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A Phy/Mac Layer Mechanism to Improve Aggregation in WLANs

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Abstract - In recent years, the growth of WLANs (Wireless Local Area Networks) is very high and it has become the common means of access to the internet. The proliferation of Wi-Fi based WLANs/Wi-Fi hotspots in public places enables ubiquitous internet access. The public places are referred to as large audience environments, in which each Wi-Fi access point (AP) normally serves a crowd of mobile stations (STAs) simultaneously. The performance of those Wi-Fi hotspots is extremely poor in terms of low throughput and severe delay. After carefully investigating the traffic characteristics in Wi-Fi hotspots the studies shows that the main causes of such poor performance are media access control (MAC) inefficiency and downlink-uplink traffic asymmetry. To cope with these issues, the key idea is pooling, which facilitates, an access point (AP) to pool frames for multiple STAs in a single transmission. It reduces contention overhead in downlink transmission and conveys more frames in each channel access. As such, each downlink transmission carries more payloads for multiple receivers, it enables in time response for multiple STAs concurrently in a single transmission and thus improves MAC efficiency and solves traffic asymmetry simultaneously.

Keywords - *MAC Efficiency, Frame Aggregation, Contention Reduction, Pooling, Wi-Fi, IEEE 802.11, WLAN.*

1. Introduction

With the growing popularity of Wi-Fi-based wireless local area networks (WLANs), Wi-Fi hotspots in public places have gained significant importance over the last decade. A recent industry report projected an annual growth rate of 350% for such public Wi-Fi deployments in the near future. Those Wi-Fi hotspots are usually deployed in crowded places such as large conventions, malls and cafeterias. These public places are referred to as large audience environments, in which each Wi-Fi access point (AP) normally serves a crowd of mobile stations (STAs) simultaneously. Unfortunately, the performance of Wi-Fi hotspots in such crowded environments is usually extremely poor. A previous study on the SIGCOMM 2008 trace show that as the number of active STAs increases, traffic demands grow accordingly; while the throughput of the whole network diminishes significantly[4]. High traffic demands in large audience environments even incurs network failure such as the wireless network collapse during the Steve Jobs iPhone 4 keynotes, where the wireless network recovered only after most of the audience turned off their wireless devices. The fundamental causes of this problem are high media access control (MAC) overhead and downlink-uplink traffic asymmetry. In large audience environments, a significant number of STAs contend a limited number of channels within a carrier sensing range, which results in intensive contention.

High contention in distributed coordination function (DCF) based Wi-Fi networks can cost a large amount of overhead, including carrier sensing, back-off, and high collision probability [3]. Moreover, several studies on SIGCOMM traces report that downlink traffic volume is about four times larger than uplink traffic volume [4].However, the DCF-based Wi-Fi networks provide equal opportunity for APs and STAs to access channel, which conflicts with the downlink-uplink asymmetric traffic pattern. This conflict results in congestions in the downlink, thereby incurring severe downlink throughput degradation.

A major solution for such large audience environment scenario is from the view point of coordination and scheduling. Centralized coordination is advocated in many enterprise WLAN proposals to reduce unnecessary contention among APs [5],[6]. There are also several existing priority control schemes that prioritize AP's channel access over STAs to address the traffic asymmetric issue [3]. However, these works focus on coordination and scheduling, which does not address the inefficiency issue caused by the MAC overhead. As the most recent standards IEEE 802.11n and 802.11ac have largely improved maximum PHY data rates over the previous IEEE 802.11a/g from 54 Mbit/s to 600 Mbit/s and over 1Gbit/s, the MAC efficiency of Wi-Fi networks degrades rapidly in current high speed Wi-Fi networks due to reduced time used for data transmission (while the time occupied by MAC overhead like contention overhead and preamble remain unchanged). Thus, it is urgent and necessary to cope with the MAC inefficiency issue.

To improve the MAC efficiency of each single link transmission, frame aggregation [7], is proposed in IEEE 802.11n to reduce contention by aggregating multiple frames for the same destination together at MAC layer. The applications of MAC frame aggregation are limited to bulk transmissions as the sender needs to wait to collect enough payloads before actual transmission, and thus it is not applicable to real-time applications like VoIP and other short data flows such as short HTTP transactions. Although the multi-user frame aggregation can be achieved at MAC layer, it suffers from the many limitations in large audience environments. There are a bundle of active STAs associated with one AP in large audience environments. Explicitly indicating each receiver's MAC address at header would incur substantial overhead, which compromises the transmission efficiency.

