

# Characterizing the Performance of Beamforming WiFi Access Points

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**Abstract**—Recently beamforming WiFi access points (APs) have been commercially available from multiple vendors. The promise of beamforming APs is the enhanced range and data transmission rate, albeit at a premium price for the AP which can be an order of magnitude more expensive than regular omnidirectional APs. In this work, through live measurements, we study the throughput performance of beamforming APs and compare it with that of regular omnidirectional APs. We consider two systems with multiple WiFi clients and: 1) a single expensive beamforming AP, and 2) multiple low-cost omnidirectional APs. We find that while in some situations the beamforming AP outperforms multiple regular APs when downloading data, in other scenarios typical of home and office use, multiple regular APs results in higher throughput and service quality. Moreover, multiple regular APs always outperforms the beamforming AP when uploading data.

## I. INTRODUCTION

### A. Background

Beamforming is used to control the directionality of transmission and reception of radio signals. By using beamforming it is possible to direct the majority of signal energy in a chosen angular direction. Beamforming methods can be divided into two categories: fixed and adaptive. In fixed beamforming, the space is divided into multiple sectors and the signal is transmitted in one of these predetermined directions. In adaptive beamforming, the location of a non-stationary target is estimated and based on its direction relative to the transmitter, the signal is transmitted accordingly [1].

From another point of view, beamforming techniques can be divided into open-loop and closed-loop methods. In open-loop methods, receivers do not participate in finding the proper orientation of transmitted signals and the transmitter has to calculate the direction according to received data signals, while in closed-loop methods, there is a feedback channel between the two ends to help estimate the direction of the signal. The IEEE 802.11n standard defines these two methods as *Implicit Feedback* and *Explicit Feedback* beamforming [2]. In either case, by detecting the direction of clients, signals can be focused at a particular angle to avoid wasting the signal energy in other directions. Moreover, by knowing the appropriate angle for each client, signals from other directions can be regarded as interference and the reception performance as well as the range of transmission are increased considerably.

### B. Our Work

Various inexpensive IEEE 802.11n APs are available in the market that only exploit MIMO with omnidirectional

transmissions. However, APs with beamforming capability are commercially available but cost around ten times as much. The beamforming APs calculate the direction for each client to perform beamforming and interference mitigation. The question we ask is whether we can achieve a performance similar to that of beamforming APs using multiple regular APs by spreading them over the coverage area of the network. Each regular AP has a shorter range and less antenna gain, but combining them may result in performance comparable to that of costly beam-forming APs. Our measurements show that beamforming can significantly increase the downlink throughput when there is no obstacle blocking the Line-of-Sight (LOS) path between the AP and WiFi clients. However, in large indoor environments like office spaces where there is a large number of walls and partitions separating different rooms, using multiple inexpensive regular APs can result in a higher throughput and service quality. When upstream is the main concern, deploying multiple regular omnidirectional APs always outperforms a single beamforming AP.

### C. Related Work

The work in [3] evaluates the performance of different adaptive beamforming algorithms in wireless networks with smart antenna. A performance evaluation of LMS adaptive beamforming algorithm in smart antenna system is presented in [4]. Using hardware emulator, an evaluation of beamforming and multi-antenna techniques in non-stationary propagation scenarios is presented in [5]. Two types of beamforming technologies, namely chip-based beamforming and antenna-based beamforming are evaluated in [6], where the authors measure the TCP and UDP throughput achieved with these two beamforming technologies and compare it with that of a standard IEEE 802.11n device. In our work, we are interested in comparing the performance of beamforming APs with multiple regular APs when there are multiple clients in the network each with potentially several active data flows.

The rest of the paper is organized as follows. Section II describes our testbed and measurement methodology. Section III presents our measurement results for TCP, UDP and voice applications, and Section IV concludes the paper.

## II. EXPERIMENTAL METHODOLOGY

### A. Wireless Devices

As mentioned earlier, our goal is to study the performance gain that results from signal directionality of beamforming



Fig. 1: *Scenario 1: Two clients in a 10x10m office space. In Mode-1 (left) there is 1 beamforming AP in the middle, and in Mode-2 (right) there are 2 omnidirectional APs. The black circles are WiFi clients.*

APs. In our experiments, we use Ruckus ZoneFlex 7962, a dual-band 802.11n Smart WiFi AP which exploits dynamic beamforming to direct signals toward individual clients. This AP is designed to operate indoors, features 2 to 4 times extended range, automatic interference avoidance, up to 7 dB signal gain and integrated smart antenna array with over 4000 unique patterns.

