IEEE 802.11 Traffic Measurement and Analysis

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ABSTRACT

Despite extensive measurement based study of IEEE 802.11 *wireless channels*, rare work has performed to investigate the use of IEEE 802.11 protocol variants in practice and its traffics in various environments. This paper presents a traffic analysis on two different IEEE 802.11 networks under operation: one is inside a university campus and the other is out of the campus. The investigation focuses are on protocol efficiency, frame delivery, application types and IEEE 802.11 variants (i.e. a/b/g/n/ac/ad). With more than 10 million frames collected, the results show: (1) the IEEE 802.11 protocol could be more efficiency with a smaller retry limit, (2) various environments vary largely in traffic application types in that the users have various needs, and (3) users upgrades their devices quickly because the traffic dominates with latest IEEE 802.11 protocol variant. These observations will be valuable to future protocol design of IEEE 802.11 networking.

1. INTRODUCTION

IEEE 802.11 (a.k.a WiFi) networks have become indispensable to our life today. Its value and significance can never be underestimated. Empirical traffic measurement and analysis of IEEE 802.11 networks is not a new topic with many works performed for decades [1,6–9,17,18]. However, the most recent IEEE 802.11 traffic analysis can be traced back to a decade ago. Since then, the IEEE 802.11 has undergone many updates and innovations in standards, applications and technologies. We observe a big gap that there has been no traffic analysis reported on IEEE 802.11 networks for almost ten years. With many new Internet services such as Twitter and Facebook introduced, the traffic in the IEEE 802.11 networks as the last hop to users should be significantly different from what was ten years ago. Therefore, it is of utmost interest to understand the traffic patterns in current IEEE 802.11 networks.

In this work, we are particularly interested in the traffic analysis of protocol variations (e.g. IEEE 802.11a/b/g/n/ac) in use, application types, frame types and frame delivery. We have collected more than 10 million IEEE 802.11 frames at different places and at different moments. The traffic analysis will be significantly valuable in providing insights to the design of future IEEE 802.11 network architectures and protocols.

The rest of the paper is organized as follows. §2 presents related work on IEEE 802.11 network traffic measurement and analysis in literature. §3 overviews the basics of IEEE 802.11 protocol. In §4 we introduce the measurement platform and scenarios of this work. Then, the measurement results and analysis is discussed in §5. The paper is concluded by §6.

2. RELATED WORKS

Extensive work has been performed on IEEE 802.11 networks based on measurements. They observed that these two standards behave noticeably differently even under the same environment because of the difference in the physical layer coding schemes. Bianchi et al. [6] conducted measurement experiments outdoor on a campus to identify the network performance between IEEE 802.11b and IEEE 802.11g channels. Long-range wireless link measurements conducted by Gupta [9] in an outdoor IEEE 802.11b WLAN shows that with possible interference around, SNR of a link is not closely related to modulation schemes that the link can support as in wireless communication principle. On the other hand, Chebrolu et al. [17] and Gokhale, et al. [8] found that the loss rate changes as a function of received signal strength, but their experiments were conducted in a wild space with each link operates on non-overlapping IEEE 802.11 channels. As a result, interference or collision is almost avoided. Another long-distance link measurement work is conducted by El-Sayed, Zeadally and Boulmalf [4]. Kotz et al. [18] verfies the hypothesis about radio propagation that many network simulation models are based upon. In wireless communication, the commonly accepted assumptions are: (1) the wireless signal is propagated in the circular shape; (2) all signals have equal transmission range and symmetric links between two nodes; and (3) signal strength is a simple function of communication distance. They conducted a set of IEEE 802.11 measurements in both indoor and outdoor environments and observed that these assumptions do not adequately match real world channel behaviors. Cheng et al. Giustiniano, et al. [7] revealed an engineering issue significantly impacting measurement experiments that the hardware/software diversity at a transmitter may induce weird behavior of wireless signal at a receiver in practice. [1] con-

