Beacon Flooding Problem in High-density WLANs

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Abstract—With the rapid growth of smart devices such as smartphones, tablets, and laptops, traffic demands in IEEE 802.11 wireless local area networks (WLANs) has increased exponentially. To meet the demand, in recent years, numerous access points (APs) have been deployed in many places such as residential areas, shopping malls, airports, office and campus buildings. As the density of 802.11 WLAN increases, clients often experience significant performance degradation due to the interference from other basic service sets (BSSs). In this paper, we focus on investigating the impact of beacon frames transmitted by adjacent APs on the network performance. Through measurement results, we confirm the periodic beacon transmissions from neighboring APs occupies a large portion of the air-time in the medium, thus degrading throughput performance of associated clients. In addition, via ns-3 simulations, we further verify the beacon flooding problem is especially severe in good channel conditions.

Index Terms—802.11, high-density WLANs, management frame, beacon frame, air-time.

I. INTRODUCTION

Since the advent of mobile devices such as smartphones, tablets, and laptops, the demand for wireless data has grown tremendously [1]. To satisfy the demand, IEEE 802.11 wireless local area network (WLAN) has been considered as one of the most efficient technologies to offload mobile traffic from cellular networks at its relatively low cost.

Thereafter, the popularity of WLANs has led to a dramatic increase in the density of wireless access points (APs) in a wide variety of places such as residential areas, shopping malls, airports, office, and campus buildings. As a result, a typical WLAN nowadays comprises tens or even hundreds of APs covering an area.

In this paper, we investigate the impact of beacon frames on the network performance in such a high-density WLANs. To this end, we first analyze real packet traces captured from a wireless channel, and confirm periodic beacon transmissions reduces a lot of air-time available for data transmission, leading to significant performance degradation of associated clients. Using network simulator 3 (ns-3) [2], we further verify the impact of the beacon flooding problem as the density of APs increases in various channel conditions.

The rest of the paper is organized as follows. Section II introduces 802.11 frame types and beacon frame transmission procedures. In Section III, we analyze real packet traces and shows the measurement results. Section IV presents the simulation results and confirm the beacon flooding problem in high density WLANs. Finally, Section V concludes this paper.

II. PRELIMINARIES

A. Frame types in 802.11

The IEEE 802.11 standard [3] defines 3 frame categories according to the role of each frame, i.e., data, management, and control frames. Specifically, the data frames carry data from upper layers in the frame body. The management frames allows AP and clients to establish and maintain communications. Lastly, the control frames assist the exchange of data frames between AP and clients. The followings are the some common frame subtypes for each frame category.

- Data frames: QoS/Non-QoS Data, CF-Poll, CF-ACK.
- Control frames: ACK, RTS, CTS, PS-Poll, CF-End, Block ACK, Block ACK Request.

B. Beacon frame transmission procedures

Beacon frame is one of the management frames in IEEE 802.11 WLANs. It is periodically sent out by an AP to announce presence of a WLAN and to deliver all the information about the network. To this end, beacon frames contain mandatory fields such as timestamp, beacon interval, capability information, service set identifier (SSID), supported rates and some optional fields including traffic indication map (TIM), delivery TIM (DTIM).

After receiving each beacon frame, associated clients adjust their clock to a value in the timestamp field for synchronization. The beacon interval field contains the time interval value between consecutive beacon frames, which is often set to a default 100 time units (TUs). Here, 1 TU is defined as 1024 microseconds in the 802.11 standard. The capability information field contains capability of device and network.

Fig. 1 shows the overall beacon transmission procedures. At every target beacon transmission time (TBTT), the AP broadcasts a beacon frame to the network. Each beacon contains TIM field, which indicates whether there are buffered data in the AP for power save mode (PSM) clients. Then, the PSM clients staying in the sleep mode wake up periodically to check the existence of the buffered data from the TIM field. For indicating the presence of buffered broadcast and/or multicast data in the AP, DTIM is included in the beacon at every DTIM interval. After a DTIM beacon, the AP sends broadcast/multicast data based on carrier sense multiple
access/collision avoidance (CSMA/CA). Note that the DTIM interval can be multiple number of beacon intervals.

