency, Tx/Rx gain, and Tx/Rx power.In a single-user and SISO scenario, both 802.11ac and 802.11ax outperform 802.11n. Significantly, 802.11ax surpasses the previous 802.11n/ac standards, highlighting substantial advancements in wireless performance.

KEYWORDS

WLANs,IEEE 802.11n, IEEE 802.11ac, IEEE 802.11ax, SISO, NS-3 simulator.

1. INTRODUCTION

In the ever-evolving landscape of wireless communication standards, the IEEE 802.11 family has played a pivotal role, shaping the way we connect and communicate. Among its notable iterations are 802.11n, 802.11ac, and the upcoming 802.11ax, each introducing innovations to meet the escalating demands of wireless networks. Wireless standards, including IEEE 802.11n, 802.11ac, and the upcoming 802.11ax, have transformed communication. Introduced in 2009, 802.11n enhanced data rates with MIMO technology. To cater to increasing wireless demands, IEEE 802.11n is extensively employed in WLANs, incorporating technologies such as MIMO, 40 MHz bonded channels, frame aggregation, and block acknowledgment, elevating data transfer rates to 600 Mbps [1][2][3]. In 2013, 802.11ac prioritized enhanced throughput via broader channels and advanced MIMO. IEEE 802.11ac delivers accelerated and versatile performance, achieving speeds of 6.9Gbps with 160MHz channels and 8X8 MIMO, establishing robust connections from users' devices to the Internet [4]–[6].

In anticipation of evolving network needs, 802.11ax strives for heightened efficiency and data rates, especially in dense environments. The transformation of the IEEE 802.11 standard led to the advent of IEEE 802.11ax, addressing specified concerns by enhancing throughput and raw bit rate capabilities. This protocol brings significant improvements to network performance and efficiency, aligning with the requirements of modern communication systems. Introducing expanded QAM constellation sizes (up to 1024) and crucial MAC layer mechanisms like

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OFDMA, MU-MAC, downlink, and uplink MU-MIMO, OBSS-PD, TWT, and MCS 10 and MCS 11 [7]–[12].

The improvements to the IEEE 802.11n/ac WLAN minimum AP configuration optimization technique were reported in [13]. To minimize the workload for throughput estimation model parameter optimizations, the throughput measurements minimization approach was described and in the AP setup optimization, the coordinate shift was taken into account as an optimization parameter. The efficiency of them was validated by extensive experiment findings in three different network domains. The article [7] summarizes IEEE 802.11ax technologies, confirming their effectiveness in improving user experience in high-density deployments. It successfully meets the single-user throughput requirements set by PAR, achieving a fourfold increase compared to legacy IEEE 802.11. The efficiency of Wi-Fi networks depending on the recently released IEEE 802.11ax standard is examined in [14]. Two situations are examined: one in which solely 802.11ax devices are used, and the other with a combination of legacy devices. The authors in [15] detailed the ns-3 implementation of the channel sounding process in the IEEE 802.11ax MAC layer. Simulation results are provided to illustrate the channel sounding process's overhead, serving as an initial assessment of its impact on network performance.

IEEE 802.11n improved wireless networks with higher data rates and enhanced coverage compared to previous standards, utilizing spatial multiplexing through MIMO for simultaneous data stream transmission and supporting up to four antennas, resulting in a significant capacity boost. Whereas, IEEE 802.11ac improved data rates with expanded channel bandwidth and higher-order modulation. It introduced Downlink Multi-User MIMO (DL MU-MIMO) for simultaneous transmission to multiple receivers through multiple spatial streams, enhancing multi-user beamforming [16]. The IEEE 802.11 working group established the IEEE 802.11ax Task Group (TGax) to enhance individual user performance in high-density areas and improve power efficiency for battery-powered devices. TGax developed the IEEE 802.11ax standard, focusing on redesigning legacy PHY and MAC layer protocols to enhance user experience in terms of fairness, delay, and throughput in high-density networks [16]–[18]. Authors in [19] highlight the necessity for next-gen WLAN protocols, summarizing ongoing standardization within TGax. They delve into anticipated features and challenges in designing PHY and MAC for the IEEE 802.11ax amendment.

