Poster: Analyzing Bitrates in Modern Wi-Fi Networks

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ABSTRACT

The IEEE 802.11 standard has become the dominant protocol for Wireless Local Area Networks (WLANs). In a span of 20 years, the speed of these networks has increased from 1 Mbps to more than 1 Gbps. Today's Wi-Fi networks may consist of a variety of client devices, ranging from slow legacy 802.11a/b/g to modern and fast 802.11n/ac devices. We describe preliminary findings from a large-scale study obtained from 448 Google Wifi and Google OnHub access points with 2,975 clients. We focus on characterizing the maximum achievable bitrate of heterogeneous wireless links. We also determine the average physical-layer bitrate used on the down link (AP to client) and compare it with the maximum supported bitrate. We find that about 75% of 802.11n and 50% of 802.11ac client devices operate at 75% of their maximum or more and that the bitrates of the remaining devices can be very far from their maximum. These low bitrates could significantly reduce the throughput of high-bitrate devices.

1 INTRODUCTION

Wireless Local Area Networks (WLANs) are widely used in homes, schools, and many other public places. The growth of the Wi-Fi market is driven by many factors including Wi-Fi enabled IoT devices, the widespread use of smart phones and the demand for free public Wi-Fi hot spots. It is anticipated that over 20 billion Wi-Fi chipsets will be shipped between 2016 and 2021 [1]. Most importantly, it is estimated that in 2021, 50% of all fixed and mobile IP traffic will be delivered over Wi-Fi networks [2].

In the past 20 years, several IEEE 802.11 standards have been introduced for WLANs. The speed of wireless links in these networks has increased from 1 Mbps to more than 1 Gbps. Since 802.11 standards are backward compatible, today's Wi-Fi networks may consist of a variety of client devices ranging from legacy 802.11a/b/g to modern 802.11n/ac devices. The drawback of backwards compatibility is that devices with lower bitrates can potentially reduce throughput for higher bitrate devices. In addition, the throughput of Wi-Fi networks is affected by many other factors including the density of devices on the same wireless channel and the time-varying channel conditions that can lead to errors in wireless links. Consequently, the quality of experience can differ considerably from one device to another, even in the same WLAN.

As a result, very little is known about the maximum achievable bitrate of Wi-Fi links in commonly used home and office settings. Knowing information about device capabilities is valuable to ISPs and service providers that deliver content to end users connected to the Internet via Wi-Fi networks. For example, for a video streaming service, it is difficult to find root causes of performance issues because it is not clear if the problem is in the ISP to modem connection or the user's local wireless network [3]. A few studies have characterized WLANs in terms of the achievable bitrates of wireless links and transmission rates used for communication [4, 6, 7]. The study closest to our work is the research by Sundaresan et al. [6], where they compute the distribution of bitrates for Wi-Fi devices in 2.4 GHz and 5 GHz spectrums. They also present the normalized bitrate in which the average bitrate is divided by the maximum achievable bitrate of each device. To the best of our knowledge the devices studied in previous work did not include 802.11ac capable access points, and as a result they have no information about such devices. Our data shows that in modern WLANs, the majority of devices using the 5 GHz spectrum operate in 802.11ac mode.

In this work, we study bitrates used by devices and their capabilities by examining a large data set collected from modern commercial Google access points. We characterize modern networks comprised of 802.11ac access points which are backwards compatible with legacy protocols. We also examine how close the physical-layer bitrates are to their maximum as a first step in understanding how to improve the bitrates used in practice.

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2 METHODOLOGY

Our data set was obtained from 448 Google Wifi and Google OnHub access points (APs) and includes 2,975 clients. Data is collected from a 24 hour period with data sampled every 5 minutes. We exclude client devices for which there are fewer than 12 samples. At each 5 minute interval the AP records PHY and MAC-layer statistics about the last packet transmitted to and received from each client that is currently associated with the AP. The vast majority of the access points for which we have data are 802.11ac Google Wifi devices. These devices support communication using up to 2 spatial streams, channel widths up to 80 MHz, short guard and long guard intervals, and 10 modulation and coding schemes (MCS 0 – 9). In total there are 120 transmission rates and the maximum is 866.7 Mbps. Google OnHub devices are similar except they support up to 3 spatial streams for a maximum physical rate of 1,300 Mbps. Both devices operate on 2.4 and 5 GHz bands simultaneously and are backwards compatible with legacy protocols. The data collected is concerned with the transmission and reception statistics like PHY rates, errors, signal strength, etc. All data is anonymized and cannot be traced back to any particular access point, client device or user. Furthermore, no payload data or IP addresses are collected or examined.

