# Introduction

This research explores distributed rendering in XR systems, emphasizing VR environments for collaborative experiences. It examines scenarios where users with VR headsets interact in a virtual space, sending visual data to a central server via Wi-Fi. The server processes and integrates these inputs into a unified 3D environment, then redistributes it to users, ensuring a seamless 360-degree view. This approach aims to enhance real-time immersion by leveraging high bandwidth, low latency, and low power wireless communication, crucial for effective and accessible XR applications. The uplink distributed rendering scenario is a multiple-input-multiple-output (MIMO) multiple-access channel (MAC). The multiple-access channel is a fundamental model in communication, characterizing a situation where multiple transmitters are sending information to a single receiver. The uplink MIMO system with additive white gaussian noise (AWGN) can be expressed as:

Where is the Gaussian noise, and , are the transmitted and received signals, respectively.

Two primary challenges emerge as significant roadblocks for distributed XR rendering: the uplink bandwidth constraint and the edge devices’ considerable power consumption, which have inherent resource constraints. XR heavily relies on Head-Mounted Displays (HMDs), which necessitate stringent adherence to power and weight limitations. The imperative to optimize the Quality-of-Experience (QoE) mandates that HMDs be lightweight and compact. Consequently, this necessitates the offloading of substantial computing and storage tasks to external processing units, such as computers or cloud-based servers. Complex three-dimensional imagery transmission, a cornerstone of these VR applications, necessitates data rates reaching upwards of 500 Mbps or more per user. However, existing wireless methods’ capabilities, even those conforming to the latest Wi-Fi standards (802.11b/g/n/ac/be) , are insufficient for such high data rate demands, especially when the number of users’ antennas exceeds the number of access-point (AP) antennas, and/or the channel is low rank. This issue complicates transmitting uplink 3D image data. Additionally, the current achievable data rates through Wi-Fi, while substantial, lead to prohibitive power consumption levels. This scenario is particularly challenging for devices like Augmented Reality (AR) glasses, where limited power resources are a critical constraint. These limitations significantly impede XR systems’ development and practical realization suggest improved real-time data transmission for distributed VR rendering.

This work addresses these challenges by optimizing the data rates and the power consumption using a non-linear generalized decision feedback equalizer (GDFE) . These systems achieve the maximum possible data rates for each of the users in a VR setting, considering factors such as the channel impulse responses between the users and the AP, the number of antennas, the distance from the AP, and the transmit signal-to-noise ratio at each user’s device. In a converse approach, given each user’s prerequisite minimum data rates, the objective minimizes the edge devices’ power consumption. Tthe proposed GDFE-based solutions achieve much higher data rates with much lower power consumption, compared to current Wi-Fi standards, using the time-sharing (vertex sharing) technique. This dual optimization strategy also overcomes the prevailing bottlenecks in uplink communication capacity, thereby paving the way for high-fidelity XR systems’ development and deployment.

A presented series of extensive experiments evaluate the proposed system’s performance for Extended Reality (XR) applications. These experiments encompass a broad parameter range, which includes channel impulse responses, the number of users involved, the quantity of antennas per user, requisite minimum data rates, signal-to-noise ratio (SNR), and the spatial distances from the access point (AP). The proposed GDFE-based approach augments the traditional Orthogonal Frequency Division Multiplexing (OFDM)-based Wi-Fi methods.

These GDFE results demonstrate a significant achievable-rate increase, reaching upwards of 500 Mbps per user antenna. This figure notably surpasses the data rates feasible through traditional Wi-Fi methodologies. Furthermore, results find a substantial energy-saving improvement. Specifically, for a given minimum required data rate, a threshold that traditional Wi-Fi can accomplish, the proposed algorithm achieves this benchmark with an order of magnitude lower user-device energy consumption. This finding is particularly impactful, considering the constraints of power resources in edge devices such as Augmented Reality (AR) glasses, commonly employed in XR systems.