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ducted experiments to study the impact of the antenna orientation to an unmanned aerial vehicle (UAV) with extensive outdoor measurements. They installed the UAV and the ground stations of IEEE 802.11a adapters. They concluded that the best throughput performance can be achieved when both antennas of the UAV and the ground station should be omnidirectional and placed horizontally with their null pointing to a direction perpendicular to the flying path. Gass, Scott and Diot [5] measure the performance of UDP and TCP transfers between a car traveling and an 802.11b access point, and analyze the impact of bandwidth and delay limitations in the network with motions. Petrova, at al. [20] conducted traffic measurements to study interference on performance degradation when IEEE 802.11g/n coexists with IEEE 802.15.4. Henderson, Kotz and Abyzov [10] analyzes extensive network traffic from a mature on campus 802.11 WLAN, including more than 550 access points and 7000 users over seventeen weeks to study the types of users and devices, as well as applications.

Our project is different from the above measurement works in that: (1) this work measures on current IEEE 802.11 networks operating in practice, which runs on most recent protocol versions, and (2) the study focus is not on the channel dynamics, but on the network traffic.

3. OVERVIEW OF IEEE 802.11

IEEE 802.11 Variants: Since its inception in 1997, IEEE 802.11 has evolved for twenty years with variants from IEEE 802.11a/b, IEEE 802.11g, IEEE 802.11n, IEEE 802.11ac and IEEE 802.11ad [11–16, 19]. The supported carrier frequency bands also move from dual-band (2.4/5GHz) to tri-band (2.4/5/60GHz). All of these IEEE 802.11 variants have similar frame formats and services to upper layers. IEEE 802.11n included multiple-input multiple-output antennas (MIMO), IEEE 802.11ac introduced Multi-user MIMO (MU-MIMO), and IEEE 802.11ad targeted 60GHz frequency band for a rich 2GHz bandwidth.

Frame Format: The general format of IEEE 802.11 frames is illustrated in Figure 1. IEEE 802.11 has three types of frames: data, management and control frames, which are specified in the subfield of "Type" of the field of "Frame Control". Each type has its own size and purpose. In fact, data frame has the largest size because it contains the actual data that is transmitted. On the other hand, management frame is used to announce the existence of a wireless access point or router and its identity. Control frames have three: RTS, CTS and ACK, which help relief possible collisions and guarantees the correctness of frame delivery.The types of applications carried in IEEE 802.11 frames can only be identified through the payload of data frames. This work studies both the types of IEEE 802.11 frames and the application types of data in frames.

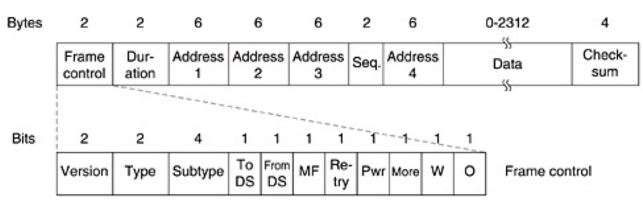

Figure 1: IEEE 802.11 Frame Format

4. MEASUREMENT PLATFORM AND SCENARIOS

4.1 Software Tools

At the present time, there are many software programs and hardware devices used to monitor network traffic. These programs are called packet analyzer, network analyzer or network sniffer, or they may be called according to the type of networks that they work on, an Ethernet sniffer or wireless sniffer. Among them, the most known network analyzer programs are Wireshark [3], Colasoft packet sniffer [2], and tcpdump [21]. Wireshark provides GUI to the core of tcpdump, making it more friendly to end users with graphic visualization and decoding. All these programs allow users to monitor the network traffic and capture frames, but they have different purposes. For instance, Wireshark is the most used program to monitor and capture packets passing through a network interface due to the capabilities it offers. Moreover, the Wireshark has built-in filters that help analyzing captured packets. However, Wireshark filters are limited in analyzing some data and presenting results. For this reason, the researchers, who want to fully analyze captured data and generate specific statistic, have to to create their own programs to do that. Wireshark is the program we chose for this project.

