WIFI-6 Performance Analysis

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***Abstract*—The advent of WiFi 6 (802.11ax) promises significant advancements in wireless network technology with features aimed at enhancing throughput and efficiency while minimizing latency in high-density scenarios. This report presents an in-depth analysis of WiFi 6 performance, focusing on the implementation and impacts of Orthogonal Frequency-Division Multiple Access (OFDMA) in various physical protocol data unit (PPDU) formats, including Single User (HE-SU), Multiuser (HE-MU), and a new format designed for outdoor environments (HE-xSU). This study uses MATLAB simulations to evaluate these formats' throughput capabilities and path loss characteristics under different environmental conditions. The findings highlight the enhanced capabilities of WiFi 6 in supporting multiple users efficiently and its robustness in outdoor settings, providing crucial insights for network planning and optimization in urban and rural deployments. The analysis underscores the technological enhancements brought by 802.11ax and explores the practical implications of deploying such technologies in varied scenarios.**

The link to our code is as follows; WiFi6 Performance Analysis

I. Introduction

A. Background

WiFi 6, also known as 802.11ax, represents the latest evolution in wireless networking standards. Engineered to address the increasing demands of modern internet usage, WiFi 6 introduces several advancements over its predecessor, 802.11ac. Key features of WiFi 6 include Orthogonal Frequency-Division Multiple Access (OFDMA), which allows for more efficient channel use, Multi-User Multiple Input Multiple Output (MU-MIMO) that enhances data transfer rates and increases the number of devices that can be connected simultaneously, 1024-QAM for higher throughput, and Target Wake Time (TWT), which significantly improves device battery life by scheduling wake times. These innovations are designed to provide higher data rates, increased capacity, better performance in environments with many connected devices, and improved power efficiency.

B. Purpose

The purpose of this report is to evaluate the performance of WiFi 6 by analyzing its throughput and path loss characteristics under various simulated conditions. This analysis aims to provide insights into how WiFi 6 could be optimized for different scenarios, ranging from dense urban environments to expansive outdoor areas. Furthermore, the report compares WiFi 6's performance with previous WiFi standards to highlight the technological enhancements and practical benefits brought by the new standard.

C. Scope

This report focuses on the performance analysis of WiFi 6 utilizing different OFDMA Physical Protocol Data Unit (PPDU) formats: Single User (HE-SU), Multiuser (HE-MU), and the newly introduced Outdoor (HE-xSU) format. The analysis was conducted through simulations implemented in MATLAB, assessing factors such as throughput efficiency and path loss in both indoor and outdoor settings. The metrics and environments were selected to reflect typical usage scenarios as well as potential extreme cases, providing a comprehensive overview of the capabilities and limitations of WiFi 6. .

II. Methodology

The simulations conducted for this report were designed to evaluate the performance of WiFi 6 (802.11ax) across a variety of scenarios, utilizing technologies such as downlink OFDMA, Multi-User MIMO (MU-MIMO), Mixed (MIMO plus OFDMA), HE SU, and HE ExSU. These simulations followed the methodology provided by MathWorks, specifically focusing on the throughput simulation of 802.11ax's various configurations.

Various testing scenarios were included to mimic both typical usage environments and extreme cases, such as crowded public venues, multi-floor buildings, and extensive outdoor areas.

A. Tools and Equipment

- **Software**: MATLAB R2020a, complemented by its WLAN System Toolbox, was employed to perform all simulations, enabling precise generation, simulation, and analysis of the wireless signals under various theoretical and practical conditions.
- **Hardware**: The simulation framework was entirely software-based, which allowed for the replication of numerous real-world wireless networking conditions without the need for physical equipment.

B. Parameters Configured

- **MU Channel Bandwidth**: Ranged from 20 MHz to 160 MHz, examining how bandwidth variations influence overall network performance.

