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A Reliable A-MSDU Frame Aggregation Scheme in 802.11n Wireless Networks

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Abstract

IEEE 802.11n standard is introduced to enhance the throughput to more than 100Mbps at the MAC service access point. This high throughput is achieved through several enhancements at the physical and MAC layers. Frame aggregation is a key enhancement at the MAC later in which multiple frames are concatenated and then sent in one channel access. In error free channels the 802.11n MAC service data unit aggregation (A-MSDU) performs better than the MAC protocol data unit aggregation (A-MPDU) due to its smaller headers. However, the performance of A-MSDU at erroneous channels is poor due to lack of sub-frames integrity check. In this paper, we proposed an A-MSDU frame aggregation with sub-frame integrity check and retransmission at the MSDU level without altering the original MAC frames header structure. The results show that the proposed scheme improves the system performance in terms of throughput and delay even under highly erroneous channels.

Keywords: Frame aggregation, rA-MSDU, A-MSDU, next generation networks, 802.11n.

1. Introduction

Accessing shared channels in IEEE 802.11 wireless networks is accomplished via the MAC channel access function, namely, distribution coordination function (DCF). The contention-based DCF uses control messages, frames headers and various waiting times in order to ensure a reliable and fair frame transmission. With every frame transmission, existing controls and timers produce a large overhead that consumes the channel time and limits the throughput compared with the actual data rates even if the data rate goes into infinite high [1]. The IEEE 802.11n [2] standard introduces many enhancements at both the PHY and MAC layers in order to overcome these limitations and achieve a throughput of more than 100 Mbps at the MAC service access point (SAP). A key enhancement in 802.11n MAC is frame aggregation in which several frames are concatenated into a single PHY frame and then transmitted in a single channel access. Concatenating multiple frames into a single frame increases the channel utilization and improves the MAC throughput, especially for small frames such as TCP ACK and VoIP frames.
Although many aggregation proposals were introduced in early attempts, such as packing and concatenation [3], and aggregation above the MAC layer [4], their aggregation headers are still considered large for small payloads and they did not address the behavior under erroneous channels. Other aggregation schemes [5, 6] adopted frame fragmentation before performing the aggregation and introduced error control over these fragments. However, these schemes attached large fragmentation headers to the actual frame for de-fragmentation at the receiver side. Moreover, large buffers are required to enable the fragmentation/de-fragmentation processes. The IEEE 802.11n standard adopted two aggregation schemes from TGn Sync [7] and WWiS [8] high throughput proposals for the next generation wireless networks. These schemes are aggregate MAC service data unit (A-MSDU) and aggregate MAC protocol data unit (A-MPDU).

The A-MSDU aggregation is performed at the higher levels of the MAC layer where the coming MAC service data units (MSDUs) are buffered before being transmitted. In this aggregation scheme, if there is a corruption in any subframe of the A-MSDU frame, the whole A-MSDU frame will be dropped.

The A-MPDU frame aggregation is performed at the lower part of the MAC layer where multiple MAC protocol data units (MPDUs) are combined in a single PHY protocol data unit (PPDU) frame. The A-MPDU is formed from the already available packets in the buffer, thus, no waiting time for the MPDUs to arrive during the A-MPDU construction. The corruption of any A-MPDU subframe does not require the retransmission of the whole A-MPDU, only the corrupted MPDUs need to be retransmitted.

Yi-hua, et al. [9], proposed a scheme called gathering error-free block (GEB), which makes use of the correctly received blocks of the frame by extracting and buffering correct bits in the received incorrect frames to assemble the original frame. GEB divides the frame into small blocks and add checksum for these blocks to ensure sending reliability during transmission. Even though this proposal increases the network reliability, overheads are introduced due to frame fragmentation and extra checksum with each block of the frame.

The backlogged queue aggregation (BQA) approach proposed by [10] takes into account both the delay imposed while waiting for more frames to be aggregated and the packet error rate of large aggregated frames. The approach only relays on the length of the backlogged queue as an indicator for the delay-optimal framing and ignores the effect of collision rates. Moreover, the approach will not function properly in unsaturated network where no enough frames are backlogged.

The aggregation from the energy consumption perspective is addressed in [11, 12]. S. Jeon and J. Lee [11] introduces a frame aggregation scheme to enhance the energy efficiency while supporting robust frame delivery. In this scheme the estimation of frame aggregation size depends on the user’s battery status and the high energy efficiency can be achieved by reduction of the excessive channel accesses. D. Camps-Mur, et al. [12] proposed an algorithm called the Congestion Aware-Delayed Frame Aggregation (CA-DFA). The CA-DFA improves the energy efficiency and network capacity by adapting the 802.11n aggregation by the level of congestion in the network. The authors did not consider the congestion and retransmission of the sub frame that might occur due to bit errors.