This paper uniquely stands out by providing a comprehensive comparison of WLAN standards. While previous works often focused on comparing either n and ac or ac and ax, our paper distinguishes itself by thoroughly evaluating and comparing n, ac, and ax simultaneously. In this paper, we conduct a comprehensive performance evaluation of 802.11n, 802.11ac, and 802.11ax WLANs using ns-3 simulations. Our analysis covers critical features, including Maximum Throughput, the Influence of Doubling Channel Width on Throughput, the Impact of Tx/Rx Gain on Throughput, and a Comparative Assessment of TCP vs. UDP Throughput.

We structure the paper into the following sections: Section 2 covers Related Work, followed by Section 3, which presents an overview of IEEE 802.11n/ac/ax technologies. This section also addresses Crafting Simulation Environment and Proposing Methods and Framework for Research Methodology. Moving on to Section 4, we engage in a comprehensive discussion of results, concluding with Section 5, where we summarize our findings.

2. RELATED WORK

Nowadays, a significant amount of academic research is focused on using simulation approaches to investigate different comparisons of the 802.11 standards in wireless local area networks (WLANs). A brief overview of important earlier research that is pertinent to our issue is given in this section.

In the study [20] , the authors examined diverse connection attributes of 802.11ax WLANs via NS-3 simulations, encompassing MCSs, bonded channels, GI, data encoding, antennas, data rates, link distance, Tx/Rx power, gain, and payload size. Additionally, they assessed their performance against 802.11ac, revealing NS-3's accurate support for 802.11ax capabilities and its superior performance across multiple scenarios.

In [1], the paper examined 802.11n WLAN features like MCSs, channel width, GI, frame aggregation, data encoding, antennas, data rate, and link distance using ns-3 and evaluated performance in scenarios with a single host connected to an AP and in an enterprise setup following IEEE 802.11ax guidelines. In [21], the study compared 5 GHz wireless protocols, IEEE 802.11ax Mcs-11 and 802.11ac Mcs-9, using NS-3 simulation. It focused on throughput with varying clients and payload sizes. In the simulation, parameters like spatial stream, channel width, modulation, coding scheme, guard interval time, and simulation time were set. Accessing a node with 512 clients, IEEE 802.11ax Mcs-11 initially had a longer delay than IEEE 802.11ac Mcs-9 but stabilized with higher throughput after 0.5 ms, surpassing IEEE 802.11ac. The authors in [7] summarized an article that surveyed IEEE 802.11ax technologies and evaluates their performance using a proposed simulation platform (SLISP), confirming substantial improvements in high-density deployment. It successfully met IEEE 802.11ax throughput requirements, surpassing legacy IEEE 802.11 fourfold. This study stands as the inaugural comprehensive evaluation of IEEE 802.11ax performance compliance. An introduced algorithm, TCP Small Queues (TSQ), limits the packets a TCP socket can enqueue, disrupting WLAN frame aggregation logic. This compromises throughput-latency tradeoffs in TCP variants. The paper [22], experimentally evaluates the issue, studying network efficiency with various TCP congestion controls and different TSQ policies.