To cope with these issues, here present pooling, a practical design that enables frame aggregation for multiple receivers at PHY in the orthogonal frequency-division multiplexing (OFDM) based WLANs. Instead of restricting each downlink transmission to one STA, if we can "pooling" frames for multiple STAs into a single transmission, downlink contention would be significantly reduced and each downlink transmission could carry more traffic. One direct benefit of Pooling is the MAC efficiency improvement by reducing the contention overhead [11]. Another benefit of Pooling is that it inherently relieves downlink traffic congestion at AP caused by downlink-uplink traffic asymmetry since each downlink transmission conveys more traffic for multiple receivers.

Pooling employs a lightweight frame structure to aggregate frames for multiple STAs. In particular, a Bloom filter based aggregation header is introduced in the new frame format to indicate the receiver of each sub-frame [8]. The aggregation header is placed right after the preamble so that irrelevant STAs within the transmission range can drop the frame without decoding it.

The main contributions of this paper are summarized as follows. First, describes pooling to improve efficiency in public WLANs. Specifically, described a lightweight aggregation mechanism based on IEEE 802.11 OFDM PHY to facilitate scalable and reliable transmissions in large audience environments.

2. Overview of Pooling

Pooling is a PHY/MAC design that enables frame aggregation for multiple receivers in OFDM-based WLANs, especially for large audience environments such as conference rooms, airports, and coffee shops. Frames for multiple STAs queued at the AP are aggregated as a single large frame, where an aggregation header is inserted to indicate the destination of each subframe. Each subframe can be a single frame or multiple frames aggregated at MAC layer that contains the MAC data for one destination. The STAs who hear the frame first detect whether the frame contains payload for them by checking the aggregation header. If an STA detects no subframe for it, the STA drops the whole frame without decoding the payload, otherwise the STA locates its subframe in the frame and only decodes this subframe[11].

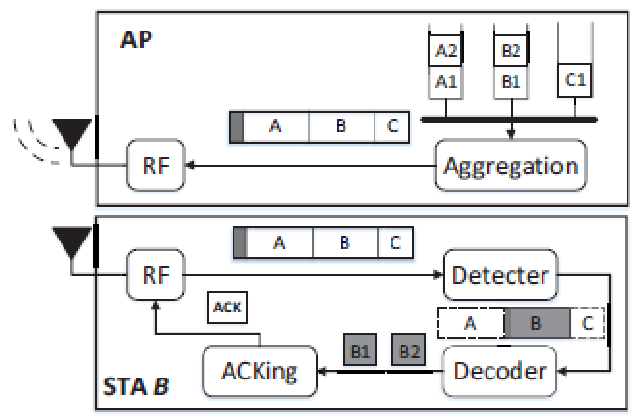

Fig.1. Mechanism of Pooling

Fig. 1 depicts a typical flow of a Pooling frame transmission. The AP aggregates five frames for three STAs into one Pooling frame. STA *B* checks the header in the Pooling frame and detects its payload in the second subframe. STA *B* filters out other irrelevant subframes before feeding the frame into the detector. Then, STA *B* returns an acknowledgement frame (ACK) to the AP. To avoid ACK collisions at AP, receivers need to return ACKs one by one, which can be achieved by simply modifying the Network Allocation Vector (NAV) [11].

3. Aggregation Mechanism Design

An aggregation header in pooling frame is designed to support multiple receiver aggregation. In the new frame format, a Bloom filter-assisted aggregation header is introduced. A Bloom filter structure is choose to indicate the receivers of the frame and the order of sub-frames. The Bloom filter is placed at the PHY header so that irrelevant STAs within the transmission range can drop the frame without decoding it.