4.2 Hardware Platform

In the measurements, we used an Macbook Pro laptop that has OSX 10.11 operating system to capture frames from IEEE 802.11 network with Wireshark because Microsoft Windows is limited in the capability to support frame capturing. The WiFi interface of the laptop was configured at the monitor mode. Also, we used two different models of Macbook laptops with different versions of OSX to observe if the version of OSX and the model with different WiFi hardware have any impact on frame capturing, especially for retransmitted frame. The WiFi interface cards of the laptops are Airport Extreme supporting IEEE 802.11a/b/g/n/ac, but the WiFi routers (Netgear WNR200 off-campus and Cisco Aironet 1140 on-campus) support IEEE 802.11a/b/g/n, not 802.11ac. So, the traffic monitored does not include any of IEEE 802.11ac/ad variants.

4.3 Scenarios

Figure 2: Traffic Measurement Locations

The traffic data captured in this project is from two different networks in use: on-campus and off-campus. In total, the measurements took six captures. Each capture lasted for 15 minutes. Three of the captures happened on Ball

State University campus WiFi network in different buildings, which are the Teacher College (TC), the Atrium (AT) and the David Letterman Communication and Media Building (LM). These captures were taken around 12:00pm in different days so that the traffic of regular use can be represented. The other three captures were on a different WiFi network offered by an apartment complex out of the university. The time of these captures was around 9:00pm when the residents were normally back in using the WiFi network. The locations of capture are illustrated in the map on Fig 2.

After using Wireshark to do the captures inside the university campus for 45 minutes, more than 7 million frames were captured. Outside campus measurements captured about another 3 million frames. Therefore there are totally about 10 million frames available for our analysis.

The analysis on the traffic has the following focuses:

- *Frame Types*: what is the percentage of each type of frames (Date, Management and Control) in the traffic.
- *Protocol Variants*: what is the percentage of each IEEE 802.11 (a/b/g/n) variant traffic, which indicates what types of WiFi cards are being used by the general public.
- *Application Types*: what applications, e.g. WWW and emails, are embedded in the traffic and what is the percentage of each type.
- *Transmission Types*: what is the percentage of each transmission type traffic, i.e. broadcast, multicast and unicast.
- *Delivery*: how many transmissions does a frame attempt till successful delivery.

5. MEASUREMENT AND ANALYSIS

As it was mentioned above, traffic was captured at two locations: on-campus at Ball State University and off-campus at an apartment building. Each location has three captures. This section will present the analysis and observations that we obtained from the trace. In the following, we first discuss the on-campus case, followed by the off-campus case and a comparison between them.

5.1 On-Campus

The three captures on campus took places at different locations and days. The first capture was in the Teacher College (TC), the second capture occurred in the Atrium (AT) cafeteria while the last capture was in the Letterman (LT) building. After completing all the three captures, the total number of frames for three locations was 1086432, 1780016 and 4425088 respectively.

Frame Type. First, we analyze the traffic to obtain the percentage of three types of IEEE 802.11 frames (i.e. Data frame, Management and frame Control frame). We display this analysis for each capture and then the average over the three captures, as shown in Fig 3. From the data, we can observe that the number of control frames triples the number of data frames, which means, in most cases, the optional control frames of RTS/CTS are enabled although only ACK is required for each data frame. This indicates that if we can successfully reduce the use of control frames in future IEEE 802.11 protocols, we can significantly improve the channel efficiency in terms of transmitting data. The management frames only use a small portion of channel resources in regular uses at daytime.