The IEEE 802.11 standard, introduced by the IEEE LAN/MAN committee in June 1997, has undergone several upgrades to align with evolving communication technologies. In [23] ,the authors conducted a comparative analysis of IEEE 802.11a, b, g, n, and ac standards, examining their unique features. The authors in [24] , focuses on the upcoming IEEE 802.11ax standard and its impact on Wi-Fi network performance. It presents simulation results comparing the performance of newly introduced modulations with those from the IEEE 802.11n/ac network. The article in [25] outlines new enhancements in WLAN technology in four main categories: spatial reuse, temporal efficiency, spectrum sharing, and multiple-antenna technologies. It discusses potential benefits and drawbacks, along with key system-level improvements for next-generation WLANs. The author in [26] compared the performance of Wi-Fi IEEE 802.11ac and Wi-Fi IEEE 802.11n by measuring throughput and streaming rate for big data streaming. The performance test is categorized into four scenarios: 1) streaming data to a single device, 2) streaming data at varying distances, 3) streaming data to multiple devices, and 4) live broadcasting of big data streaming. The authors in [27] extend the single BSS Markov chain model to a multi-BSS model, incorporating STAs' interference range and carrier sense range effects on transmission and collision probabilities. The paper [28] offers a comprehensive review of the progression of Wi-Fi technology and its applications based on the authors' experiences over the past few decades. In [29] , the authors qualitatively and quantitatively evaluated WLAN network performance through real network tests and simulations, comparing current IEEE 802.11g networks with future IEEE 802.11ax networks. They focused on QoS assessment using simple metrics and scenario consideration for current and future WLAN network requirements. In the paper [30], the authors analyzed the coexistence of IEEE 802.11ax networks with legacy stations (802.11ac, 802.11n, and 802.11a). IEEE 802.11ax introduces features enhancing performance and capacity. The study focused on mitigating the negative impact of legacy devices in a mixed network environment. The aurthors in [31] assessed outdoor deployment of WiFi standards (802.11ax, 802.11ac, and 802.11n) by testing data transfer throughput. Two configurations are examined: a direct single-user connection and a relayed connection through an access point.

Expanding on our prior discussion, it's evident that many past studies inadequately examined performance metrics for IEEE 802.11n, IEEE 802.11ac, and IEEE 802.11ax protocols. This study specifically evaluates the performance of IEEE 802.11ax in single-user communication, comparing it to its predecessors, IEEE 802.11n/ac. Our findings highlight the superior performance of IEEE 802.11ax, positioning it as the optimal choice for practical WLAN installations.

3. IEEE 802.11N/AC/AX TECHONOLOGIES OVERVIEW

The term "Wi-Fi" encompasses the ever-evolving IEEE 802.11 standard, progressing through iterations to improve WLAN communication performance. Within the spectrum of WLAN standards, IEEE 802.11n introduces advancements beyond its predecessors (IEEE 802.11a/b/g/), while its successors, IEEE 802.11ac/ax, incorporate further features. Notably, IEEE 802.11ax stands out as the most popular standard among its predecessors, having been integrated into various devices, including Wi-Fi access points, routers, laptops, mobile devices, smart TVs, smart watches, and more.

Wi-Fi 4, defined by the IEEE 802.11n standard, transformed wireless networking by operating in dual bands—2.4 GHz and 5 GHz. Key features include the introduction of channel bonding for 20 MHz or 40 MHz wider bandwidth, significantly boosting data rates. The widespread adoption of MIMO technology with multiple antennas enhanced spatial diversity, leading to substantial overall data throughput improvements. Wi-Fi 4 supporting up to four spatial streams with MCS-0 to MCS-7, including 64-QAM. Ensuring backward compatibility, it set the stage for subsequent standards while delivering enhanced wireless range and throughput.

Wi-Fi 5 (802.11ac), surpassing its predecessor 802.11n, delivered elevated data rates and improved network performance. Operating in the 5 GHz frequency band, it introduced 80 MHz and 160 MHz channel bandwidths for enhanced data speeds. Include MU-MIMO for efficient operation in crowded environments, flexible MIMO technology with spatial stream configurations from 1x1 to 8x8, and beamforming for strengthened signal coverage. OFDM increased reliability by utilizing multiple subcarriers, and diverse MCS that is MCS-0 to MCS-9 with 256-QAM coding rates adapted to varying channel conditions.

Wi-Fi 6 (IEEE 802.11ax), the latest iteration, tackles challenges in connected devices, faster data rates, and network performance. Operating in 2.4 GHz and 5 GHz bands, it introduced OFDMA for optimized spectrum use. Up to 12 spatial streams enhance data streams between access points and devices. Multi-User Multiple Input, Multiple Output (MU-MIMO) and 1024-QAM elevate communication efficiency. Wi-Fi 6's with MCS-0 to MCS-11 adapt to diverse channel scenarios, with 1024-QAM responding to changing conditions. Target Wake Time (TWT) optimizes power usage, ideal for contemporary high-speed, densely connected networks. Extending from 802.11ac, Wi-Fi 6 introduces OFDMA and 1024-QAM, elevating data rates, network efficiency, and power management for evolving wireless communication demands.