For omnidirectional APs, we use two Linksys EA2700 wireless AP/routers. Our equipment also includes three commodity laptops running Microsoft Windows 7, used as clients and server. Client laptops are equipped with TP-Link TL-WN821N USB WiFi dongles. The server laptop is connected to Gigabit network infrastructure of ICT building on the University of Calgary campus, which exceeds the maximum wireless throughput of our devices and thus ensures that we can achieve the maximum bitrate capacity of WiFi connections during our experiment. All of the APs and WiFi clients used in our experiment have theoretical maximum user throughput of 300 Mbps achieved by two parallel spatial streams specified in the IEEE 802.11n standard.

Since the number of APs in our experiment is predefined, we set the frequency channel of the APs manually to avoid interference. One of the regular APs was set to work in channel 1 (2412 Mhz) and the other one in channel 11 (2462 Mhz). Since the channels are 40 Mhz wide, and the gap between these two channels is 50 Mhz, and hence there will be no interference when these two are working concurrently. Since the beamforming AP is not going to be used simultaneously with the other two, it can have any arbitrary channel (we configured it to work in channel 6).

### B. Testbed Topology

We have conducted our experiments in two locations to compare the performance of each AP in different environments varying by size and the extent to which obstacles interfere with signal propagation. In each scenario, three groups of measurements are performed to study performance of APs in different categories:

- Raw TCP and UDP throughput in uplink and downlink
- Retrieving small files from a HTTP server
- Quality of voice over IP protocol

The first scenario occurs in a 10 by 10 meter office room containing partitions separated by thin partition walls. In this scenario experiments are conducted in two configurations:



Fig. 2: *Scenario 2: A 60m by 40m floor containing several rooms and walls. The blue circle indicates the beamforming AP in Mode-1 (left), and red circles indicate omnidirectional APs in Mode-2 (right). The black circles are WiFi clients.*

- **Mode-1:** In Mode-1, there is one beamforming AP in the middle of the room, as shown in Fig. 1 and two clients are placed near the corners of the room to be as far from the AP as possible, and both clients are associated to the AP simultaneously.
- **Mode-2:** In Mode-2, two omnidirectional APs are placed in the room as shown in Fig. 1, and each client connects to the nearest AP in a different wireless channel.

An entire floor of ICT building is used to host the second scenario of our experiments, shown in Fig. 2. In Mode-1 we place the beamforming-enabled AP in the middle of the 60 meters long and 40 meters wide floor, and the clients are placed sufficiently far from the AP. In Mode-2, the locations of regular APs and clients are shown in Fig. 2, where each client laptop associates with the closest AP.

In these figures the blue circle indicates the beamforming AP, red circles represent regular omnidirectional APs, and black ones are clients. Each set of measurements takes place in the two mentioned environments to see how distance and obstacles affect signal transmission quality in directional and omnidirectional manners. The measurements are done during nighttime in order to minimize the interference caused by other devices such as cell phones and laptops in the environment.

### C. Raw Data Experiments

Measuring raw data throughput in both uplink and downlink directions can be the most clear and straightforward way to evaluate network performance. To measure link throughputs, we use *Iperf* [7], a commonly used network testing tool that can create TCP and UDP data streams to measure the throughput of the network. *Iperf* has a client-server architecture. When operating in unidirectional mode, the client generates data, and the server counts the size of received data and ignores the content. To perform uplink test, we run a client instance of *Iperf* on client laptops and a server instance on the server laptop. The other direction is accomplished by running an *Iperf* server on each client laptop, and two instances of *Iperf* client on the server laptop, one for each client.

Our experiments also include a more realistic scenario in which we establish multiple connections from each client

laptop to the client server. In these cases, using Iperf options we create varying number of connections from the client to the server. Using this approach, we also eliminate rises and falls caused by TCP congestion protocol in the total throughput.

#### D. HTTP Experiments

In another set of tests we emulate web browsing by clients. Most common activities expected from laptops or smart phones of users in a wireless network consist of checking email, social networks activities such as Twitter and Facebook, reading news or generally surfing web pages. A lot of applications on smartphones rely on HTTP, even for video streaming. As an example, Netflix protocol which runs on top of HTTP, accounts for about 32 percent of downstream traffic during primetime Internet hours. When users are browsing websites, they most probably retrieve a large number of small objects using short-lived connections, rather than downloading a large file. In this situation, data throughput is not as crucial as it is when dealing with large files. What plays an important role in a convenient web browsing experience is the round trip time to which the wireless link delay is a major contributor. A weak signal to noise ratio, collision, contention, interference, or any other factor that prevents successful signal transmission can severely impact the web browsing quality perceived by users.

