Comparative Analysis of Wi-Fi 6, 6E, and 7 in Smart Campus NetworksCase

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Abstract— **This research examines the three Wi-Fi 6, Wi-Fi 6E, and Wi-Fi 6 technologies from the perspective of their potential to be used to change the way we learn in the universities of the future in relation to what we can expect to see from King Faisal University with its planned digital campuses for its future by 2030. The increasing dependence on the Internet and new forms of digital learning, along with an increasing number of large and small-scale IoT (Internet of Things) deployments, has created the need for wireless networks to provide consistent and reliable performance, large amounts of data transmission, and ultra-low latency. At the same time, the number of connected devices is rapidly increasing along with the number of data-heavy applications, which puts pressure on wireless technologies to support a high density of connections in high traffic environments, and provide support for critical to immediate or highly sensitive educational processes. The work performed as part of this study has evaluated Wi-6, Wi-Fi 6E, and Wi-Fi 7 on a number of key performance objectives including: Throughput - Latency - Jitter - Signal to Noise Ratio (SNR) - Energy Efficiency. Both the highest level of quality was achieved in each of these parameters in the performance of Wi-Fi 7, while Wi-Fi 6 and Wi-Fi 6E were unable to provide the same level of performance as Wi-Fi 7. Deterministically lower latencies (less than 50ms) through several different types of HD Video Streaming and VoIP were generated through automated testing and subsequently analyzed through MATLAB along with the mobile network simulator program called NS-3. The overall conclusion is that Wi-Fi 7 provides a determined level of low latency communication and better spectral efficiency than both Wi-Fi 6 and Wi-Fi 6E. Some significant examples where Wi-Fi 7 supports lower latencies than Wi-Fi 6 and Wi-Fi 6E. Examples of these features include MLO and 320 MHz channels, both of which provide a significant increase in performance over previous generations of Wi-Fi. Wi-Fi 7 is a foundational component of the next generation's distributed university wireless networks that enable schools to support the deployment of AR/VR technologies, facilitate timely decision making using real-time technology, and serve as a backbone for the growing number of sensor devices used as part of IoT networks. Moreover, given the information gained from this research, KFU has created opportunities for KFU to provide support for the development of new, high-speed wireless systems that can be utilized by their smart campuses.**

Keywords— Wi-Fi 6, Wi-Fi 6E, Wi-Fi 7, Smart Campus, KFU 2030, Latency, Jitter, Throughput, NS-3 Simulation, IoT

I. INTRODUCTION

The speed at which higher education is undergoing digital transformation has created a need for wireless connectivity to be a key component of many modern smart campus ecosystems. As colleges and universities continue to deploy cloud-based learning platforms, enhanced AR & VR applications, advanced smart classes, and extensive IoT sensor networks, there is an increasing requirement for stable, high-speed, and low-latency Wi-Fi networks. The 2030 smart campus modernization plan for King Faisal University also expresses the importance of implementing state-of-the-art Wi-Fi technology that provides the infrastructure for supporting data-intensive education-related activities, real-time analytics and critical service delivery. Therefore, emerging Wi-Fi standards must be assessed to evaluate their suitability for meeting the quality standards of future educational environments. The evolution of IEEE 802.11 wireless technologies can be summarized in three main advancements: Wi Fi 6, Wi Fi 6E and Wi Fi 7. Each upgrade has made significant improvements to the efficiency, reduction of congestion and placement of devices at higher device density. The use of OFDMA, MU-MIMO and BSS Colouring by Wi-Fi 6 resulted in optimized use of the available radio waves in very busy environments (e.g. lectures halls and student centers). The additional use of the 6 GHz spectrum by Wi-Fi 6E allows for the use of wider channels, lower levels of interference, and ultimately better performance for high bandwidth applications. Wi-Fi 7 introduces new features such as Multi-Link Operation (MLO), 4K-QAM, and 320 MHz channel widths to provide deterministic latency and greater throughput that will be required by advanced smart campus applications. Wireless workloads in higher education institutions have changed dramatically with the rise in mobile devices and the types of wireless equipment utilized in this environment. Wireless workloads can include a variety of functions such as video conferencing, using virtual labs, monitoring energy consumption and reducing the energy consumption of devices through the use of Internet of Things (IoT) devices, and allowing devices to autonomously monitor energy usage patterns. Because of the complexity of the multiple generations of the 802.11 Wi-Fi standard, to understand how each generation has evolved, and how all of the previous generations of Wi-Fi have evolved, it is imperative to run every generation of Wi-Fi under real academic or business conditions. To help KFU, this paper compares Wi-Fi 6, Wi-Fi 6E and Wi-Fi 7 on throughput, latency, jitter, signal to noise ratio and energy efficiency. In addition to using lab-level testing, we also used NS-3 simulations to test the capabilities and limitations of Wi-Fi under the influence of simulated interference, congestion and multiple users in a dense environment to mimic what will occur in actual operational use of Wi-Fi in KFU as a smart campus application. The findings of this comparison will guide KFU on how to better deploy its future strategies for wireless services. In addition, the findings will provide a framework for supporting planned educational and operational service requirements of KFU through the comparison of each Wi-Fi standard and help identify the strengths and weaknesses of each of the Wi-Fi standards.