3.1. Crafting Simulation Environment and Proposing Methods

Evaluating the IEEE 802.11 WLAN MIMO/SISO protocol involves using the NS-3 network simulator, a prevalent tool in academia. The "ns" suite, including NS-1, NS-2 [29], and NS-3 [30], traces its roots to Lawrence Berkeley National Laboratory in the mid-1990s. Funded by DARPA and NSS, NS-2 emerged in 1997, while NSF sponsored the development of NS-3 in 2003. Initiated in July 2006 in C++, NS-3 incorporates IEEE 802.11n/ac/ax components, simulating WLAN algorithms at various frequencies. Performance assessment includes WLAN formation scenarios, examining MCS choice, bandwidth, antenna configurations, and frame size, with simulation settings detailed below:

a. NS-3.37.
b. OS: Linux (Ubuntu 20.04.5LTS).
c. Hardware specifications:Lenovo ThinkPad P14s Gen 2: Intel Core i7-1165G7, 11th Gen, 4 cores, 8 threads, 2.80 GHz–4.70 GHz, 12B CPU Cache.

3.2. Framework For Research Methodology

The methodology encompasses simulating and testing the IEEE 802.11n/ac/ax-based WLAN with NS-3.37 on Linux. Post-installation, code files are adapted to assess performance factors such as data throughput, transmission range, MCSs, connection distance features, and antenna layouts. Additionally, variations in guard interval and channel bandwidth are considered. The determination of throughput involves employing a flow meter and a predefined equation.

a) Install NS-3.37 through the Linux terminal following the procedures outlined at https://www.nsnam.org/.
b) Once installation is complete, access the installation directory on your PC. Open the wifi-vht-network.cc and wifi-he-network.cc files located in ns-allinone-3.37/NS-3.37/examples/wireless.
c) Copy these files to the scratch folder for code adjustments and open them in an editor. The modified code section is detailed in the appendix.
d) Launch the altered code using the Linux Terminal by typing the command:./ns3 run scratch/filename, where "filename" represents the modified code file to execute.
e) Develop a simulation of an 802.11ac and 802.11ax-based WLAN with a single host and an AP.
f) Assess the impact of various factors on network performance, including data throughput, transmission range, MCSs (802.11n supports MCS-0 to MCS-7, 802.11ac supports MCS-0 to MCS-9, and 802.11ax supports MCS-0 to MCS-11), and link distance features by rate adaptation.
g) Consider the effects of increasing channel bandwidth for 802.11ac and 802.11ax (both supporting 20 MHz, 40 MHz, 80 MHz, and 160 MHz or 80+80 MHz bonded channels) and Guard Interval (GI) (3200ns, 1600ns, and 800ns for 802.11ax, and 800ns(long) or 400ns(short) for 802.11ac).
h) Determine throughput for each VHT and HE bit rate value using the flow monitor and Equation (1).

$$\text{Throughput} = \frac{\text{rxBytes} * 8}{\text{TimeLastRxpkt} - \text{TimeFirstRxpkt}} \qquad (1)$$

Here, the total number of received packets is denoted by rxBytes, while TimeLastRxPacket represents the timestamp of the final packet received. TimeFirstRxPacket indicates the initiation time of the flow monitor when it began receiving packets.

4. RESULTS DISCUSSION

In this section, we will discuss the research outcomes related to the performance of IEEE 802.11n/ac/ax protocols. Table 1 displays the common configuration parameters. The topics covered include the throughput impact at varying distances, the impact of channel bonding, the effect of varying Tx/Rx gain/power on throughput, and the performance of UDP and TCP flows on throughput. These aspects are explained in detail in the following sub-sections.

Table 1: Performance Parameter for IEEE 802.11n/ac/ax.

