A Frame Aggregation Scheduler for IEEE 802.11n

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***Abstract*—Wireless Local Area Networks (WLANs) based on the IEEE 802.11 standard are widely deployed in the home and enterprise segments across the globe. The IEEE 802.11n is the latest amendment that aims to achieve throughput higher than 100 Mbps at the medium access control (MAC) layer. It defines two frame aggregation schemes to improve the efficiency over the basic 802.11 MAC layer. However, the IEEE specifications do not specify the scheduler for these schemes and it is left as vendor's choice. This paper presents a detailed simulation study of these aggregation schemes and presents a simple frame aggregation scheduler. The proposed method dynamically chooses the aggregated frame size and aggregation technique based on various relevant parameters.**

Index Terms— 802.11n, A-MSDU, A-MPDU, Frame Aggregation, WLAN

I. INTRODUCTION

The main objective of the IEEE 802.11n standard is to achieve 100 Mbps of throughput at the MAC layer. To achieve this goal, the IEEE 802.11n Task Group (TGn) has come up with many amendments to address the various issues related to physical (PHY) layer, medium access control (MAC) layer and enhance the functionalities of WLAN. Products that are commercially available in the market are based on the stable draft version of the IEEE 802.11n standard. The Wi-Fi Alliance (WFA) is an industry consortium which certifies the WLAN products using draft 2 version of IEEE 802.11n [1]. The IEEE 802.11n enhances both MAC and PHY layer to support higher data rates, better coverage, and backward compatibility with legacy devices. The use of multiple input multiple output (MIMO) technology along with OFDM (MIMO-OFDM) and doubling of the channel bandwidth from 20 MHz to 40 MHz helps increase the data rate of the PHY layer up to 600 Mbps. Frame aggregation and enhanced block ack are the most important new MAC layer features in IEEE 802.11n. Apart from these enhancements, there are plenty of optional MAC features. Some of them include advanced power save techniques and the ability to reserve the medium for a bidirectional link [2-3]. Recently, the IEEE 802.11n standard has been ratified [4]. However most of the changes are editorial changes with reference to the draft version that has been used.

An analytical model for distributed coordination function (DCF) based on two-dimensional Markov chain was proposed by Bianchi [5] to determine the saturation throughput in a WLAN. Yuxia Lin *et al*. [6] extended the Bianchi model to support frame aggregation schemes and proposed a simple optimal frame size adaptation algorithm for aggregation schemes under error prone channels. Dionysius Skordoulis et al. [7] investigated the improvement of throughput by using these aggregation schemes in an ideal channel. Previous studies have discussed the performance of aggregation schemes rather than the scheduling. In this paper, we present a simple scheduler for frame aggregation technique which will determine the size of the aggregated frame and choose the particular aggregation scheme based on various relevant parameters in the network.

The rest of this paper is organized as follows. Section II discusses the aggregation schemes in detail. In section III we briefly introduce the design of our proposed scheduler. Section IV deals with the simulation setup and results. Finally, section V concludes with future work that we plan to do.

II. AGGREGATION IN IEEE 802.11N

Increasing the data rate of PHY layer alone is not sufficient to achieve the desired MAC layer throughput of more than 100 Mbps due to rate independent overheads [8]. To overcome this issue, frame aggregation at the MAC layer is proposed in 802.11n to improve the efficiency. There are two types of aggregation defined in IEEE 802.11n [2-3] which are listed below.

- Aggregate-MSDU (A-MSDU)
- Aggregate-MPDU (A-MPDU)

A. A-MSDU Scheme

In the A-MSDU scheme, multiple MSDUs are aggregated to form a MPDU which could consist of multiple sub frames either from multiple sources or for multiple destinations. Fig. 1 illustrates the frame format of an A-MSDU. An A-MSDU consists of multiple sub frames. Each sub frame of an A-MSDU has a sub header (Destination address, Source Address, Length), MSDU, and padding bytes. The size of the MSDU in each sub frame can be different. The padding bytes are appended to make the length of the sub frame a multiple of 4 bytes except for the last sub frame. All the sub frames share a common MAC header and frame check sequence (FCS) which is calculated over all the sub frames and a common MAC header and then appended as the trailer. The A-MSDU frame is considered as a single MPDU by the PHY layer. Since there is no checksum for the individual sub frames, selective retransmission of corrupted sub frames is not possible. All the sub frames have the same sequence number and traffic identifier (TID) [2-3]. The maximum length of an A-MSDU frame can be 3839 or 7955 bytes. This capability information is exchanged during the time of association.