When users open a web page, a few number of concurrent connections are made to retrieve different objects in the web page at the same time and increase the loading speed of the page to make it seem smoother. Similar to raw throughput measurements, we emulate a more realistic web browsing experience by sending a number of HTTP requests to the web server at the same time.

#### E. Sound Quality Experiments

To test sound quality, we use Skype, one of the most popular existing VoIP protocols. Traffic generated from voice over IP applications are growing at a stunning pace. Statistics show that Skype constituted 34 percent of the international call market share in 2012, and have a record number of more than 50 million concurrent online users. Considering the popularity of Skype and its availability on many mobile and desktop platforms, we decided to use Skype to assess the quality of voice transmission over our WiFi networks.

### III. EXPERIMENTAL RESULTS

#### A. Raw Data Throughput

On the CDF plots in this section,  $B_n$  and  $O_n$  represent the throughput when there are  $n$  data flows in beamforming and omnidirectional setup, respectively. The plots are drawn based on executing each group of tests for 200 seconds in different scenarios. For UDP, since there is no congestion control, transmission rate should be selected by the user using Iperf parameters. Essentially, we choose a rate that saturates the network to drive the wireless links to their maximum utilization. In our experiments, choosing 200 Mbps for the Ruckus AP and 100 Mbps for the regular ones turned out to be the choice that leads us to the maximum UDP bitrate. The

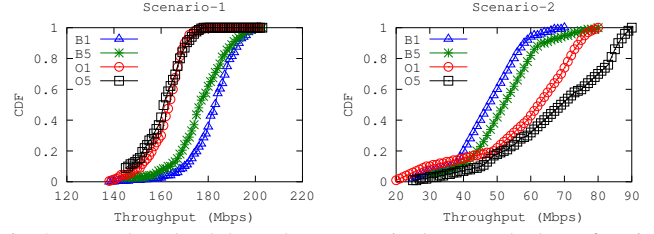


Fig. 3: UDP download throughput. In a single room the beamforming throughput reaches close to 200 Mbps, more than the sum of throughput of two omnidirectional APs. In scenario-2, however, the omnidirectional setup achieves higher speeds.

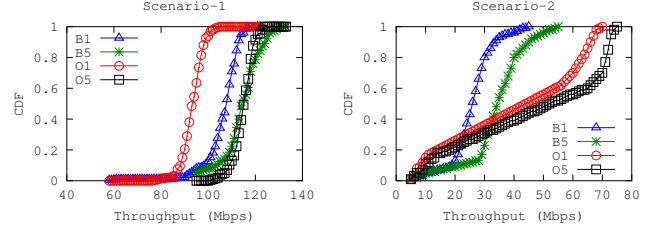


Fig. 4: TCP download throughput. In a single room(left), download throughput of the beamformer is more than 2 omnidirectional APs. In a building floor(right) throughput of 2 regular APs is higher.

amount of UDP throughput is very close to the theoretical bitrate of WiFi links. For TCP throughput, however, the maximum rate will be determined by TCP congestion control algorithm and the rate of packet losses.

1) *Downlink Throughput:* As can be seen in Figs. 3 and 4, the beamforming AP outperforms the two omnidirectional APs in the downlink in scenario-1, which is a small office room. In Fig. 3, during a 200ms experiment in scenario-1, the maximum throughput of omnidirectional APs with one flow is 180 Mbps, while in more than 60 percent of the time, the throughput in beamforming AP is more than 180 Mbps. However, in scenario-2 which is conducted in an entire floor of a building which consists of various walls and partitions, beamforming is neutralized and deploying two omnidirectional APs turns out to be more effective than using one beamforming AP.

2) *Uplink Throughput:* As depicted in Figs. 5 and 6, in the uplink experiments, the beamforming AP is outrun by the omnidirectional APs in both scenarios. This behavior stems from the fact that having two APs working in different channels eliminates the interference and leads to a much better performance than having one beamforming AP. Moreover, beamforming is only performed by the AP, not by the clients, and thus having an AP with beamforming capability should not affect the upload throughput unless it supports other techniques to have a stronger signal reception.

#### B. HTTP Performance

We use *htperf* [8] as a HTTP client to send a small request from clients to the server and fetch a fixed-size file from an Apache web server. We repeat the request for 100 times and calculate the average time spent for a single request. As shown in Fig.7, having a beamforming AP did not benefit us in terms of reducing HTTP delay, especially when we emulate

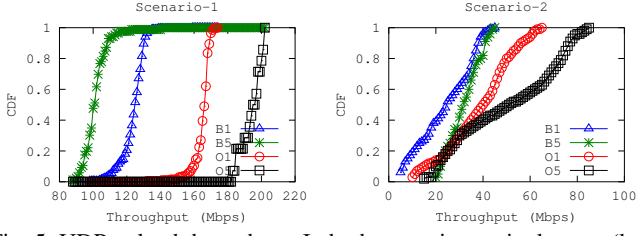


Fig. 5: UDP upload throughput. In both scenarios, a single room(left) and an entire building floor(right), the throughput when having 2 omnidirectional APs is way higher than having one beamforming AP, especially when there are multiple flows.

