Poster: Dissecting 802.11ac Performance - Why You Should Turn Off MU-MIMO

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ABSTRACT

While the recent Wi-Fi standard 802.11ac achieves Gb/s theoretical capacity with Multi-User MIMO (MU-MIMO) technology, several studies reported that throughput of 802.11ac in practice is far from Gb/s link speed. We investigate the downlink throughput of Wi-Fi systems with commercially available 802.11ac products in multiple indoor environments to reveal the throughput of MU-MIMO system that user experiences in practice. From our experiments, Single-User MIMO (SU-MIMO) outperformed MU-MIMO at every experimental environments. We further provide analysis on our experimental results considering channel sounding overhead, user grouping, environmental impact, and transmission mode selection.

CCS CONCEPTS

• **Networks** → **Network performance analysis**.

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1 INTRODUCTION

The Wi-Fi standard 802.11ac has included Multi-User MIMO (MU-MIMO) as a key technology to enable Gb/s downlink throughput. By applying MIMO beamforming towards multiple clients, MU-MIMO is expected to boost up the throughput as the theoretical capacity proportionally scales with the number of antennas at the Access Point (AP). Thus, AP and mobile device manufacturers have been adopting 802.11ac to their products. However, user experienced throughput of 802.11ac with MU-MIMO is far from Gb/s wireless link speed [1]. A industrial report demonstrates that the aggregated throughput of MU-MIMO with 10 client devices is only about 100 Mb/s at 20 MHz bandwidth, and another research study even shows that Single-User MIMO (SU-MIMO) outperforms MU-MIMO by throughput at 25% of their experiments [2].

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While there are numerous studies that measured the performance of Wi-Fi systems, no work has revealed the user throughput of MU-MIMO system with commodity products at real-world environments. In this paper, we investigate the downlink user throughput of a Wi-Fi system that consists of commodity 802.11ac AP and clients at diverse environments. In specific, we explore the throughput of both MU-MIMO and SU-MIMO at our experiments to analyze the root cause of the throughput degradation of MU-MIMO.

From our experiments, we have observed that SU-MIMO outperformed MU-MIMO at all of our experiments, and maximum MU-MIMO throughput from our experiments was less than SU-MIMO. We further analyze the experimental results in terms of channel sounding overhead, user grouping, environmental impact, and transmission mode selection.

2 EXPERIMENTAL SETTINGS

We used a commodity AP that supports MU-MIMO transmission and user grouping with 2 x 2:2 clients at a capacity of 1.73 Gb/s with 80 MHz bandwidth. We used two types of smartphones as clients that support 2 x 2:2 MU-MIMO at a capacity of 866 Mb/s. We used *iPerf* to generate traffic and to measure the throughput, and we configured the total sending rate not to exceed 700 Mb/s. We conducted the experiments at university classrooms, varying number of clients, position of clients, and obstacles. We observed sniffed wireless packets and Wi-Fi driver logs to analyze the experimental results.

3 RESULTS AND ANALYSIS

We measured the throughput of SU-MIMO and MU-MIMO in six different indoor environments. Figure 1 shows the layouts of those environments. Those environments have different indoor layouts, thereby differentiating multipath effects on devices. Figure 2 shows the aggregated throughput of SU-MIMO and MU-MIMO settings in those environments. We observed that SU-MIMO outperforms MU-MIMO in every case we had experimented.

There are four main findings in this experiment. The first finding is that the channel occupation ratio of channel feedback is more significant in MU-MIMO than in SU-MIMO. Since channel feedback is an essential step to transmit data, it is important to reduce the channel occupation ratio of channel feedback as much as possible. In our experiment, the overhead was very low as 1.1% when the AP performed SU-MIMO, but it became about 10% after the AP changes transmission mode to MU-MIMO. Also, the size of the channel state that is sent to AP in MU-MIMO systems is up to 1.7x larger than that of SU-MIMO. Moreover, MU-MIMO is more sensitive to environmental change than SU-MIMO since the AP should acquire the CSI of every associated client in MU-MIMO at every moment.

