Transmission of Multimedia Data over Next Generation Wireless Networks*

Muhammad Mahbub Alam, Md. Mamun-or-Rashid, Choong Seon Hong**
Department of Computer Engineering, Kyung Hee University
1 Seochun-ri, Kiheung-eup, Yongin-si, Kyunggi-do, Korea, 449-701
{mahbub, mamun}@networking.khu.ac.kr and cshong@khu.ac.kr

***Abstract* — To overcome the low effective throughput of the popular IEEE 802.11 WLANs, a high performance WLAN standard is being developed. This new standard not only increases the raw PHY data rate but also increases the effective throughput with different MAC layer enhancements, such as frame aggregation. For small size multimedia data packet frame aggregation can improve the quality of service (QoS) of the applications. However, the wireless channel is often time varying and location dependent. Therefore aggregation of frames increases the probability of error, since the size of the frame is increased. With erroneous wireless channel an optimum value of aggregation size can greatly improve the performance of the multimedia applications. In this paper we propose a mechanism to dynamically select the aggregation size based on the channel condition prediction which reduces the number frames dropped due to wireless error. Also within a certain delay bound a link level retransmission mechanism can be used to improve the quality of the multimedia applications.**

***Keywords* — Wireless LAN, Multimedia data, Frame Aggregation, End-to-end Delay, Retransmission.**

1. Introduction

Wireless networks are becoming more popular in the recent days and the demands of the users are increasing rapidly especially for different type of multimedia applications. These applications have very stringent quality of service (QoS) requirements such as high data rate, low delay and low delay jitter. Examples of such applications are multimedia conferencing, MPEG video streaming, simultaneous transmission of multiple HDTV signals, audio and online gaming etc. To meet these requirements currently the IEEE 802.11 task group is working on the next generation of WLAN standard which will support at least 130 Mbps, and potentially goes beyond 600 Mbps [1], which is about ten times higher than the current IEEE 802.11a/g.

The IEEE 802.11 with PHY rates 1 and 2 Mbps is the first international standard for wireless local area networks (WLANs), and it has been used widely in most commercial WLAN products available. Also two new high speed PHY specifications were additionally defined, IEEE 802.11a [5] and IEEE 802.11b [6]. The IEEE 802.11a provides PHY transmission rates from 6 to 54 Mbps, while IEEE 802.11b provides 1, 2, 5.5 and 11 Mbps raw PHY transmission rates. The IEEE 802.11g [7] supports up to 54 Mbps. Recently the IEEE 802.11 task group is working on the next generation of WLAN standard which is IEEE 802.11n [1].

The throughput of IEEE 802.11 WLAN is very poor as compared to the underlying PHY layer data rates [4]. The practically achievable throughput using the 802.11a 54 Mbps transmission rate is about 25 Mbps. The reason for this low achievable throughput is the overheads of MAC and PHY layers such as MAC header, Physical layer convergence Protocol (PLCP) preamble/header, acknowledgement (ACK) transmission at the MAC layer, the Inter Frame spaces used at the MAC layer. The use of RTS/CTS mechanism further reduces the effective throughput. Each transmitted data frame in WLAN incurs these overheads. So the size of the data frame has impact on the effective data rate. If the size of the data frames is small then the effective throughput will also be low, that is the throughput decreases with decrease in the size of the data frames.

In order to improve the throughput and enhance QoS support, different techniques at the MAC and PHY layers have been adopted, such as frame aggregation, block acknowledgement, traffic differentiation of IEEE 802.11e [2], multiple-input and multiple-output (MIMO), channel bonding, etc. However, the wireless channel is often time varying and location dependent. The channel capacity can vary significantly due to fading effect which causes variable signal to noise ratio (SNR) and has a high bit error rate (BER) as compared to the wired networks. On the other hand, to provide better QoS, especially for multimedia applications, a high data rate is also desirable [8].

In this paper we propose a combined technique of frame aggregation and retransmission in the link level to increase the performance of multimedia applications, such as video streaming over IEEE 802.11n which can be used over single or multi-hop networks.

The rest of the paper is organized as follows. Section 2 describes the overview of the throughput of IEEE WLANs. In section 3, the problems of the WLAN are explained for the transmission of multimedia data. Section 4 presents the proposed mechanism and is followed by the performance evaluation in section 5. In section 6 we conclude by conclusion and future work.