II. Background and Related Work

As the popularity of wireless communication continues to expand rapidly, it, in turn has caused the IEEE 802.11 (also known as Wi-Fi or WLAN) standards to expand rapidly as well, due primarily to the more significant amount of data being transferred through outdoor locations (overload) and the emergence of new low-latency time-sensitive applications on these systems. Wi-Fi 6/802.11ax has introduced several features to alleviate some of the challenges created by the increasing number of users/devices sharing access to one or more channels (multi-user). Specifically, Wi-Fi 6/802.11ax introduced important improvements in spectral efficiency and overall performance to provide enhanced broadband to multiple users, equipped with the necessary hardware for utilizing the benefits of many features inherent in Wi-Fi 6 such as: OFDMA (Orthogonal Frequency Division Multiple Access) which partitions the broadband into smaller resource blocks of more efficient use of the frequency spectrum; MU-MIMO (Multi-User Multiple Input and Multiple Output) which allows multiple users to communicate simultaneously with a single access point; and BSS Coloring is used as a way to differentiate between multiple BSS's that are in close proximity and therefore subject to mutual interference. Liu & Choi's experiments demonstrate that the introduction of these features have resulted in an increase in throughput and reduced contention for access to the medium (spectrum) when a significant number of devices are trying to access the same access point, situations frequently occurring on college campuses, as well as in environments utilizing smart learning (e.g., smart classrooms). Wi-Fi 6E has increased the performance capabilities of wireless technology to include the use of the 6 GHz frequency range, which allows for much more bandwidth and significantly less interference from legacy Wi-Fi technologies. As a result of introducing the new 6 GHz channels, Wi-Fi 6E provides opportunities for the use of more sophisticated modulation techniques, resulting in more stable latency in transferring large amounts of data, such as during Web-based training and virtual classrooms. Research conducted by Mozaffariahrar et al. (2022) concluded that because of the clean (less crowded) communication methods and higher number of channels, Wi-Fi 6E provides significantly greater levels of Quality of Service (QoS) when operating in high-density environments. The benefits of using Wi-Fi 6E technology will ultimately depend on the availability of compliant devices as well as regulations regarding the use of the 6 GHz frequency range. The term "802.11be" also known by the name "Wi-Fi 7," represents the newest version of the Wireless Local Area Network (WLAN) technology and incorporates many enhancements to both the Layer 1 (Physical) layer as well as the Layer 2 (Media Access Control) layer of the IEEE (Institute of Electric and Electronic Engineers) WLAN protocols. These enhancements allow for predictable low latency communication and extremely high-speed data transfer (from one gigabit to many gigabits).With Multiple Link Operation (MLO), Wi-Fi 7 introduces a new way for all Bluetooth devices to connect with each other concurrently on multiple frequency bands, meaning device owners can connect their devices using wireless technology while minimizing their wait time for an accepted Bluetooth connection from another Bluetooth device and providing superior MLO user experience by reducing the amount of interference and congestion. MLO is only one of the advancements made by Wi-Fi 7; it also includes increased bandwidth (320 MHz/channel), new, faster modulation techniques (4K-QAM), and advanced methods for distributing bandwidth among users of the system. In their study published in 2024, Chen & colleagues show significant increases in both throughput growth rates and consistency of network response times with the Wi-Fi 7 system relative to previous versions of Wi-Fi. Wi-Fi 7 will likely provide a new foundation. Existing scholarly work has detailed aspects of the individual capabilities of the Wi-Fi 6, 6E, and 7 wireless standards, but the majority of such studies focus on the development of individual wireless standards in isolation or under theoretical ideal test scenarios. There exists an identified gap in comparative studies incorporating both laboratory experimental testing and simulations to accurately represent actual smart campus operational requirements. In this research study, we are attempting to fill this gap by conducting an extensive wireless performance evaluation based upon a diverse set of user traffic types, including Digital Video Streaming, Internet Telephony (VoIP), and Internet of Things (IoT) Bursts Based upon Testing Laboratory and Network Simulation. Our goal is to obtain a set of performance metrics for each of the Wi-Fi Wireless Standards as well as to determine the strategic evolution of the Wireless Infrastructure Upgrade Required to Support the Implementation of Smart Campus Transformation for Efficiency, Effectiveness, and Reliability in 2030 at King Faisal University.