III. MEASUREMENT STUDY

As shown in Section II-B, an AP transmits beacon frame periodically to announce information about the network, even when there is no associated clients. Due to the nature of the beacon transmissions, its influence to the network becomes significant as the density of WLANs grows. In this section, by analyzing real packet traces, we investigate the impact of the beacon transmissions on the channel.

A. Measurement Setup

To obtain the packet traces, we have used a well-known packet capturing tool, Wireshark [4]. We have captured wireless packets in the air for 10 minutes in an office environment in our building. The operating channel number is 2 with 2,417 MHz center frequency. Note that 7 APs are deployed in the channel.

B. Measurement Results

We first compare the number of frames transmitted in the wireless channel. Fig. 2(a) shows the ratio of each frame type, i.e., data, management, and control frames. Among all frames, majority of frames are data and management frames while control frames take up relatively small portion. To compare the portion of each frame type in detail, the number of frames of each frame type is shown in Fig. 2(b). Surprisingly, we can see majority of management frames are beacon frames, and its amount is comparable with the number of data frames.

Next, Fig. 2(c) shows the air-time of each frame type. We can see most of the air-time is occupied by data and beacon transmissions. Moreover, total air-time duration for beacon transmission is similar with that of data transmission. Note that, although quite large number of ACK frames are transmitted as shown in Fig. 2(b), the total air-time of ACK frame is relatively small because its frame size is much smaller than that of data or beacon frame. Finally, Fig. 2(d) shows the cdf of data and beacon transmission duration. The duration of most beacon frames is longer than that of data frames. This is because beacon frames are transmitted using the lowest basic rate, i.e., 1 Mbps, while data frames are transmitted with higher data rate depending on their channel conditions.

From the measurement results, when a large number of APs are deployed in the same area, we can predict beacon frame transmissions have a significant impact on the network performance by taking up the air-time of the channel. Next, we further confirm the severity of beacon flooding problem using ns-3 simulations in various channel conditions.
IV. SIMULATION

A. Simulation Setup

We deployed multiple APs from the same distance from a client as illustrated in Fig. 3(a). The distance between the AP and clients is set closely enough, i.e., 1 m, so that all AP and the client can sense each other. Among all APs, one AP generates fully saturated UDP traffic to its associated client while other APs only transmit beacon frames. To effectively show the impact of beacon transmissions, we do not consider channel error. Also, beacon interval is chosen as a default value in the standard, i.e., 102.4 ms. We assume 802.11g standard are used for PHY layer, and each simulation run lasts for 10 s. Lastly, to reflect different channel conditions, we assume that AP sends data using different data rates such as 54 Mbps, 24 Mbps, and 6 Mbps.

B. Simulation Results

Fig. 3(b) shows the throughput according to the number of adjacent APs. For all different data rate configuration of the sending AP, the UDP throughput decreases as the density APs increases. This is because data transmissions of the client are deferred by the beacon transmissions from other APs.

To show the extent of performance degradation depending on the data rates of sending AP, we further compare the normalized throughput with different number of APs in Fig. 3(c). Note that the normalized throughput is obtained based on the throughput when the number of AP is 5. As the data rate increases, the relative throughput degradation gets severe. Therefore, the performance degradation due to the beacon flooding problem is worse in a high data rate configuration.

V. CONCLUSION

We confirmed performance degradation due to the beacon transmissions can be a severe problem in the high-density WLANs. Based on the real packet traces, we verified a large portion of air-time is occupied by beacon transmissions even when there is no associated clients or downlink traffic. From ns-3 simulations, we also demonstrated that the performance degradation gets worse as the number of APs grows, especially for high data rate conditions.

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