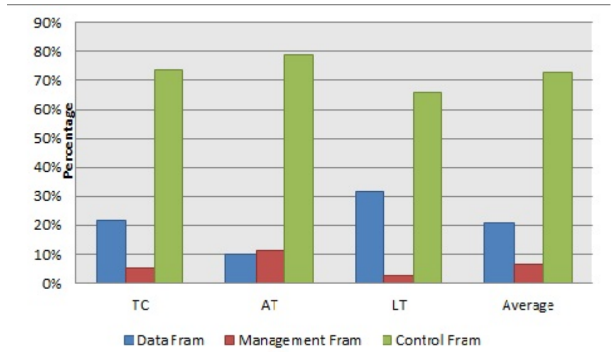

Figure 3: On-Campus Frame Types

Protocol Variants. In this analysis, we focus on the percentage of each IEEE 802.11 variant (i.e. 802.11b, 802.11a, 802.11g and 802.11n) in captures and their averages over the whole three captures. Fig 4 below shows the percentage of protocol variants in the traffic that was captured on-campus. The results show that the majority of the traffic occurred in IEEE 802.11n, particularly in 5GHz frequency band shared with IEEE 802.11a, with a marginally light (barely observable on the figure) portion traffic in IEEE 802.11g. This indicates that most of the wireless interfaces of user devices are already IEEE 802.11n capable. In to reduce cost in future design and engineering, we may not have to consider to be compatible far back to the earliest variants such as IEEE 802.11b because of fast adaption of new variants such as IEEE 802.11ac/ad.

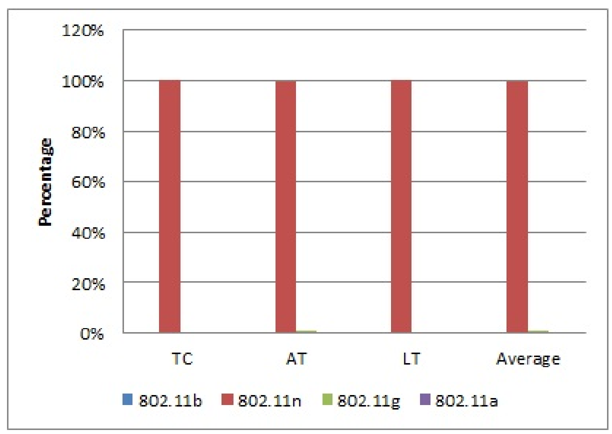

Figure 4: On-Campus Protocol Variants

Application Types. In this scenario, we analyze what types of applications are carried in the data frames of each capture, such as web, email, video, audio etc. From the measurements, most applications are for web, emails, file transfer and audio files in the traffic. However, there are other application types at very low percentages. The results are plotted in Fig 5. From the figure, we can observe that web based applications contribute to the largest portion of the traffic, with email and file transferring the second. The pure multimedia applications are not common as expected. This might be because most of user applications today including the most popular social media and Youtube are implemented in the approach of web based. Because most users on campus are students, they often check emails and submit course work, which account for the second largest portion of the traffic. It should be very beneficial to design location and application aware network protocols in future IEEE 802.11 networks to intelligently adapt to the application types that are mostly likely in a particular environment and group of users, which can significantly improve the quality of service (QoS) of the applications and the user experience as well.

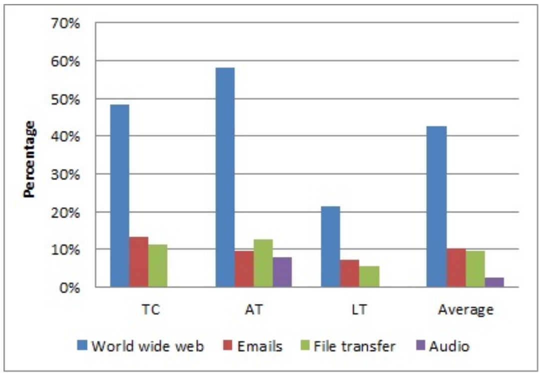

Figure 5: On-Campus Application Types

Delivery. Furthermore, we continue analyzing the frame delivery on the all frame. We first plot the retries, which means how many retransmissions attempted before a successful delivery if a frame fails on its first try. If a frame is transmitted successfully on its first try, there is no retry needed, but if it fails, it can retry. In IEEE 802.11 there are two retry limits: long retry counter (LRC) of 7 or short retry counter (SRC) of 4. Fig 6 demonstrates the percentage of different retries captured on campus. From the figure, about half of the frames can be delivered after only one retransmission. After four retries, more than 95% of frames can be delivered successfully. This indicates that the SRC is most likely enough to make sure most frames to be successfully delivered.