III. General Overview

This study examines the performance of Wi-Fi 6, Wi-Fi 6E, and Wi-Fi 7 technologies in the context of smart campus networks. It combines laboratory experiments and network simulations to assess their performance based on key metrics such as throughput, latency, jitter, signal-to-noise ratio (SNR), and energy efficiency.

The performance of Wi-Fi 6, Wi-Fi 6E, and Wi-Fi 7 was tested in a lab designed to simulate a smart campus. The tests included a variety of IoT devices and high-bandwidth apps like HD video streaming and VoIP. The network was set up to reflect real campus scenarios, with multiple access points and different levels of congestion, offering a more accurate picture of how these technologies would perform in the real world.

Equipment:

- Wi-Fi routers supporting 802.11ax (Wi-Fi 6), 802.11ax (Wi-Fi 6E), and 802.11be (Wi-Fi 7).
- IoT devices (e.g., sensors, smart devices) simulating a real-world campus environment.
- Traffic generation tools to simulate HD video streaming and VoIP calls.

the Use of Simulations

The performance of Wi-Fi 6, Wi-Fi 6E, and Wi-Fi 7 was tested in a lab designed to simulate a smart campus. The tests included a variety of IoT devices and high-bandwidth apps like HD video streaming and VoIP. The network was set up to reflect real campus scenarios, with multiple access points and different levels of congestion, offering a more accurate picture of how these technologies would perform in the real world.

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IV. METHODOLOGY

This study adopts a mixed methodology that combines practical laboratory experiments with NS-3 simulations to evaluate the performance of Wi-Fi 6, Wi-Fi 6E, and Wi-Fi 7 in a smart-campus environment. Both parts of the methodology were designed using the same traffic patterns and network conditions to ensure a fair comparison across all technologies.

A. Laboratory Test Setup

A controlled laboratory environment was created to reflect realistic wireless activity within a university campus. The setup included access points supporting 802.11ax (Wi-Fi 6), 802.11ax on the 6 GHz band (Wi-Fi 6E), and 802.11be (Wi-Fi 7).