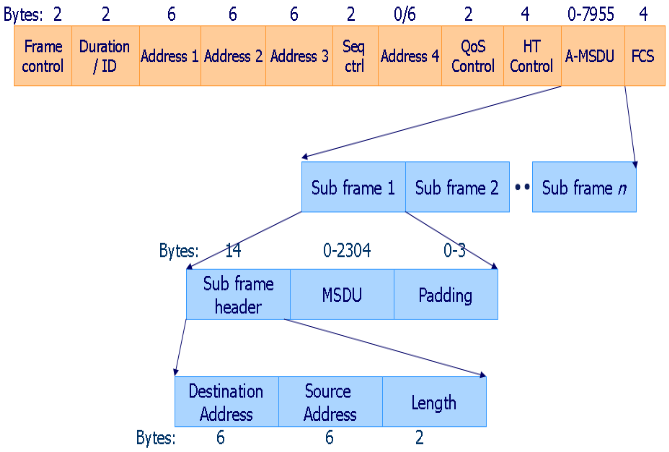

Figure 1. A-MSDU Frame format

In uplink transmissions the common MAC header contains only source and the access point's (AP's) address. The corresponding destination addresses are present only in the sub headers. In the uplink transmission, a station can pack MSDUs destined for multiple destinations and send it to the AP. In downlink transmission, the AP can pack multiple MSDUs from various source addresses and send it to a single radio destination. An A-MSDU frame cannot be sent to multiple radio receivers.

B. A-MPDU Scheme

Multiple MPDUs with a common PHY header are aggregated as an A-MPDU which can contain MSDUs and/or A-MSDUs. The size of each subframe must be a multiple of 4 bytes except for the last sub frame.

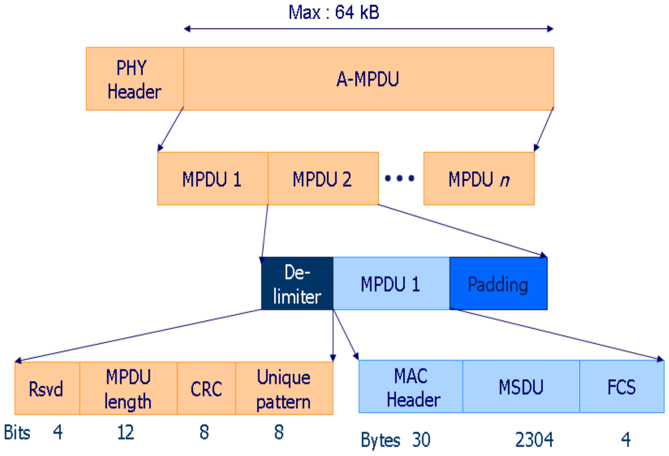

Figure 2. A-MPDU frame format

Fig. 2 shows the structure of an A-MPDU frame. Each MPDU is prefixed with a delimiter. The delimiter contains MPDU length, cyclic redundancy check (CRC) and unique pattern. The first four bits in the delimiter are reserved and currently not used. MPDU Length subfield consists of 12 bits that are used for representing the length of the current MPDU. CRC calculation includes reserved and length sub fields. The unique pattern is used to find the next delimiter with minimal computation in case of a corrupted delimiter. Padding bytes are appended at the end of each MPDU to make the size as a multiple of 4 bytes. Padding bytes are not necessary for the last MPDU.

In the uplink, the transmission procedure is the same as A-MSDU. In the downlink, the AP can aggregate frames from multiple sources destined to a single radio receiver with the help of block acknowledgement (BA). Selective retransmission is possible in this aggregation scheme due to the presence of individual FCS for each MPDU. All the MPDUs in an A-MPDU belong to the same TID to effectively work with BA mechanism. The maximum length of an A-MPDU frame is 64 KB. Capability to receive max size of A-MPDU is different for each STA and this capability information is announced at the time of network entry process.

Even though an A-MPDU frame can have a maximum size of 64 KB, it can aggregate a maximum of 64 MSDUs. This limitation arises due to the use of BA mechanism. Two level aggregation can be used wherein multiple A-MSDUs each carrying more than one MSDU are aggregated to form an A-MPDU. In this scheme the size of A-MSDU frame should not exceed 4 KB.