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** Corresponding author

2. Overview of the IEEE WLAN

A. IEEE 802.11n: High Throughput WLAN

The IEEE 802.11n is a standard with a maximum bandwidth of 540 Mbps, and is designed to replace the slower IEEE 802.11a and IEEE 802.11g. The standard differs from its predecessors in that it provides a variety of optional modes and configurations that gives different maximum raw data rates. One of the most important features in the draft-n specification is to improve performance by frame aggregation. Rather than sending a single data frame, the transmitting station can bundle several frames together. Frame aggregation can reduce the overhead of PHY/MAC and thus can improve the effective throughput of WLAN. IEEE 802.11n supports the following methods of frame aggregations:

Aggregated MSDU Format (A-MSDU): The purpose of the A-MSDU is to allow multiple MSDUs being sent to the same receiver to be aggregated and sent in a single MPDU, which improves the efficiency of the MAC layer, particularly when there are many small MSDUs such as TCP acknowledgement. The structure of a Data MPDU containing an A-MSDU, which is a sequence of n MSDU sub-frames is shown in figure 1. This aggregation is performed between LLC and MAC layer.

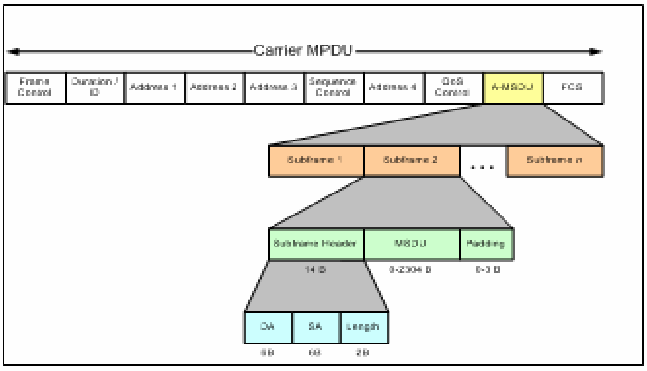

Figure 1. A-MSDU Structure

Aggregated MPDU format (A-MPDU): An A-MPDU consists of a number of MPDU delimiters each followed by an MPDU. Except when it is the last MPDU, padding octets are appended to make each section a multiple of 4 octets in length. The purpose of the MPDU delimiter is to robustly delimit the MPDUs within the aggregate. Robust in this case means that the structure of the aggregate can usually be recovered when one or more MPDU delimiters are received with errors. Individual delimiters have the same BER as the surrounding MPDUs. The structure of an A-MPDU is shown in figure 2. This aggregation is performed at the MAC layer.

B. Impact of Frame Aggregation

In ideal channel condition, with frame aggregation the channel utilization can be given by (1) [3]:

$$S_{ideal} = \frac{T_{payload}}{T_{DIFS} + T_{\overline{CW}} + T_{RTS} + T_{CTS} + 3T_{SIFS} + 4T_{PHYhdr} + 4T_{MAChdr} + n * T_{Payload} + T_{ACK} + 4\delta} \quad (1)$$

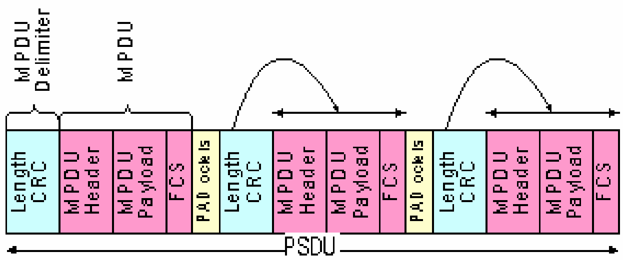

Figure 2. A-MPDU format

Since the PHY/MAC layer parameters of 802.11n have not been decided by the TGn group, to measure the throughput we assume its compatibility with the IEEE 802.11a/g standards. Table 1 summarizes the default MAC/PHY layer parameters we have used for performance measurement. Fig. 3 shows the analytical result of the channel utilization as function of aggregation size. The channel utilization increases as the aggregation size is increased, which is expected.

Table 1. parameters used for 802.11n PHY/MAC

Parameter	Value
MAC transmission rate	144 Mbps
SIFS	16 micro seconds
DIFS	34 micro seconds
CW_{min}	15
RTS Duration	2.7 micro seconds
CTS Duration	1.93 micro seconds
MAC Header (Bytes)	30
PHY Header duration	20 microseconds
Payload Duration	12.2 microseconds
ACK Length (bits)	112
CRC (bits)	32
Propagation Delay, δ	1 microseconds