J. Lin, et al. [13] studied the aggregation from the retransmission perspective, they proposed two automatic repeat request (ARQ) mechanisms with the consideration of frame aggregation under the IEEE 802.11n networks. The aggregated selective repeat ARQ (ASR-ARQ) protocol incorporated the conventional stop-and -wait ARQ scheme, while the aggregated hybrid ARQ (AH-ARQ) algorithm adopted the Reed-Solomon block code for error correction under worse channel quality. All of the above works adopted A-MPDU aggregation and none of them tried to work on the A-MSDU aggregation and take benefit of its small headers.

Yin, et al. [14] studied the effect of the noisy channels on the transmission and showed that the corruption of large frames waste the channel time and lead to low MAC efficiency. However, the main concept behind frame aggregation is to construct large frames out of the small frames. The authors tried to overcome this contradiction by introducing a model that estimates the optimal frame size under a certain bit error rate. Since the A-MPDU provides an integrity check over its subframes while the A-MSDU does not, the integrity check enables the A-MPDU to achieve higher throughput than A-MSDU under noisy channels. However, the case is different under clear channels, where A-MSDU outperforms A-MPDU under the same aggregation size due to its smaller aggregation headers [15, 16]. Ginzburg and Kesselman [17] presented an analytical framework for estimating the maximum throughput of 802.11n using A-MPDU and A-MSDU aggregation schemes and concluded that the performance of A-MSDU aggregation significantly degrades under high bit error rates and high PHY rates. Dionysius, et al. [18] have investigated the improvement of 802.11n throughput under error free channel. They have shown that, both schemes enhance the throughput with an advantage for the A-MPDU due to its large aggregation size. They clearly demonstrated that small packet size is the
key factor that lowers the throughput efficiency. Impact of subframe’s header size while aggregation is investigated in [19, 21]. The work shows that, having an aggregation with small subframe’s header improves performance especially for small packet size applications such as VoIP. More details on frame aggregation types, structures, algorithms and challenges are addressed in [20].

Motivated from that, having frame aggregation with compact headers and robust against bit errors would enhance the system performance. Thus, enabling a subframe integrity check and retransmission at the MSDU level, where the headers are still small, would improve the system performance even under error-prone channels.

In this paper we propose a reliable A-MSDU frame aggregation (rA-MSDU) that enables the sub-frames integrity check and retransmission at the MSDU level and preserves the MSDUs ordering at the receiver side.

The rest of the paper is organized as follows:- section 2 presents the proposed aggregation scheme along with its frame format and algorithms while the performance evaluation and discussion are addressed in section 3. Finally, the conclusion and future works are stated in section 4.

2. The rA-MSDU Aggregation Scheme

The rA-MSDU aggregation scheme enhances the A-MSDU aggregation by adding control fields to the subframe header in order to enable a subframe integrity check and retransmission. The MAC header of the A-MSDU frame is kept unchanged. We only used the variable part of the frame to send the control fields. Since the MAC sequence control is handled at the MPDU level and not at the MSDU level, we have introduced our own implicit MSDU's sequence control based on their relative index in the rA-MSDU frame. The implicit sequence control along with the subframe integrity check and retransmission enables the corrupted subframes to be retransmitted without any duplication and preserves the order of the subframes at the receiver buffer.

2.1. The Frame Format

During the design of the rA-MSDU we have kept the structure of the actual MAC layer unchanged, we only used the variable payload of the MAC frame to build the aggregation. Figure 1 shows the rA-MSDU frame structure where the first byte of the payload is assigned for the common aggregation header (CMN\textsubscript{hdr}) and the remaining payload is assigned for the subframes. From now on we will refer to the aggregated frames as the superframe. The common header is a one byte field, its first 6 bits represent the number of subframes in the superframe, thus, 64 subframes can be addressed. The Lost packet (lp) is a one bit field with a default value of 0. It is set to 1 if the preceding superframe is dropped due to either exceeding the retransmission limit or due to lost ACK. The last bit is reserved for future extension.