A range of devices—IoT sensors, laptops, and mobile devices—was used to generate traffic workloads that represent common campus usage, such as HD video streaming, VoIP calls, and IoT sensor bursts.

The test area was arranged to resemble typical campus spaces, including classrooms, study zones, and crowded student areas. Throughout the experiments, measurements such as throughput, latency, jitter, and signal-to-noise ratio (SNR) were collected using MATLAB, Wireshark, and RF spectrum-monitoring tools.

B. NS-3 Simulation Framework

To extend the laboratory findings, NS-3 simulations were conducted to model scenarios that are challenging to reproduce physically, especially high-density and large-scale deployments. Each Wi-Fi standard was tested under identical conditions, including:

- Network topology
- Device density
- Traffic intensity
- Interference and congestion levels

These simulations provided additional insight into the behavior of each Wi-Fi generation under heavy load, complementing the real-world measurements taken in the laboratory environment.

C. Data Analysis

All results from both the lab experiments and the simulations were processed and compared across key performance indicators, including:

- Throughput stability
- Latency under varying loads
- Jitter behavior
- SNR performance
- Overall efficiency in dense and mixed-traffic scenarios

v. Experimentations

a. Simulation Environment and Tools

The system under consideration was evaluated using MATLAB, which is a well-regarded tool for modelling wireless communications. In addition to its capabilities and numerous built-in functions for analyzing performance and visualizing output data, the feature of flexibility made MATLAB an ideal choice of tool for this project. All simulations were conducted using a standard PC setup to assess wireless network performance and mobility.

b. Simulation Parameters and Performance Metrics

Several simulation parameters were identified to allow for an accurate assessment of the system under investigation, and some were considered as performance metrics. These performance metrics meet industry standards for measuring mobile and wireless networks; thus, it was possible to determine the effectiveness and reliability of the wireless network.

To determine the performance of the system under consideration, the following performance metrics were utilized:

Throughput: Mbps – the speed at which successful data can be transferred across the wireless network.

Latency: ms – the overall time from initial transmission of a packet to its reception.

Jitter: ms – how much variation there is in packet delays and thus helps assess the reliability of packet arrival times.

Packet Loss Ratio: – percentage (%) of packets that were unsuccessful in reaching their intended target during network transmission.

In addition, the simulation parameters were formulated based on user traffic patterns and usage (activity) levels, to replicate what may be expected in an operational mobile and wireless environment.

c. Experimental Scenarios

To evaluate the performance of the system under different conditions, numerous simulation scenarios were performed.

Scenario 1 - A single connection was established between a single user and the network to provide a baseline measurement of the performance of the network.

Scenario 2 - Multiple users simultaneously sent data to measure the capacity and scalability of the network.

Scenario 3 - Different traffic patterns were used to simulate different types of applications such as bulk data transfer and real-time communication. Multiple simulation iterations for each scenario were completed to produce statistically valid results and reproducible results.

d. Results and Discussion

Part Problem D: Results and Discussion. The results of each experiment were plotted in MATLAB to allow for comparison of the different performance metrics associated with each of the three experimental scenarios. The plots indicate that the suggested system provides good throughput and low latency when there is minimal to moderate traffic. However, like other wireless systems, there was an observable drop in performance as more than one user attempted to access a resource simultaneously. Therefore, this study supports the conclusion that this design is an appropriate candidate for building real-world wireless mobile networks.

vi. Conclusion

To determine how a wireless network will respond to different operating environments, this research evaluated it with a wide range of indicators in a simulated environment (MATLAB). Included in this evaluation were throughput; latency; jitter; packet loss, etc. The main findings from these experiments indicate that there is good reliability and quality of service (QoS) for the network regardless of the changing demand for services. This platform has excellent potential to be implemented into an actual wireless or mobile infrastructure. Future research will look at scaling the size of the network as well as developing dynamic mobility models and evaluating more sophisticated security measures and performance measures.

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