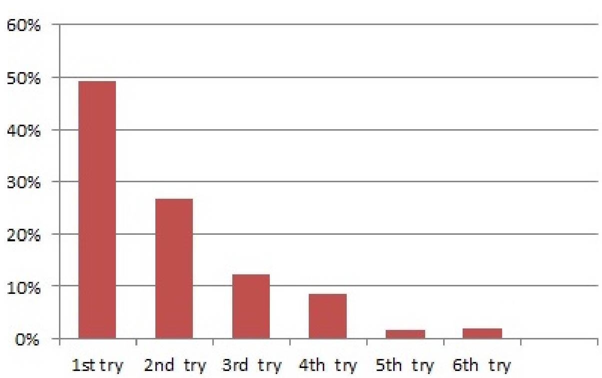

Figure 6: On-Campus Retransmissions

We further analyze the frame delivery across these three different locations. Among these locations, the Letterman building has the largest student and faculty population of more than 3,000 people regularly. We found that the number of frames captured in the Letterman building is the largest among these three locations with more than 4 million frames, even though each location took the same time, 15 minutes, in capturing traffic. Additionally, the percentage of retransmissions in the Letterman building is also the largest because more users/frames are easier to incur collisions between transmissions. The result also indicates that the retransmission is not a big issue in the regular use of IEEE 802.11 network because the retransmission only happens at very small percentages, about 3% of total traffic.

Transmission Types. Finally, we analyze the captured frames to determine the portions of unicast, multicast and broadcast frames. Fig 7 presents this analysis. No surprise, the largest portion of the traffic is unicast frames with a percentage of about 96 over all the three cases. The broadcast traffic mostly is for the management frames, for example the periodically broadcast beacons.

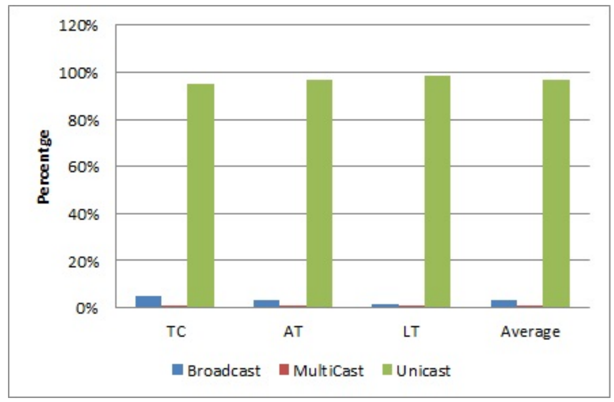

Figure 7: On-Campus Transmission Types

5.2 Comparison of On-Campus and Off-Campus

In addition to the on-campus IEEE 802.11 network traffic measurement, we also conducted measurements on a network off campus to see if both scenarios give us identical observations. It is obviously expected that off-campus captures will have much fewer frames than on-campus because the number of the users using the network are much fewer than on campus. ăAfter three captures of 15 minutes each off-campus, totally 3,059,162 frames were captured, compared to 7,291,533 frames captured in on-campus network traffic. We particularly compare two cases that indicate a large difference between on-campus and off-campus: retransmission and traffic application types.

Retransmission. The retransmission comparison is plotted in Figure 8. This diagram shows that off-campus network has much fewer retransmissions than on-campus. This is because there are much more users on campus and their transmissions are likely to generate more collisions than off-campus. Another observation is that not all the frames succeeded even after retransmissions. A very small portion of frames are discarded after being transmitted for more than the retry limit.

Application Types. We compare the application types in the traffic of on-campus and off-campus measurements and plot in Figure 9. It is interesting to observe that these two networks have significantly different applications in their traffic. The on-campus network has most users of students and they check emails and listen to music much more than

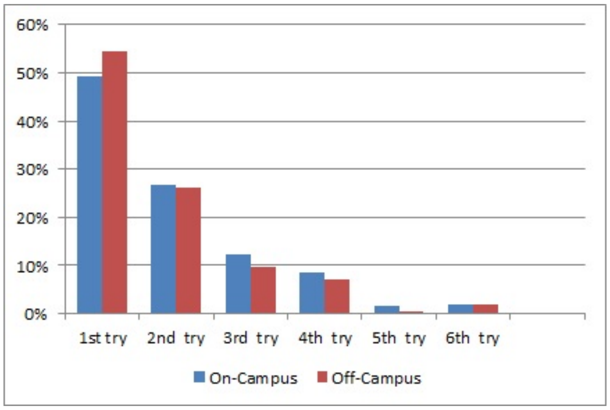

Figure 8: Comparison on Retransmissions

regular users. It is very common that many students listen to music while working on their course work out of classrooms. Both networks have the web browsing as the largest portion of traffic, which includes many online videos today such as Youtube.