The subframe has a maximum size of 2322 bytes and consists of three fields: the subframe header (sf\textsubscript{hdr}), MSDU, and subframe check sequence (sf\textsubscript{fcs}). The MSDU has a variable size of up to 2304 bytes, which is the maximum 802.11 transmission unit. The aggregation size shall not exceed 7935 bytes, which is defined for the A-MSDU in 802.11n. The two bytes sf\textsubscript{fcs} are used to check the integrity of the subframes. Upon failure of the integrity check, the subframe will be marked for retransmission.
The subframe header has a 4-byte control field that holds the subframe length and current attributes. The 12 bits length field is used to express the size of the actual MSDU in the subframe. The retry bit will inform the receiver whether this subframe is a retransmitted subframe or not. If so, this subframe will be checked before being added to the receiver queue (RQ) to avoid duplication. The flush bit is set if the subframe is a retransmitted subframe and its lifetime has expired. Upon receiving a subframe having a flush bit of 1, the receiver will flush out the corresponding subframe from the RQ that has a status flag of 0. The one byte FCS is used to check the validity of the subframe header and the signature byte is used to align the de-aggregation in case there is a corruption in any subframe.

For the ACK frame, we have used the same compressed BA variant of the 802.11n block ACK. However, the start sequence control is not used in our scheme since we are using a session based implicit sequencing in which the index of the MSDU in the superframe is used as a sequence number relative to the current transmission session.

2.2. The Aggregation Scheme Operation

At the scheme operation is shown in figure 2, the received MSDUs from the upper layer are queued in a queue called the transmitting queue (TQ). While constructing the superframe, only the MSDUs that have the same destination address will be associated with the necessary aggregation headers and then appended to the superframe. The index of the subframe in the superframe will be considered as a sequence number of that subframe and the index filed in the TQ of the corresponding MSDU will be updated accordingly. The MSDUs in the TQ that are not involved in the current superframe will have an index of -1. Upon receiving the superframe by the receiver, the de-aggregation process will
start. Based on the FCS of the subframe, the subframe will be added to the RQ with a status flag of 1 if received successfully or 0 otherwise. If the RQ is full the remaining subframes of the current superframe will be dropped and considered as if they were received with errors. The bitmap acknowledgement will be constructed according to the status flags of the subframes in the RQ and then the CBA will be sent back to the sender. If the correctly received subframes are in the correct order, they will be forwarded to the upper layer and then removed from the RQ.

Once the sender receives the CBA, the TQ will be updated according to the received ACK bitmap. If the \( i \)th bit in the bitmap is set to 1, the MSDU with index \( i \) in the TQ will be considered as received correctly and then removed, otherwise it will be considered as lost and will be retransmitted at the head of the next superframe. The lost superframe will be retransmitted according to the 802.11 long retry limit. If the retry limit is exceeded, the MSDUs in TQ that have constituted the current superframe will be dropped and the lost packet flag in the next superframe will be enabled in order to flush out the subframes from the RQ that have a status flag of 0 and were involved in the previous retransmission.

3. Performance Evaluation

Simulation experiments have been conducted in order to evaluate the rA-MSDU performance under different network conditions, MSDU sizes, and data rates. The results are compared with the standard 802.11n A-MSDU under the same conditions.

3.1. Simulations scenarios

We have adopted the point-to-point simulation scenario 17 of the usage model [29], which is intended to evaluate the performance of various aggregation proposals in terms of network throughput and delay. The scenario consists of a single-hop WLAN in which the transmission power of all the stations is high enough to ensure no hidden terminals in the network. All the stations are operating over a 20 MHz. The experiments have been conducted under different frame sizes and bit error rates. The stations have a data source that provides an offered load of 54 Mbps constant bit rate (CBR) traffic. The maximum superframe is set to 8k to agree with the MSDU aggregation size of the 802.11n 2. All the experiments are conducted under high data rights of 150Mbps and 300Mbps using NS-2 simulator version 2.31 [30]. Other simulation parameters are as follows: \( T_{SIFS} = 16 \mu s \), \( T_{DIFS} = 34 \mu s \), \( T_{idle} = 9 \mu s \), \( CW_{min} = 16 \), and \( TQ = RQ = 20 \).