Parameter	IEEE 802.11n	IEEE 802.11ac	IEEE 802.11ax
Propagation Model	LogDistancePropagationLossModel	LogDistancePropagationLossModel	LogDistancePropagationLossModel
Mobility Model	ConstantPositionMobilityModel	ConstantPositionMobilityModel	ConstantPositionMobilityModel
Remote Station Manager	ConstantRateWifiManager	ConstantRateWifiManager	ConstantRateWifiManager
Packet Size	TCP/UDP,1472bytes	TCP/UDP,1472bytes	TCP/UDP,1472bytes
Tx/Rx Gain	1dBi[20]	1dBi[20]	1dBi[20]
Channel Width	40MHz	40MHz	40MHz
Guard Interval	800ns	800ns	800ns

4.1. Evaluating the Maximum Throughput for Various Distances of IEEE 802.11n/ac/ax

In this sub-section, we conduct an assessment to explore the relationships between link distance and throughput within the context of IEEE 802.11n (Wi-Fi 4), 802.11ac (Wi-Fi 5), and 802.11ax (Wi-Fi 6) protocols. Specifically, we examine the highest achievable MCSs for each protocol: MCS 7 for IEEE 802.11n, MCS 9 for 802.11ac, and MCS 11 for 802.11ax. Through the utilization of equation 1, we calculate the corresponding throughput. The results of this evaluation are presented in both Figure 1 and Table 1 for clarity and reference.

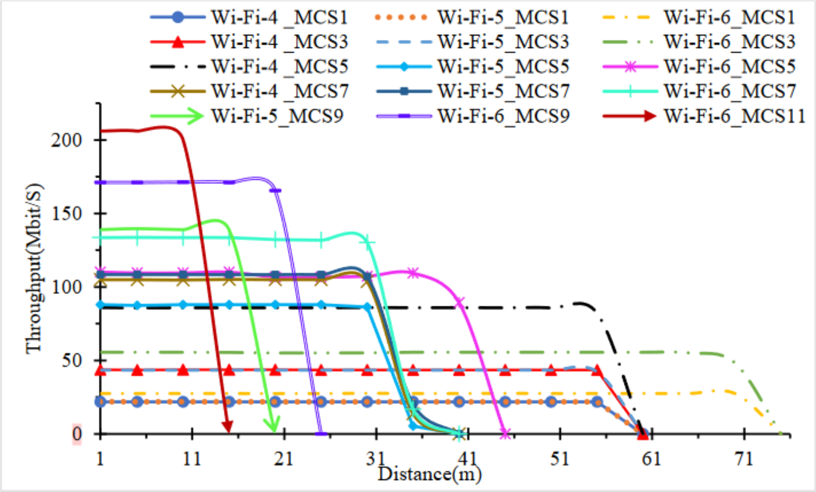

Figure-1:Scaling Throughput Peaks with Higher MCS

In our investigation, we observed that under MCS 7 for each standard, Wi-Fi 4 achieved the highest throughput at 105.155 Mbps. Wi-Fi 5 exhibited a modest increase of 3.13%, reaching 108.442 Mbps. In contrast, Wi-Fi 6 demonstrated a significant improvement, with a 27.04% increase, resulting in a throughput of 133.586 Mbps. When we compared Wi-Fi 5 and Wi-Fi 6 under MCS 9, Wi-Fi 5 still achieved the highest throughput at 139.657 Mbps. However, Wi-Fi 6 made a substantial leap with a 22.66% increase, reaching 171.307 Mbps. It's worth noting that Wi-Fi 6 also offers a 5-meter greater coverage compared to Wi-Fi 5 under MCS 9. Furthermore, when considering Wi-Fi 4 and Wi-Fi 6 as different protocols in terms of performance, Wi-Fi 6 delivered exceptional results, experiencing an incredible 96.01% increase and achieving a throughput of 206.114 Mbps under MCS 11.