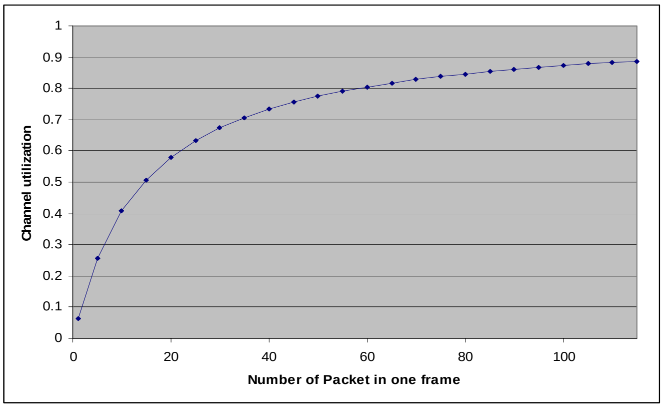

Figure 3. Channel utilization as a function of aggregation size

As shown in figure 3, the throughput increases with the increment of frame size. If we infinitely increase the number of frames in an aggregate frame the effective channel utilization reaches very close to 1.

C. Retransmission at the Link Level

Even though a simple packet aggregation scheme improves the throughput in an ideal wireless condition, the throughput can be degraded in noisy/fading wireless channel condition. With aggregation the size of the aggregated frame increases, whereas the BER is related with the size of the frame, a large frame has higher probability to be corrupted. Therefore an aggregated frame has higher probability of error. If only the corrupted frame(s) within an aggregated frame is retransmitted then the throughput of the MAC layer can be significantly improved even with bad channel condition. However, in sequence data delivery is not possible with selected MAC level data retransmission. So the MAC layer may deliver the data out of sequence. Out of sequence delivery is also useful for multimedia application, it increases channel utilization. In-sequence data delivery, which uses simple retransmission mechanism, such as ARQ, does not send the next packet until it receives the acknowledgement of the previous packet. On the other hand, for every packet of a multimedia stream there is an end-to-end delay bound. A node should not retransmit the packet after a long delay or should not retransmit repeatedly, because if the delay is greater than the delay bound the delivery of this packet is useless. The retransmission mechanism and the maximum retransmission limit are very important for the transmission of multimedia data over wireless network especially with frame aggregation.

3. Problem Description

As mentioned earlier multimedia applications require certain QoS guarantee such as bandwidth, delay and delay bound. To support these, there are several important PHY/MAC features in IEEE 802.11n such as frame aggregation, high PHY layer transmission rate, MIMO and block acknowledgement, etc. to achieve the requirement(s). But the presence of time varying and location dependent error in wireless channel is a problem to achieve the goals consistently. To overcome this, a dynamic setting of frame aggregation size, n that is, the number of frames in an aggregate frame and a suitable retransmission policy is required which in turn will achieve the stringent requirement of multimedia applications.

In a multimedia application often the size of the packet is small and packets are generated at a high rate. For such small packets the overhead of the MAC/PHY layer results in a poor throughput efficiency which severely affects the quality of the high data rate video applications such as MPEG2 TS. IEEE 802.11n frame aggregation scheme can significantly reduce the MAC/PHY layer overhead and thus improves the throughput of the network which in turn improves the quality of the video transmission. But the number of frames in an aggregate frame can greatly affect the performance of the video transmission. If a large number of frames are aggregated in a single frame this will create following problems. First, if a node waits for a long time to get maximum number of frames, this will increase the end-to-end delay. Second, the probability of error will increase if we increase the size of the aggregated frame. So we need to find an optimum value of aggregation size for a particular application. Third, a suitable link level retransmission strategy is required to retransmit a damaged frame which meets the delay bound, because retransmitting a frame which does not meet the deadline is completely useless and just a wastage of the limited wireless resource. Furthermore, the maximum retransmission limit can affect the performance of the multimedia applications. If a particular frame is repeatedly retransmitted, then the delay for the frame is increased and the frame may be useless to the destination multimedia application.

4. Proposed Mechanism

In this section, explain the proposed mechanism which achieves high throughput for multimedia data over IEEE 802.11n WLAN.

A. Frame Aggregation Size

Aggregation of more than one frame can improve the network efficiency due to the fact that the overhead associated with MAC/PHY layer can be overcome by transmitting long frame [3]. However, there is a trade off between the number of aggregated frames and the throughput gain [4]. So we need to find the maximum aggregation size (number of frame in an aggregated frame) for a particular application in an ideal wireless condition.

The throughput efficiency of about more than 80% at an ideal wireless condition can be considered as optimum. The aggregation size on the other hand is directly related with the packet size of a particular multimedia application. So for a particular application with a given packet size, the maximum aggregation size can be found in ideal wireless condition. Therefore the aggregation size is dynamically calculated the wireless node based on the maximum size of an aggregated frame.