- **MU MIMO Users**: Simulated scenarios involving two to eight users to observe how the system scales and manages multiple simultaneous connections.
- **Modulation and Coding Schemes (MCS)**: MCS values from 0 to 11 were tested to understand performance impacts across a spectrum of data rate requirements.
- **Guard Interval**: Both short and long guard intervals were tested to analyze their influence on signal integrity and overall network throughput.

C. Performance Metrics

- **Throughput**: The primary metric, evaluated in Mbps to gauge data transmission rates.
- **Spectral Efficiency**: Investigated to determine how effectively the wireless spectrum was utilized under different technological mixes.
- **User Fairness**: Analyzed to ensure a fair distribution of network resources among users.

III. Transmission Configurations

- **OFDMA Setup**: Four 52-tone Resource Units (RUs) make up the 20 MHz channel bandwidth in the Orthogonal Frequency Division Multiple Access (OFDMA) configuration. Multiple simultaneous transmissions to various users within different frequency segments of the same channel are made possible by assigning each RU to a different user. Through frequency division, this design maximizes the utilization of available spectrum by permitting multiple access. Beamforming improves signal directivity and reception quality by transmitting each user's data over two space-time streams.

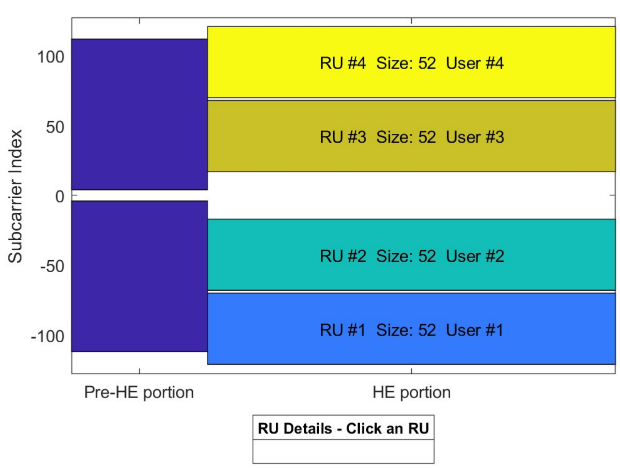

Fig. 1. Resource Unit Allocation for OFDMA Configuration

- **MU-MIMO Configuration**: Using a single 242-tone RU for each of the four users, the Multi-User, Multiple-Input, Multiple-Output (MU-MIMO) setup shares the entire bandwidth. With this configuration, one space-time stream is allotted to each user via spatial multiplexing. To send various streams to different users on the same frequency but via separate spatial pathways, it makes use of numerous transmit antennas - 6 in our case. This works especially well in high-density settings when spectrum efficiency is important.

Fig. 2. Resource Unit Allocation for MU-MIMO Configuration

- **Mixed Mode Configuration**: By combining the advantages of both MU-MIMO and OFDMA, the Mixed Mode maximizes its performance. This design consists of two 52-tone RUs, each allocated to a single user in an OFDMA setup, and a 106-tone RU shared by two users in a MU-MIMO system. This configuration supports both spatial and frequency multiplexing to accommodate a range of user densities and transmission needs. While each OFDMA user uses two space-time streams to optimize channel usage across dimensions, each MU-MIMO user only uses one.