Frame structure: Fig. 2 represents the pooling frame structure. Compared with legacy frame structure, added an aggregation header (A-HDR) after the preamble. A-HDR consists of two symbols, which are coded using the lowest coding rate, to indicate the receiver of each subframe[11]. A-HDR is followed by a sequence of subframes. Each subframe contains the SIG symbols and MAC data for exactly one receiver. IEEE 802.11 uses one or two symbols for SIG in different modes. The SIG symbols contain information about modulation and coding scheme (MCS) and frame length. Note that the MAC data can be either single data unit or aggregation data unit determined in IEEE 802.11 MAC aggregation (MSDU or MPDU aggregation). Different subframes can adopt different MCSs.

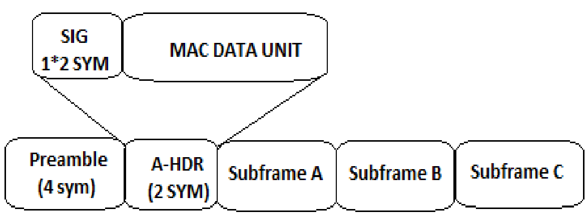

Fig.2 Frame Structure in Pooling

Based on the frame structure above, pooling receivers detect their subframes as follows. Each receiver hearing the frame first checks A-HDR to find out its intended subframe[11]. Then, for every subframe whose position in the frame is prior to the receiver's subframe, the receiver only decodes the SIG symbol to obtain the subframe's length and then skip the whole subframe. This is feasible in existing IEEE 802.11 PHY as the SIG is not scrambled. After decoding its subframe, the receiver drops all rear subframes. For example, as STA *B* checks A-HDR and learns that the second subframe contains its payload. Then, STA *B* decodes the SIG symbols of the first subframe to obtain its length, based on which the location of *B*'s subframe can be computed. STA *B* only decodes the second subframe and drops the rest of the frame.

4. Sequential ACK

The downlink aggregation for multiple receivers, call for a new design of ACK mechanism. As the differences in the signal propagation delays and processing delays can be very small, multiple receivers receive and decode a frame at roughly the same time. In the traditional ACK mechanism, multiple receivers wait for an SIFS interval and return ACKs simultaneously, which would result in collision at AP.

To avoid ACK collisions at AP, a sequential ACK mechanism is adopted to allow receivers to return ACKs one by one. Sequential ACK is achieved by modifying the Network Allocation Vector (NAV) [11]. NAV is a duration field carried by IEEE 802.11 frames to provide virtual carrier sensing. NAV is used to reserve the medium for a fixed time period. The frame uses the NAV to reserve the medium for transmission sequence, i.e., the data frame, its acknowledgement, and the intervening SIFS. To ensure that the transmission sequence is not interrupted, a node sets the NAV in its frame (normally data frame or RTS frame) to block access to the medium while the frame is being transmitted. All nodes that hear the frame defer access to the medium until the NAV elapses. Each node maintains an NAV counter: when the NAV counts down to zero, the channel is idle; otherwise, the channel is busy. All nodes monitor the headers of all frames they hear and update the NAV counters accordingly.

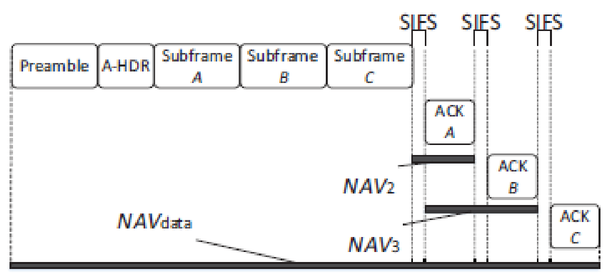

Fig.3 Illustration of sequential ACK

In pooling, it needs to reserve medium for multiple ACKs. We denote the transmission time for data frame, ACK frame, SIFS as $t_{payload}$, t_{ACK}, t_{SIFS}, respectively. If the number of receivers is *N*, the aggregated data frame sets its NAV as

$$NAV_{data} = t_{payload} + N * (t_{ACK} + t_{SIFS}). \quad (1)$$

Then, all nodes hearing the frame defer their access to the channel for NAV_{data}. Receivers return ACKs sequentially according to the order of the subframes: the receiver of the first subframe waits an SIFS interval to return an ACK, while the receiver of the second subframe waits an SIFS interval after the transmission of the first receiver's ACK, and so forth. The position of the receiver's subframe can be obtained after successfully decoding the frame.