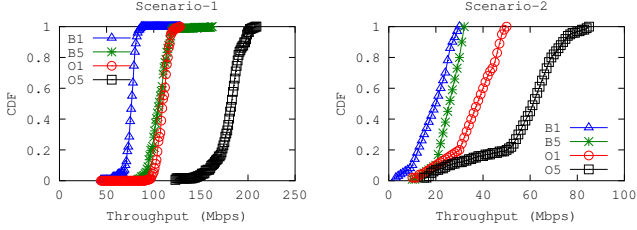


Fig. 6: TCP upload throughput. Similar to UDP, having multiple omnidirectional APs results in a higher upload throughput. The throughput in a single room ranges from 46 to 82 Mbps in the beamforming setup, while it ranges from 86 to 129 Mbps using 2 omnidirectional APs.

more realistic scenarios when each client has multiple ongoing connections to the web server. Since the delay factor in this case is more important than the size of the data transferred to the client, improving the user experience cannot be achieved by using the beamforming AP.

### C. VoIP Performance

We use two laptops and install Skype on them. We prepare a sample 20-second long WAV audio clip with 16 kHz sample rate. Laptop 1 is plugged in the Ethernet network of the ICT building at the University of Calgary, and laptop 2 is connected to the WiFi network, and both of them are connected to the Internet. We play the sample audio clip on laptop 1, the sender laptop, and send it to laptop 2, the receiver laptop, through Skype clients. On laptop 2, we record the received audio into a WAV audio file. By repeating this experiment for 50 times in each mode and each scenario and comparing the quality of the sent and received audio clips, we assess the performance of each WiFi network. To evaluate the sound quality, we use

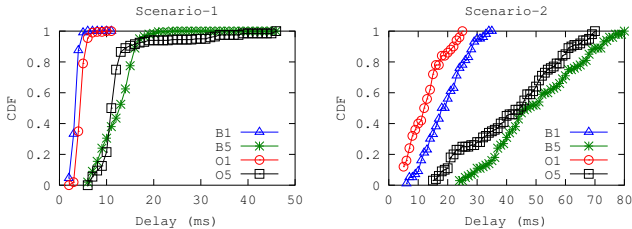


Fig. 7: HTTP delay. In scenario-1 which takes place in a single room, there is no big difference between delay of beamforming and omnidirectional APs when retrieving a small file from a web server. In scenario-2, deploying multiple inexpensive omnidirectional APs has a slight advantage over using an expensive beamformer.

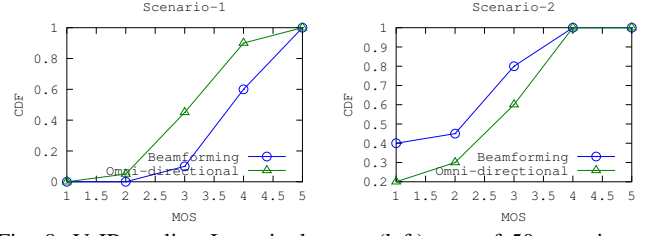


Fig. 8: VoIP quality. In a single room(left), out of 50 experiments, 90% of the time in beamforming setup and 55% of the time in omni setup, the voice quality is considered fair(MOS $\geq 3$ ). In a building floor(right), the received voice quality is higher when having 2 omnidirectional APs.

the Mean Opinion Score (MOS) which is commonly used for voice quality assessment. The MOS is produced by averaging the results of a set of subjective tests and can range from 1 (worst) to 5 (best) [9]. Fig. 8 implies that the received sound quality by clients in scenario-2 is at a higher level with the omnidirectional setup, while it is slightly lower than the beamforming setup in scenario-1. In scenario-2, 30 percent of the time, the voice quality is annoying (MOS = 2) with the omnidirectional setup, while with the beamforming setup this number rises up to 45%.

## IV. CONCLUSION

Our experiments show that beamforming can significantly increase the downlink throughput when there is no obstacle blocking the LOS path between the AP and WiFi clients. However, in large indoor environments like office spaces where there is a large number of walls and partitions separating different rooms, using multiple inexpensive regular APs can result in a higher throughput and service quality. When upload is the main concern, deploying multiple regular omnidirectional APs always outperforms a single beamforming AP.

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