3.2. Results and Discussion

In the first experiment the effect of the MSDU size on the performance of the rA-MSDU scheme has been studied. The experiment has been conducted in a network of 30 stations under erroneous channels of \( 10^{-5} \) BER. Both the throughput and delay have been investigated, figure 3. The throughput of the rA-MSDU increases with the frame size even in erroneous channels where the large frames are likely to be dropped more than the small frames. Due to the rA-MSDU retransmission mechanism, the rA-MSDU does not treat the erroneous superframe as a lost frame. Only the corrupted subframes will be considered lost and marked for retransmission. Figure 3(a) shows the throughput performance of the rA-MSDU under different MSDU sizes and data rates. At a data rate of 300Mbps the throughput is about 50Mbps when the MSDU size is set to 128 bytes and increases to 90Mbps when the MSDU size is set to 1500 bytes. At lower data rates, particularly 150Mbps, the throughput is about 37Mbps and 56Mbps for MSDU size of 128 bytes and 1500 bytes, respectively. The performance gain of the rA-MSDU over the A-MSDU ranges from 9% to 58% depending on the MSDU size. The throughput gain increases with the size of the MSDU since dropping large MSDU in A-MSDU aggregation will have a greater impact on the throughput than dropping small ones. In the case of large MSDUs, the high performance gain comes from the ability of the rA-MSDU to utilize the aggregation size to nearly the maximum with few MSDUs. However, in the case of small MSDUs, utilizing the aggregation size needs a large number of MSDUs which is difficult to obtain due to the no waiting feature. Furthermore, in the case of small MSDUs a large portion of the superframe will be headers and the remaining data part will only have a small contribution on the total throughput.

\(^2\) rA-MSDU can support large superframes payloads unless the aggregation size exceeds 64 subframes, which is the maximum number of subframes that are supported.
The average delay is depicted in figure 3(b). In both schemes the delay increases with the increasing size of the MSDU with a significant advantage for rA-MSDU. The rA-MSDU removes the correctly received subframes from the (TQ) as soon as it receives the ACK even when the superframe is not received completely. However, the A-MSDU scheme preserves the subframe in the queue and keeps retransmitting it until the complete superframe is successfully transmitted in a single channel access.

To investigate the performance of the rA-MSDU scheme under different channel states we run the simulation under different bit error rates ranging from a highly erroneous channel of $10^{-4}$ BER to an error free channel of zero BER. The stations are set to only 10 in order to reduce the impact of collisions on the system throughput. The throughput and average delay are studied under 150Mbps and 300Mbps data rates. Figure 4 shows the impact of the channel error on the throughput of the A-MSDU and rA-MSDU aggregation schemes for MSDUs of size 1024 and 128 bytes, figures 4(a) and 4(b), respectively. They show that the rA-MSDU still survives under high bit error rates due to its subframe error control and retransmission capabilities while A-MSDU can barely transmit anything, especially for large MSDUs. Furthermore, the figures show that large MSDUs are highly influenced by the bit error more than the small ones. At high bit error rates of $10^{-4}$ and large MSDUs of 1024 bytes the throughput of the rA-MSDU reaches about 52Mbps and 34Mbps under 300Mbps and 150Mbps data rates, respectively. However, under error free channels, the throughput reaches about 139Mbps and 87Mbps for the same data rates and MSDU size. Figure 4(b) shows that for small MSDUs and error free channels the A-MSDU slightly outperforms the rA-MSDU due to the control headers that are added to the rA-MSDU subframes to enable the retransmission. However, the significance of the rA-MSDU retransmission becomes clear with a performance gain of about 45% when the channel becomes more erroneous. From the figure we also infer that for error free channels the headers become source of overhead that affects the performance. Thus, optimizing the rA-MSDU headers will significantly improve the system throughput, especially for small MSDUs under any channel condition.

In Figures 5(a) and 5(b), we have shown the delay imposed by the A-MSDU and rA-MSDU while aggregating large and small MSDUs. In both cases the delay is affected by the bit error rates and increases as long as the channel becomes more erroneous. At bit error rates of more than $10^{-5}$, the A-MSDU delay increases sharply due to the large number of transmission retries while the rA-MSDU only has a small delay even for highly erroneous channels. The smaller delay when the MSDU size is small can be elaborated as follows: the smaller superframe that is constructed from small MSDUs will experience less retransmission attempts and less transmission time than the large superframe that is constructed from the large MSDUs. Thus, the high throughput and small delay of the rA-MSDU at different BER rates make it a significant aggregation solution for applications such as VoIP, which have small packet size and are subjected to delay constraints.
4. Conclusion and Future Work

Frame aggregation significantly increases the throughput by resolving the headers and timing overheads of the existing IEEE 802.11 MAC distribution coordination function. In this work we have proposed an MSDU aggregation scheme, namely rA-MSDU, which enables subframe integrity check and retransmission at the MSDU level. The proposed scheme uses an implicit subframe sequence control mechanism to manage the ordering of the frames at the receiver side without any additional sequence numbers. The simulation results show that the rA-MSDU schemes can significantly improve the system performance by increasing the throughput and reducing the delay under various channel conditions. In the future we are planning to enhance the scheme and make it dynamically adapt to the network conditions based on the subframes status carried on the ACK bitmap.

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