One initial goal of our work is to determine the maximum capabilities (maximum bitrate supported) for each client device on the network they are using. This will later be used to examine how close to or far from those maximum bitrates these devices typically operate. We determine the maximum bitrate supported by examining the configuration used for each recorded data transmission. Data transmissions are from the AP to the client device and represent down stream (incoming) traffic for the client. A rate configuration can be described using a 4-tuple. For example in the 4-tuple 2S-I8-LG-20M, 2S means 2 spatial streams, I8 means MCS index 8, LG is long guard interval and 20M means the channel width is 20 MHz. For each device we examine the configuration used for each transmission to determine the maximum value used in each component of the 4-tuple over all transmissions. Across all recorded data transmissions this provides the *maximum receiving bitrate supported* for that client device on the network it is using. This is a lower bound because the AP may not transmit any packets to the client using the client's maximum bitrate in the 24 hour period.

Once we have determined the maximum bitrate for each client device for the network (*max*) we compute the average transmission rate (*avg*) used by the AP to each client. Then for each client we compute $\frac{avg}{max}$ and finally plot these values for all clients to understand how typical transmission rates compare with the maximum possible transmission rates.

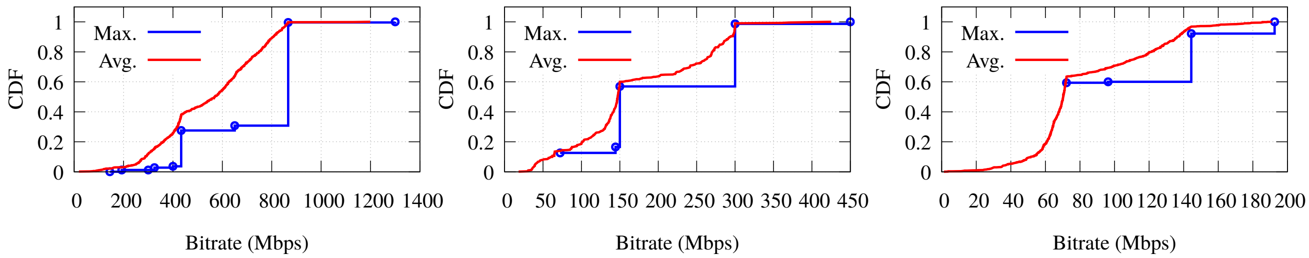
3 RESULTS

In this section, we study the maximum bitrate supported by the Wi-Fi devices in our data set. Then we analyze the ratio of the average bitrate for each device compared to its maximum. To facilitate our evaluation, we classify the client devices using 3 different categories namely, 802.11ac (5 GHz), 802.11n (5 GHz), 802.11n (2.4 GHz). A client device might appear in more than one category if it connects to the network at different times using different modes.

As explained in Section 2, we calculate the maximum bitrate supported by each client device from the transmission configurations used over the 24 hour period. Figure 1 shows the CDF of maximum bitrates as well as the CDF of average bitrates for each of the 3 categories. The y-axis shows the fraction of client devices with maximum or average bitrates equal to or lower than the corresponding bitrate on the x-axis. The line showing maximums contains a few steps in each graph which correspond to different transmission features such as the number of spatial streams or channel width. In Figure 1a there are two large steps, one at 433 Mbps and another at 866 Mbps. These represent 802.11ac devices that support 1 and 2 spatial streams (each with 80 MHz channels). This figure also shows that the number of 11ac devices that support 2 spatial streams (i.e., 70%) is roughly triple the number of 1 spatial stream devices (i.e., 25%). Similarly, in Figure 1b, the large steps at 150 Mbps and 300 Mbps represent 802.11n devices in the 5 GHz spectrum that support 1 and 2 spatial streams (each with 40 MHz channels), respectively.

In the 2.4 GHz spectrum, the Google APs are configured to use 20 MHz channels to avoid interference with neighboring Wi-Fi networks. This explains why the maximum bitrates supported by 802.11n devices in the 2.4 GHz spectrum are roughly half of the 5 GHz spectrum. In the 2.4 GHz band, about 60% of the clients support only one spatial stream and about 35% of the clients support 2 spatial streams. The sample set of devices that were used for data collection were primarily Google Wifi devices with a small percentage of OnHub devices. The OnHub devices support up to 3 spatial streams and clients that utilize 3 spatial streams when connected to these devices can be seen in all graphs (e.g., in Figure 1b the points at 150, 300 and 450 represent rates obtained using 1, 2 and 3 spatial streams respectively). Note that the percentage of client devices that support 3 spatial streams is probably much higher.