4.2. Examining the Effects of Doubling Channel Width on Throughput

In this sub-section, we investigate the impact of channel bonding on throughput for IEEE 802.11n, 802.11ac, and 802.11ax standards, with the results presented in Figure 2 and the parameters detailed in Table 1. Our study considers a communication link deployment with a 5-meter distance between the Access Point (AP) and Station (STA).Our findings indicate that at a 20 MHz channel width, Wi-Fi 4 and Wi-Fi 5 exhibit similar throughputs of approximately 52.68 Mbps and 52.61 Mbps, respectively. In contrast, Wi-Fi 6 shows a remarkable 33.48% increase, reaching 70.32 Mbps compared to Wi-Fi 4.When we examine a 40 MHz (20+20) bonded channel width, Wi-Fi 4 achieves a throughput of 104.94 Mbps. Wi-Fi 5 sees a slight 3.34% increase, reaching 108.44 Mbps, while Wi-Fi 6 experiences a substantial 27.40% increase compared to Wi-Fi 4.

Moving to wider bonded channel widths of 80 MHz (40+40) MHz and 160 MHz (80+80) MHz, it's important to note that these options are not available for Wi-Fi 4. Both Wi-Fi 5 and Wi-Fi 6 provide additional bonded channels, significantly enhancing performance. Wi-Fi 5 achieves 212.99 Mbps, and Wi-Fi 6, following a 16.43% increase, delivers 247.99 Mbps. For the 160 MHz bonded channel, Wi-Fi 5 reaches 363.93 Mbps, with a further 12.31% increase in throughput, resulting in 408.72 Mbps for Wi-Fi 6.

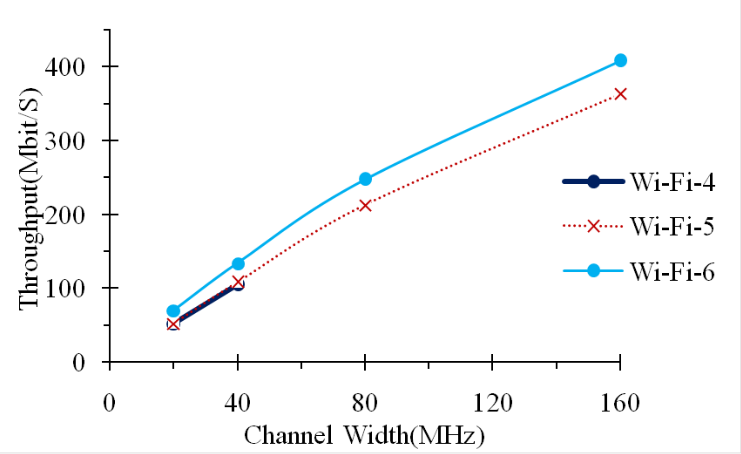

Figure-2: Doubling Channel Width's Impact on Throughput

In summary, our analysis demonstrates that Wi-Fi 6 consistently outperforms Wi-Fi 5 and Wi-Fi 4 across different channel widths and configurations.

4.3. Assessing the Throughput Impact on Tx/Rx Gain

In this sub-section, we study the impact of transmitting and receiving antenna gain on throughput for Wi-Fi 4, Wi-Fi 5, and Wi-Fi 6 protocols. Our assessment parameters are detailed in Table 1, and the performance results are displayed in Figure 3. During our surveillence, all three standards provided similar coverage for a 1 dBi gain, extending to approximately 40 meters. While Wi-Fi 5 showed quite better performance compared to Wi-Fi 4 in this scenario, Wi-Fi 6 significantly outperformed both Wi-Fi 4 and Wi-Fi 5.