However, as the size of the MAC frame increases the chance of error also increases. So transmitting frame at maximum aggregation size will increase the frame error rate. Also the channel error is location dependent and occurs for very short period time. Even though the whole aggregated frame is not corrupted due to error and only corrupted sub-frames are needed to be transmitted, for two reasons, a node should not always transmit at its maximum aggregation size. First, if a node transmits at bad channel condition, then most of the sub-frames will be corrupted, whereas other node may perceives good channel. So, in bad condition, a node should not transmit with maximum aggregation size and capture the channel where most of the transmission is useless. Second, a corrupted frame has to be retransmitted which reduces the overall link efficiency and increase the per packet delay. If another node having good channel can transmit then throughput will be increased. And later time, when this node perceives good channel can transmit. Therefore the aggregation size should be dynamically set based on channel condition. The transmitting node will observe the channel condition and accordingly set the aggregation size. The channel state can be detected as follows: each node periodically measures the signal-to-noise ratio of channel. Based on the measured value of the SNR a node can decide the channel status. If the SNR is below a certain threshold, the channel can be considered as bad and the node should transmit with minimum aggregation size. The channel status can be classified into different levels based on the measured SNR. We consider the channel condition as Good, Medium and Bad and a node transmit with aggregation size N, N/4 and N/10 respectively, where N is the maximum aggregation sizes with ideal channel. This scheme will decrease the individual frame error rate and unnecessary retransmission.

B. End-to-End Delay Bound

For multimedia applications there is an end-to-end delay bound. If the receiving station receives the data after expiration of the delay bound then most of the cases the data is useless. Frame aggregation in one hand decrease the end-to-end delay as more frames are transmitted in one group and on the other hand increase the delay when to aggregate more frames a node may has to wait a longer period of time, especially in case of multi-hop networks. Therefore a node should not wait indefinitely to transmit maximum number of frames as allowed by the current channel condition in an aggregate frame if that number of frames is not available. If the node waits to get maximum number of frames, especially the forwarding nodes, then the end-to-end delay of the multimedia data will be increased. In the worst case, all frames in an aggregated frame may reach the destination node after the delay bound and the destination node will drop these. This may decrease the ultimate goodput and effective channel utilization will be reduced. On the other hand limited wireless resource and energy of a mobile node will consumed unnecessarily. And finally such delay merely increases the packet delivery number only. Therefore, a station should not wait more than a certain amount of time, after which the station must have to transmit even with a single frame. This may reduce the overall throughput but increase the goodput, because transmitted data will be utilized at the destination node.

C. Link Level Retransmission

Even though controlling the aggregation size based on the current channel condition will reduce the probability of error but it does not guarantee error free transmission. This may happen due to the fact that channel prediction will not be perfect all the times. Also if a station transmits a single MAC frame instead of aggregating several MAC frames, this single frame can be affected by error due to the high error rate of wireless channel. So to improve the quality of multimedia application a suitable retransmission policy should be incorporated.

While retransmitting data we should consider two things: whether the whole aggregate frame will be retransmitted or only the affected MAC frames inside the aggregate frame will be retransmitted and the delay requirement of the data. In the first case, when frames are aggregated if all individual MAC frames have their CRC data then only the affected frame can be retransmitted instead of the whole frame. In the second case, before retransmitting a frame a station should consider whether the retransmitted frame can meet the deadline or not. Retransmitting a frame that does not meet the deadline is useless and just waste the limited wireless resource. But deciding whether a retransmitted frame can meet the deadline or not is very crucial, especially when a particular frame is retransmitted more than once. That is selecting the maximum retransmission limit for a particular application can greatly affect the performance. A transmitted frame can improve the video quality in one hand, on the other hand if it does not meet the deadline it will be wastage. Furthermore, most of the multimedia applications can tolerate loss of packet up to a certain limit. By simulation we have found that a value of 2 provides the optimum value. However, maximum retransmission limit can vary with the requirement of a particular application.

5. Performance Evaluation

In this section we evaluate the throughput enhancement of IEEE 802.11n by frame aggregation. At the same time the impact of aggregation and retransmission on end-to-end delay are also evaluated. For performance evaluation we used the values of different parameters as given in table 1.

A. Performance Metrics

We evaluate the effectiveness of the proposed mechanism based on the following metrics:

- *Effective channel utilization*: It is defined as the number of successful frame transmitted with aggregation or in opposite words the number of frame dropped due to wireless error with fixed aggregation size and channel condition adaptive aggregation size.
- *End-to-end delay*: It is defined as the delay of delivering a multimedia frame from source to the destination.