The red line in Figure 1 shows the CDF of average physical-layer bitrates used by the AP to transfer data to the clients on the down link. The average bitrates used with 802.11ac devices (Figure 1a) is generally very high with a median of about 600 Mbps. The bitrates of only a very small fraction of these devices is lower than 200 Mbps. The average bitrate of 802.11n devices in the 5 GHz spectrum is significantly lower



(a) 802.11ac - 5 GHz **(b) 802.11n - 5 GHz** **(c) 802.11n - 2.4 GHz**

Figure 1: CDF of maximum supported bitrate and average bitrate

with more than 65% of client devices using bitrates lower than 200 Mbps. In the 2.4 GHz spectrum, this difference is even more significant where the bitrates used to all client devices is less than 200 Mbps. These plots clearly illustrate the heterogeneity of links in modern 802.11 networks. Of particular interest are the situations in which low physical rates are used because Wi-Fi networks suffer from the unfairness problem [5] where a slow client slows down the entire network. In future work, we plan to study how the heterogeneity of links in these networks affects their performance.

Next, we compare the average physical bitrates used with the maximum bitrate supported by the devices. For each client, we divide its average bitrate by its maximum supported bitrate and plot (in Figure 2) the CDF of these ratios for all clients. This figure shows that the average bitrate of 802.11n devices (2.4 and 5 GHz) are typically fairly close to their maximum. More specifically, the bitrates of about 50% of the client devices are at about 86-90% or more of their maximum. Interestingly the 802.11ac clients generally operate farther from their maximum with about half operating at 75% or more of their maximum. This observation can be explained by considering the highest possible bitrate transmission configurations such as 256-QAM modulation and 80 MHz channels in the 802.11ac protocol. The combination of these configurations requires very high SNR to work properly and we believe that such high quality channel conditions do not exist for many devices. As a result, their average bitrate is farther from the maximum bitrate when compared to 802.11n devices.

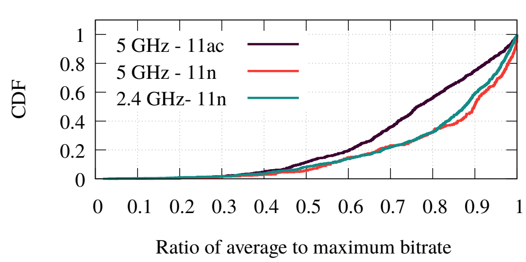


Figure 2: Average bitrate relative to maximum

Figure 2 also shows that although in general the average bitrates are relatively close to the maximum for most devices, the bitrate of about 10% of the devices (in all three modes) are significantly far from their maximum (i.e., less than 50% of maximum). Despite constituting a small percentage of all devices, they may dramatically reduce the performance of the entire network due to the unfairness problem. Studying this issue will be a topic of future work.

4 FUTURE WORK

In this work, we analyze a relatively small data set compared to what we hope to study in the future. We expect to get data from many more devices for longer periods of time. In addition, we hope to study the throughput of Wi-Fi networks by considering error rates and the competition to access the wireless channel.

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REFERENCES

[1] 2016. ABI Research report. https://www.abiresearch.com/press/abi-research-anticipates-more-20-billion-cumulativ.

[2] Cisco. 2017. *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 20162021.* Technical Report.

[3] Giorgos Dimopoulos, Ilias Leontiadis, Pere Barlet-Ros, Konstantina Papagiannaki, and Peter Steenkiste. 2015. Identifying the Root Cause of Video Streaming Issues on Mobile Devices. In *CoNEXT*.

[4] Sarthak Grover, Mi Seon Park, Srikanth Sundaresan, Sam Burnett, Hyojoon Kim, Bharath Ravi, and Nick Feamster. 2013. Peeking Behind the NAT: An Empirical Study of Home Networks. In *IMC*.

[5] Thyagarajan Nandagopal, Tae-Eun Kim, Xia Gao, and Vaduvur Bharghavan. 2000. Achieving MAC Layer Fairness in Wireless Packet Networks. In *MobiCom*.

[6] Srikanth Sundaresan, Nick Feamster, and Renata Teixeira. 2015. Measuring the Performance of User Traffic in Home Wireless Networks. In *Passive and Active Measurement*.

[7] Srikanth Sundaresan, Nick Feamster, and Renata Teixeira. 2016. Home Network or Access Link? Locating Last-Mile Downstream Throughput Bottlenecks. In *Passive and Active Measurement*.