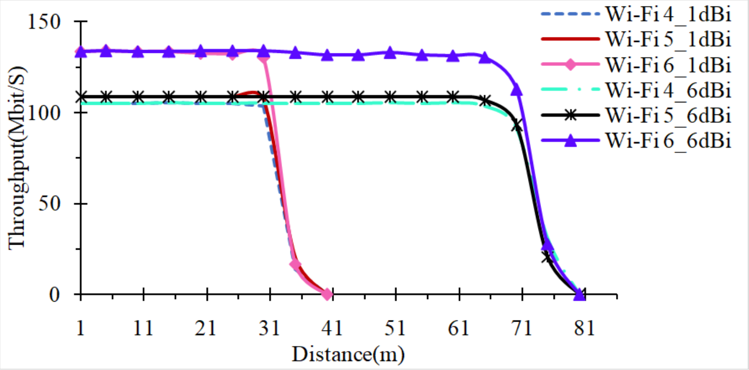

Figure-3: Assessing Tx/Rx Gain Impact on Throughput

Furthermore, when we increased the antenna gain from 1 dBi to 6 dBi, it enhanced the received signal strength (RSS), resulting in a stronger signal that covered an area of up to 80 meters for Wi-Fi 4, Wi-Fi 5, and Wi-Fi 6, providing better user performance. In this scenario, Wi-Fi 6 able to cover the 80-meter area with an average throughput of approximately 117.55 Mbps, while Wi-Fi 5 achieved 101.91 Mbps, and Wi-Fi 4 reached 95.91 Mbps.

4.4. Investigating the Tx/Rx Power Changing Impact on Throughput

In this sub-section, we delve into the impact of varying transmit and receive power levels on Wi-Fi throughput and assess the combined effects with transmit and receive antenna gain, as visualized in Figure 4. The simulation common parameters are outlined in Table 1. Our examination encompasses three prominent Wi-Fi protocols: Wi-Fi 4, Wi-Fi 5, and the newer Wi-Fi 6.

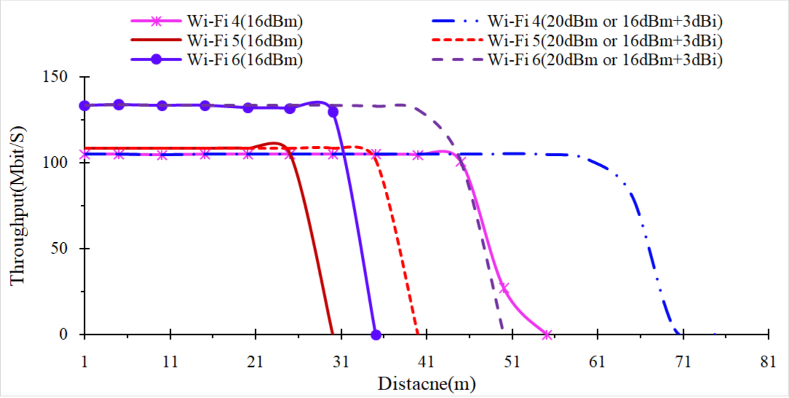

Figure-4: Throughput vs. Tx/Rx Power Analysis.

Focusing on the common factor, MCS 7, across these protocols, we analyze the consequences of adjusting Tx/Rx power levels, ranging from 16 dBm to 20 dBm. In the heart of our exploration, an intriguing pattern unfolded: Wi-Fi 4, fueled by 16dBm of power, showcased its prowess by blanketing an impressive 50-meter expanse while delivering a commendable 104.941 Mbps throughput. When comparing Wi-Fi 4 to its successors, Wi-Fi 5 exhibits a modest increase in throughput to 108.442 Mbps, albeit with a reduced coverage area from 50 meters to 30 meters. In contrast, Wi-Fi 6 not only offers a higher throughput at 133.586 Mbps but also extends its coverage to at least 35 meters.

Moreover, increasing the throughput from 16 dBm + 1 dBi to 20 dBm + 1 dBi yielded an increase in RSS, resulting in expanded coverage areas. For Wi-Fi 4, this increase stretched to 70 meters, while Wi-Fi 5 reached 40 meters, and Wi-Fi 6 elegantly spanned 55 meters. Fine-tuning these parameters proved to be an essential factor in optimizing the performance of each Wi-Fi protocol, particularly when addressing challenges such as signal coverage, interference, and overall network reliability. Remarkably, the combination of 16 dBm Tx/Rx power and 3 dBi antenna gain (16 dBm + 3 dBi) was found to deliver comparable performance to the 20 dBm Tx/Rx power with a mere 1 dBi gain.