III. SCHEDULER DESIGN

Each aggregation scheme has its benefits and drawbacks. A-MSDU is very effective in ideal channel conditions due to lesser protocol overheads. However, in a noisy environment it yields poor performance due to the lack of an individual FCS for each subframe. On the other hand, A-MPDU is robust against errors due to the presence of individual CRC per MPDU and the aggregated frame size can be up to 64 KB. Since it can accommodate large number of frames it can result in an increased delay. Even though aggregating more number of frames in any aggregation scheme helps to increase the throughput it can increase the delay. Hence, tradeoff exists between the throughput and delay. The IEEE specifications do not specify any guidelines to use these aggregation schemes. The proposed scheduler aims to aggregate frames by estimating the time deadline to transmit an aggregated frame and dynamically select the aggregation scheme. Fig. 3 illustrates the functional block diagram of the proposed scheduler. The steps involved in the scheduler are summarized as follows

- Mapping two TIDs into a single TID
- Estimation of optimal time based on deadline
- Lookup optimal frame size for the given BER
- Sort frames in ascending order
- Selection of aggregation scheme

As per the IEEE specification, all the aggregation schemes should aggregate frames from the same TID, except in certain power save operation scenarios. In general, two TIDs are mapped into a single access category (AC) and each AC has separate queues. These two different TIDs in a queue are treated similarly by the MAC layer. When aggregation is enabled, these TIDs virtually split the queue into two with the same medium access parameters. Frames are aggregated separately within a queue based on the TID. Frame aggregation can be done effectively as a single queue rather than these two virtual queues. In our work we represent the two TIDs into a single one. For instance, TIDs 4 and 5 are mapped to video AC. But the proposed scheduler renames it either 4 or 5. Hence it is easier to aggregate packets.

Frame aggregation is very effective in the case of saturated traffic. Otherwise it has to wait for further packets which increases the delay. Especially, packets that arrive earlier suffer more due to this delay. By considering this delay, we estimate the deadline which is based on the earliest expiry time of a frame which is waiting in the queue. Deadline is represented as $T_{deadline}$ and it is the absolute time to transmit an aggregated frame without violating the deadline of any of the aggregated packets. It is calculated as follows:

$$T_{deadline} = T_{ex} - \left(N_{retry} * T_{tx}\right)$$

Where T_{ex} is the earliest expiry time among all the packets that are waiting in the queue for frame aggregation. After this time, the frame is discarded from the queue. N_{retry} is the average number of retransmissions due to collisions and channel errors. T_{tx} represents the required time to transmit an aggregated frame that is inclusive of the waiting time. The parameter $T_{deadline}$ is updated whenever a new frame is added to the queue. This is due to the fact that the addition of a new frame will increase the size of existing aggregated frame which in turn will affect the parameter T_{tx}.

With increase in frame size, there is a higher chance for channel errors. Since the A-MSDU scheme does not support selective retransmission, larger aggregated frames reduce the efficiency of MAC layer in noisy environments. Thus, the size of an A-MSDU frame should be optimal. A lookup table is formed that consists of various bit error rates (BERs) and the corresponding optimal frame size [6]. Finally, the aggregation type is selected based on the buffer size. The term “buffer size” is defined as the cumulative size of frames that are waiting in the queue for aggregation. If the available buffer size is less than the optimal size, which is inferred from the lookup table, then the A-MSDU scheme is selected. Otherwise two level aggregation is selected. In the case of two level aggregation, frames in a queue are sorted by payload size in ascending order. The sorting process helps to effectively fill the frames with minimal number of sub headers. The size of A-MSDU frames which are inside an A-MPDU is based on the optimal frame size. Once the deadline is reached or the size of the aggregated frame has reached the maximum limit the frame is scheduled for transmission. When data frames are transmitted under the BA agreement they are not subject to any retry limits but only to MSDU lifetime. To utilize more retransmission attempts we have considered compressed block ack in our paper.