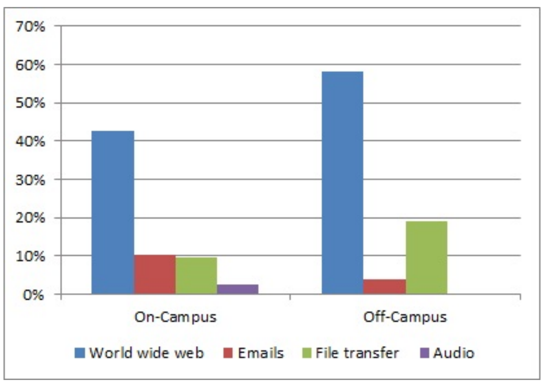

Figure 9: Comparison on Application Types

Transmission Types. It is also interesting to see the comparison of transmission types in both networks, as shown in Figure 10. Regardless of networking environments and users, both networks show similar percentages of various transmission types. This likely indicates the transmission types do not vary significantly in different scenarios of the same networking technology, i.e. IEEE 802.11 in this work.

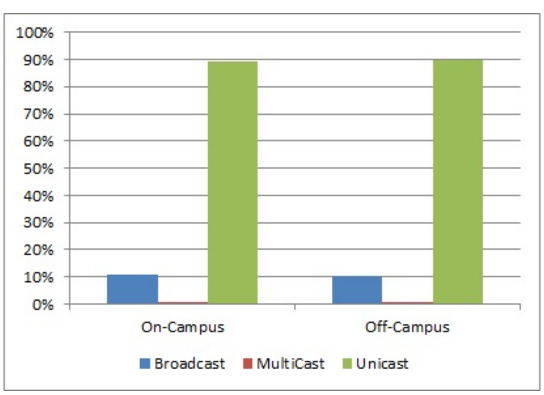

Figure 10: Comparison on Transmission Types

Frame Types. We also compare the presence of frame types in both networks and plot the result in Figure 11. Both networks have very close distributions of different types of frames. This is because each data frame has its associated RTS/CTS/ACK control frames and thus their ratio is relatively constant regardless of network environments.

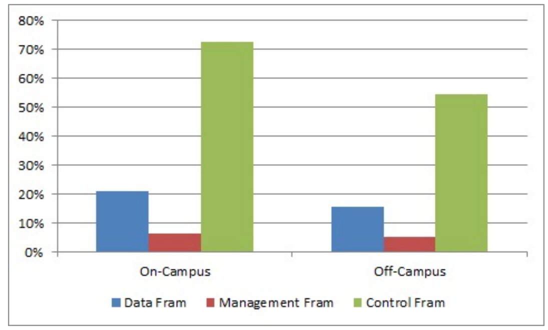

Figure 11: Comparison on Frame Types

6. CONCLUSION

This paper summarizes the traffic measurements and analysis of two different IEEE 802.11 networks: one campus network and one resident network. The traffic analysis presents very valuable insights into the network efficiency in terms of various types of IEEE 802.11 frames, the frame delivery, the application types and the protocol variants in use. The results show that current IEEE 802.11 protocols can be even improved on network resource utilization if the retransmission limit is reduced because only a marginal portion of frames are delivered after retrying for more than 3 times. This work also observes that almost all users are using IEEE 802.11n or higher versions of protocol, which implies that the adaption of latest IEEE 802.11 networking technologies is fast enough for us to be focused on newer IEEE 802.11 protocols in future network deployments and designs.

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