4.5. TCP vs. UDP Throughput Comparison

In this sub-section, we will analyze the throughput performance of three widely used wireless protocols: Wi-Fi 4, Wi-Fi 5, and the relatively new Wi-Fi 6 for both Transmission Control Protocol (TCP) and User Datagram Protocol (UDP). TCP and UDP are fundamental networking protocols, each designed for specific use cases. TCP, being a connection-oriented protocol, is chosen when reliability is crucial. It establishes a connection, checks for errors, and, if necessary, retransmits data to ensure reliable transmission. On the other hand, UDP is a connectionless protocol that emphasizes speed and reduced latency over reliability. Figure 5 displays the performance outcomes for the concurrent use of these three popular wireless protocols.

On our investigation, it’s clear that the wireless protocols: Wi-Fi 4, Wi-Fi 5 and Wi-Fi 6 for MCS7 provide the same coverage area that is 40 meters for both TCP and UDP which is displayed in Figure-5, but UDP outperforms TCP. Say, for Wi-Fi 4 the TCP throughput is 104.941 Mbps, experiencing a 16.36% increase, result in a UDP throughput of 122.144 Mbps. Similarly, for Wi-Fi 5 the TCP throughput is 108.442 Mbps, with a 12.59% increase in UDP throughput, reaching 122.091 Mbps, almost on par with Wi-Fi 4. Remarkably, Wi-Fi 6 not only excels in TCP but also in UDP, achieving 133.586 Mbps for TCP and experiencing a 14.53% increase, resulting in a UDP throughput of 152.996 Mbps. Notably, the UDP performance for Wi-Fi 6 is 24.44% and 25.31% higher compared to Wi-Fi 4 and Wi-Fi 5, respectively.

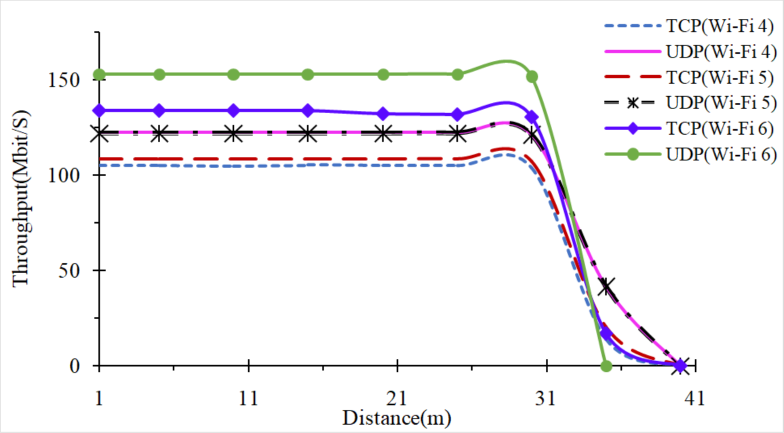

Figure-5: TCP vs. UDP Throughput Analysis.

Wi-Fi 6 demonstrates superior TCP and UDP throughput, making it a prime choice for high-speed data transmission. While Wi-Fi 4 and 5 offer similar performance, with UDP offering latency advantages. Wi-Fi 6 thrives in flexibility, serving diverse application requirements.

5. CONCLUSION

In this research, we are engaged in a simulation performance study that evaluates the key WLAN protocols, specifically IEEE 802.11n, IEEE 802.11ac, and IEEE 802.11ax. Our simulation findings indicate that in a single-user and SISO scenario, both 802.11ac and 802.11ax demonstrate superior performance compared to 802.11n. Remarkably, 802.11ax surpasses the earlier 802.11n/ac standards, exhibiting significant enhancements. Our analyses consider factors such as throughput, coverage, spectral efficiency, Tx/Rx gain, and Tx/Rx power. The results underscore the superior performance of the 802.11ax link over 802.11n/ac, making it well-suited for next-generation wireless LANs, offering improved user experiences and heightened network efficiency. Subsequent phases of our research employ machine learning techniques to identify RSS and link speed (LS) in WLANs, contributing to enhanced network reliability and performance.

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