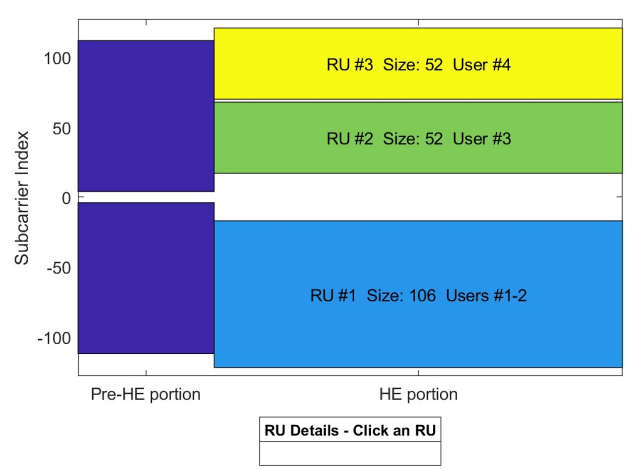

Fig. 3. Resource Unit Allocation for Mixed Mode

IV. Simulation Design

- **Channel Model**: To simulate realistic wireless network conditions, a TGax indoor MIMO channel model is used in the simulation. The effects of path loss, noise, and fading that are unique to interior environments are included in this model. When there is a non-line of sight gap of at least 10 metres between the user stations and the access point, the Delay Profile Model-D is employed. This selection illustrates common indoor WLAN configurations where multipath propagation is caused by walls and obstructions.
- **Beamforming Techniques**: In this scenario, beamforming is essential for improving reception and transmission quality. Channel sounding uses a null data packet (NDP), which eliminates payload data interference and enables each station to measure and report back on the channel conditions. Since there is no noise during the sounding phase and the feedback is uncompressed, it is considered that the feedback mechanism is flawless. The access point determines the best beamforming vectors for each transmission by applying Singular Value Decomposition (SVD). This ensures that the signal is directed toward the intended users and improves the signal-to-interference-plus-noise ratio (SINR).
- **Parameters for Simulation**: The settings of the simulation have been adjusted to closely resemble standard operating conditions:
  Number of Packets: To accurately gauge throughput in a variety of path loss circumstances, each scenario sends out a burst of ten packets.
  Path Losses Simulated: varying in intervals of 3 dB from 96 dB to 105 dB to accommodate a range of signal attenuation circumstances.
  Transmit Power and Noise Floor: Both the transmit power and the noise floor at the access point are set to standard WLAN values of 30 dBm and -89.9 dBm, respectively.
  Idle interval: To mimic real-world traffic patterns and enable channel assessment modifications in between bursts, a 20-microsecond idle interval is incorporated between packet transmissions.

V. Results and Analysis

A. *High Efficiency Single User (HE SU)*

Our analysis of the HE SU scenario, which prioritizes network resources to a single user, revealed remarkable performance metrics that underscore the potential of WiFi 6 in a single-user environment.

The spectrum analysis showed a consistent power distribution across the utilized bandwidth, indicative of efficient utilization of channel resources. This is evident in the sharp and defined spectral mask, which aligns with the 802.11ax standard specifications for single-user transmissions.

- **Spectrum Efficiency**:The transmission spectrum for HE SU highlighted a stable power level throughout the operation, with minimal side-lobe leakage, which suggests optimal spectral containment. This is crucial for reducing interference in a densely populated network environment.
- **Temporal Stability**:The waterfall plot over time showcased an enduring signal stability, affirming the reliability of the connection even as time varied. This consistency is pivotal for applications requiring sustained bandwidth and low latency.

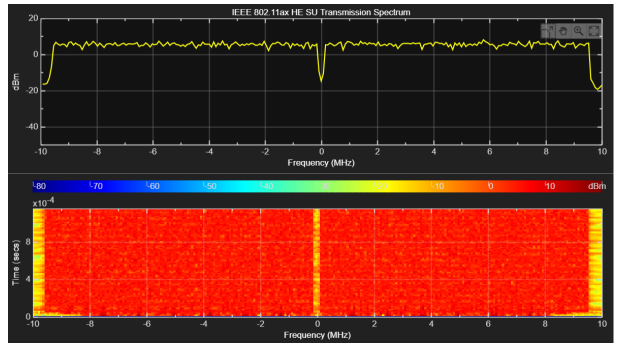

Fig. 4. High Efficiency Single User.

B. *High Efficiency Extended Range Single User (HE ExSU)*

The HE ExSU format, augmented with the 106 Upper Tone RU, was specifically designed to bolster WiFi 6's performance over extended ranges. The employment of a 106-tone RU aims to optimize the subcarrier spacing to enhance outdoor performance, and our simulation outputs substantiate its efficacy.