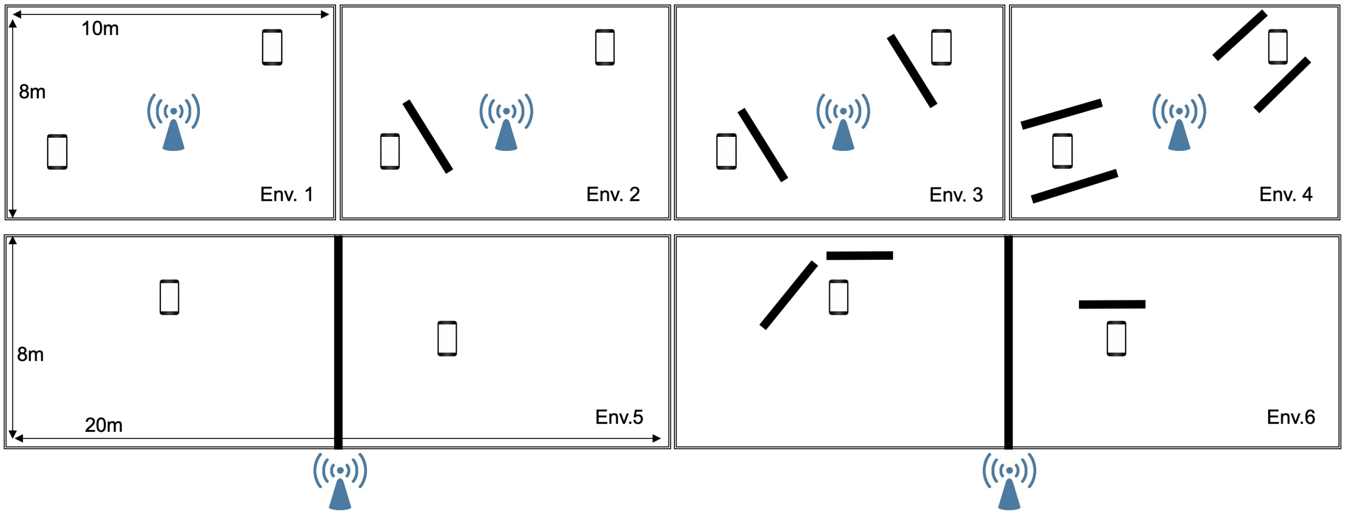

Figure 1: Experiment setup of multiple clients and APs, with different guard locations

The second finding is that user grouping algorithm from imperfect channel information resulted in poor fairness among the clients. Our measurement shows that non-optimal user grouping of commodity AP in MU-MIMO mode that we used amplifies the throughput difference among clients up to 30x. An optimal user grouping is achieved when an AP knows perfect channel information. However, it is impossible for an AP to know the perfect channel information for every data transmission because the channel sounding overhead will be too big and it will overwhelm the data transmission time. Due to this inherent limitation, a phenomenon we observed is that the AP acquires channel information from at most three clients at once. Consequently, when the AP group users, it relies on partial information of the clients, thereby resulting in poor fairness among the clients.

The third finding is related to an environmental impact. As we can observe in Figure 2, the existence of direct path results in higher SNR, which directly results in higher throughput in SU-MIMO. However, in MU-MIMO, not only SNR but channel state difference between clients have an effect on throughput. This is observed in environment 1, 2, and 3. In environment 2, clients have a higher degree of channel difference and throughput compared to other environments. On the other hand, environment 6 has achieved higher throughput than environment 5 by simply adding three guards. From these two series of comparisons, we conclude that not only SNR but also the channel difference caused by the different spatial layout around different clients takes a big role affecting the throughput in MU-MIMO systems. Since there are more factors in MU-MIMO system, we can also observe that there's larger variation in terms of throughput in MU-MIMO systems than SU-MIMO systems.

The fourth finding is related to transmission mode selection. By the sniffed packets from the experiments, we observed that the AP at SU-MIMO mode switches to MU-MIMO but soon switches back to SU-MIMO in 0.3s. There were immediate Frame Error Rate (FER) increase when switched to MU-MIMO. From other experiment, we have observed that the AP at MU-MIMO mode does not switch to

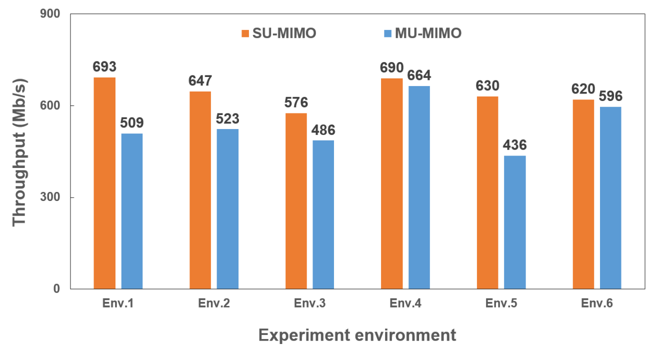

Figure 2: Aggregate throughput measured at settings in Figure 1 in both SU-MIMO and MU-MIMO.

SU-MIMO when there's no FER increase, even at the environments where SU-MIMO outperforms MU-MIMO. Thus, we infer that the commodity AP we used selects a MIMO transmission mode with trial-and-error method based on FER. We speculate that limited channel capacity estimation on APs also limits the use of mode selection algorithms.

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