B. Effective Channel Utilization

For measuring the number of dropped frames with aggregation size in the presence of wireless error, we considered the channel condition as Good, Medium and Bad. In good channel condition the sender sends packet with maximum aggregation size and in bad channel condition with aggregation size 1. But in medium channel condition, the aggregation size is variable. Figure 4 shows number of frame dropped due to error with maximum aggregation size and channel condition adaptive aggregation size. With adaptive aggregation size, the sender will send less number of frames in an aggregate frame and therefore less number of frames are affected which also reduces the number of retransmission.

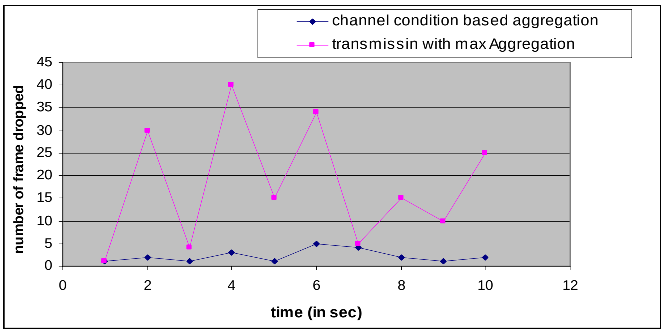

Figure 4. Number of frame dropped due to wireless error as a function of aggregation size

C. End-to-End Delay:

To measure the end-to-end delay we considered two conditions. First, we measured the end-to-end delay with no link level transmission and observed how the end-to-end delay varies with the size of frame aggregation. Second, we measured the end-to-end delay with link level retransmission. Figure 5 shows the average end-to-end delay of multimedia packet with frame aggregation and without link level retransmission.

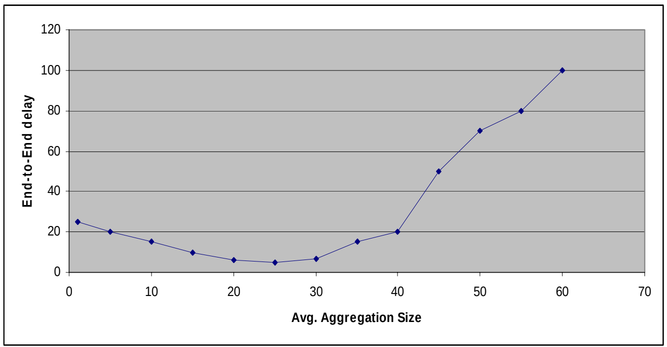

Figure 5. Average End-to-end delay with respect to aggregation size

As shown in figure 5, initially the end-to-end delay decreases with aggregation size and the reason is that more frames are transmitted simultaneously so overall delay decreases. Without aggregation the sender has to contend for the channel access for every frame and wait the backoff period, but with aggregation a single backoff period is used for all the frames. On the other hand, with a high value of aggregation size the delay also increases. The reason is that, after a certain threshold a sender has to wait to gather the frames which increases the delay of the previously received frames and increases the average delay.

Figure 6 shows the average end-to-end delay with maximum retransmission limit 2 as a function of aggregation size.

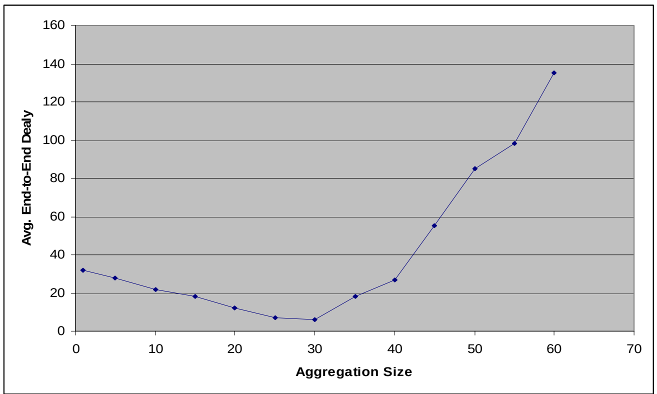

Figure 6. Average End-to-End delay with Link Level Retransmission

The average end-to-end delay increases with retransmission which is expected. If we increase the maximum retransmission limit the delay will be further increased. On the other hand link level retransmission increases the goodput and multimedia output quality.

6. Conclusion

In this paper we consider the transmission of multimedia data in IEEE 802.11n wireless networks with erroneous wireless channels where aggregation of several frame increases the throughput. We have shown that aggregation without considering the channel condition may reduce the overall goodput and we propose a mechanism that controls the aggregation size based on the wireless channel prediction. In addition, an appropriate transmission strategy can greatly improve the quality of the multimedia applications. A joint mechanism of aggregation size and retransmission policy can provide an optimum throughput of a particular multimedia application. As a future work we like to measure the performance of our proposed mechanism by analytical modeling. Also, we like to measure the fairness with aggregation.

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