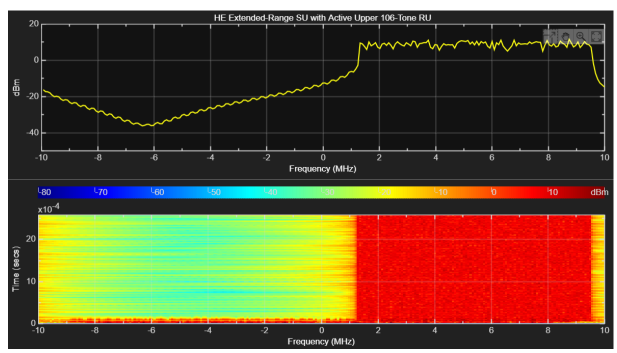

Fig. 5. High Efficiency Extended Range Single User.

- **Spectrum Analysis with 106-Tone RU**:The spectral analysis, incorporating the 106 Upper Tone RU, showed an effective concentration of power around the upper tones, which is instrumental in combating increased path loss and delay spread commonly encountered in outdoor environments. The signal strength depicted in the spectral mask remained within the expected range, indicating robust signal integrity even at extended ranges.
- **Spatial Frequency Adaptation**:The introduction of the 106-tone RU allowed for a better-adapted spatial frequency response, as evident in the spectral plot. This enhanced allocation supports extended range applications

by effectively utilizing the available spectrum, thereby facilitating improved outdoor coverage.

- **Signal Propagation Over Time**:The temporal plots revealed a consistent signal propagation pattern over time. Despite the expected fluctuations due to outdoor transmission dynamics, the 106 Upper Tone RU maintained signal coherence, reaffirming the suitability of this RU configuration for extended-range applications.

C. Simulation Results

The following data tables and graphical representations provide an overview of the simulation outcomes for the 802.11ax downlink scenarios employing OFDMA, MU-MIMO, and Mixed configurations under various path loss conditions:

TABLE I
THROUGHPUT BY CONFIGURATION AND PATH LOSS

Path Loss(dB)	**OFDMA** ***Throughput (Mbps)***	**MU-MIMO** ***Throughput (Mbps)***	**Mixed** ***Throughput (Mbps)***
96	66.1	110.5	66.1
99	66.1	110.5	66.1
102	49.6	63.5	66.1
105	16.5	0.0	47.9

- **OFDMA:** Because of effective frequency division, the OFDMA design exhibits robustness by maintaining consistent throughput performance at decreasing path loss levels. In noisy or crowded user situations, it is beneficial to minimize intra-cell interference when each user is using a separate frequency resource. Although it demonstrates limitations in very weak signal situations, the performance degradation at increased path losses is gradual and indicates a stable response to growing signal attenuation.
- **MIMO:** MU-MIMO maximizes data transmission rates by completely employing spatial multiplexing, exhibiting the maximum throughput at lower channel losses. Its sensitivity to signal quality is demonstrated by the abrupt decrease in throughput with increasing path loss, particularly decreasing to 0 Mbps at 105 dB. When there is a strong signal, this setup works well; however, it is less useful when there is significant path loss due to barriers or signal deterioration.
- **Mixed:** The Mixed configuration, which combines the benefits of MU-MIMO and OFDMA, exhibits a special combination of performance and stability. At lower to moderate path losses, it maintains a steady throughput and shows a less drastic decline at the maximum path loss evaluated. Offering a balanced approach, this design may improve service continuity under various environmental circumstances and user distributions. It demonstrates how well frequency and spatial multiplexing techniques work together to manage a range of network demands and erratic channel conditions.