To enable sequential ACK transmissions, each receiver automatically updates its NAV after the reception of the frame as follows:

$$NAV_i = (i-1) * (t_{ACK} + t_{SIFS}), \quad (2)$$

where i indicates the receiver of the ith subframe. The receiver of the ith subframe updates its NAV counter by NAV_i after the reception of the frame.

The NAV in sequential ACK is modified to indicate the end of the whole ACK sequence, that is, the jth ACK sets its NAV to NAV_{N-j+1}, where N is the number of receivers and NAV_i is defined by Eq. (2). As such, the last ACK sets its NAV to $NAV_1 = 0$, which is consistent with the legacy ACK.

Note that it is possible that the AP only receives a subset of ACKs. In this case, the AP needs to identify the sources of the missing ACKs to determine which parts of the frame require retransmission. As differences in signal propagation and processing delays for multiple receivers are quite small, the AP can match ACKs to subframes by checking the receiving timestamps of the ACKs.

5. System Evaluation

In this section, we will evaluate the MAC performance of IEEE 802.11n A-MPDU frame aggregation and pooling. Here Network simulator (NS2.34) is the simulator used to simulate the wireless network scenario. In this work, an environment of Wireless LAN network topology with number of wireless nodes is considered. In addition, implemented MPDU aggregation (A-MPDU) as defined in IEEE 802.11n MAC protocol and also implemented a WLAN using the pooling mechanisms and transmitted the packet from source to destination.

To demonstrate the merits of pooling, we implemented the MPDU aggregation (A-MPDU) as defined in IEEE 802.11n [8]. A-MPDU aggregates frames that are buffered at AP for one STA. Pooling differs from this approach in the following aspects: i) Pooling allow aggregation for multiple receivers while A-MPDU restricts aggregation to one STA. Therefore, comparison with A-MPDU shows the advantages of aggregation for multiple STAs in large audience environments, and alleviates traffic asymmetry issue by giving higher priority to downlink transmission in channel contention.

The simulated graphs show the variation End to end delay and throughput with the simulation time in the created WLAN scenario.

From the simulated graph we can observe that the Average End to End delay of the pooling is very low than the A-MPDU. The simulation result shows that the pooling reduces upto 60% delay of A-MPDU aggregation. And also observes that the pooling achieves the throughput of IEEE 802.11n A-MPDU frame aggregation.

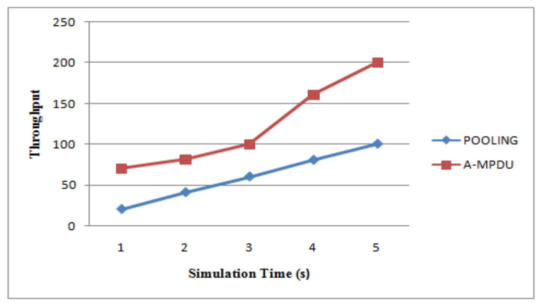

Fig.4 Throughput Vs Simulation Time

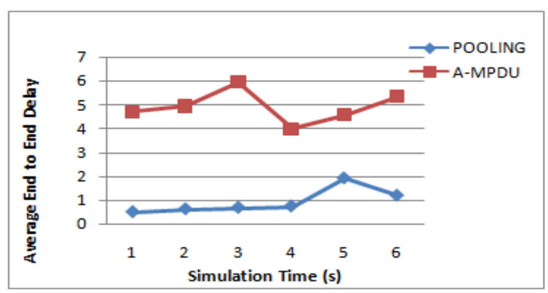

Fig.5 Average End to End Delay Vs Simulation Time

6. Conclusion

In this paper, we investigated the characteristics of Wi-Fi traffic in large audience environments and found that pooling is a promising approach to scale the performance of Wi-Fi in crowded public places. We observe that by enabling frame pooling for multiple STAs in the downlink transmission, the main causes of poor Wi-Fi performance in large audience environments can be addressed simultaneously. T he proposed pooling design facilitates a new dimension to improve the efficiency of public Wi-Fi networks. Pooling is built on the heels of a lightweight frame structure in the existing Wi-Fi standards as an optional mechanism that is enabled in large audience environments to ease heavy contention.

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