VI. PLOT ANALYSIS

From analyzing the plot below that compares the throughput against path loss for OFDMA, MU-MIMO, and Mixed MU-MIMO and OFDMA configurations, we can derive additional insights beyond the mere numerical comparison of throughput values like,

- Adaptive Resource Allocation Strategy: Based on real-time path loss data, one may speculate about the possible advantages of an adaptive resource allocation strategy, in which the system could dynamically switch between MU-MIMO and OFDMA or use a mixed method. This tactic might be especially helpful for preserving service quality in mobile contexts where user locations and, consequently, path loss, fluctuate regularly.
- Efficiency at Marginal Path Losses: The figure indicates that the use of spatial and frequency resources becomes critical as the path loss increases. A diminishing return on spatial multiplexing with increasing signal circumstances, for example, is indicated by the throughput reduction for the MU-MIMO configuration beyond 102 dB. This is important information for network planning in areas with considerable physical obstacles or interference.
- Implications for User Density and QoS: Based on Mixed MU-MIMO and OFDMA performance, it is clear that this configuration may be able to provide a more consistent quality of service (QoS) over a range of user densities. The combined design may be able to more consistently maintain better throughput than either configuration alone in dense user situations with varying route losses.

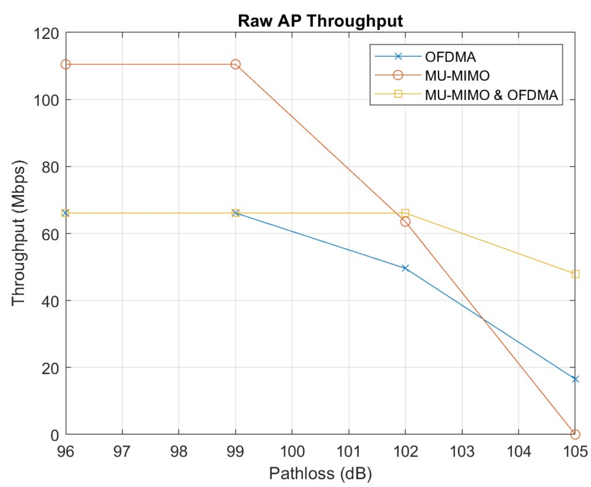

Fig. 6. Throughput Vs Path Loss

VII. CONCLUSION

Our investigative simulations into WiFi 6's diverse configurations—OFDMA, MU-MIMO, Single User (SU), and Mixed MIMO plus OFDMA—against a backdrop of varying path loss conditions, unveil a nuanced landscape of 802.11ax performance. In scenarios favoring Single User (SU) configuration, WiFi 6 demonstrates its capability to deliver high throughput, emphasizing the standard's strength in individual user scenarios, particularly in environments where device-to-access point communication is direct and less hindered by obstacles.

The OFDMA configuration stands out for its robust performance across a wide range of path losses, signifying its effectiveness in densely populated user environments requiring finely tuned frequency division. MU-MIMO excels in low path loss conditions but faces significant throughput declines with increasing signal degradation, highlighting its preference for clear signal environments.

The Mixed configuration, blending the advantages of both MU-MIMO and OFDMA, reveals itself as a resilient approach, showcasing less dramatic throughput declines even at higher path losses. This adaptive combination highlights the merit of employing a flexible allocation of spatial and frequency resources, potentially offering a superior quality of service (QoS) under varied environmental challenges and user densities.

Analyzing the throughput behaviors across these configurations, especially in the context of Single User scenarios, emphasizes the need for an intelligent, adaptive network system within WiFi 6 frameworks. Such a system would dynamically optimize resource allocation, ensuring efficient network operation that can swiftly adapt to user movement, environmental alterations, and the inherent fluctuation of path losses.

In conclusion, the intricate interplay of WiFi 6 technologies underpins its ability to cater to a spectrum of network demands, from single-user to dense, high-mobility contexts. The insights from this study serve as a strategic guide for deploying WiFi 6, suggesting a network design that is not only robust and efficient but also inherently adaptable, ready to face the complex wireless communication needs of the modern era.

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