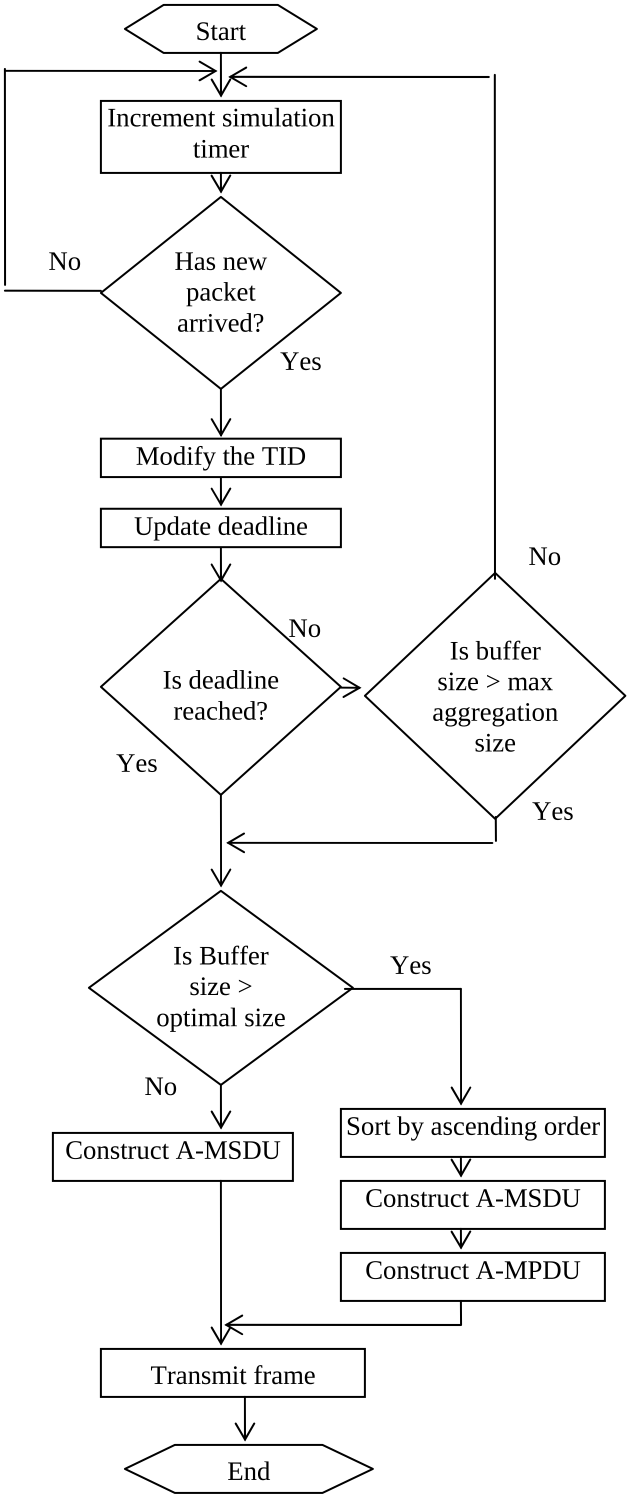

Figure 3. Functions of the proposed frame aggregation scheduler

IV. SIMULATION SETUP AND RESULTS

We have developed a customized simulator in C language for the simulation environment. This work consists of 2 phases. In the first phase, we are finding the saturation throughput of an A-MPDU scheme. In the second phase we compare the performance of the proposed method with the fixed size aggregation schemes in both ideal and error prone channel conditions. The simulation scenario consists of an 802.11n AP and an STA operating in 20 MHz bandwidth. Traffic load is generated from 1 to 70 Mbps. For the given load, packet interval is kept constant and the frame size is uniformly distributed from 100 to 1500 bytes with a granularity of 100 bytes. We assume that the maximum life time of a frame is 100 ms. A frame is dropped by the queue if it is waiting for more than this duration until scheduled for aggregation. Data frames are transmitted at 65 Mbps and the control frames are transmitted at 24 Mbps. RTS-CTS transmission is enabled.

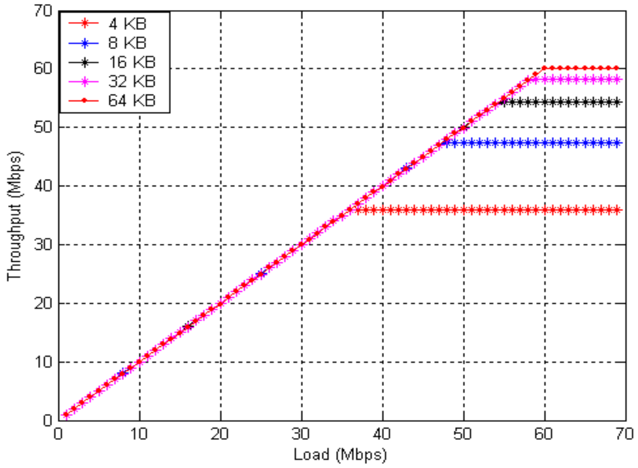

Figure 4. Aggregation size vs throughput in A-MPDU scheme

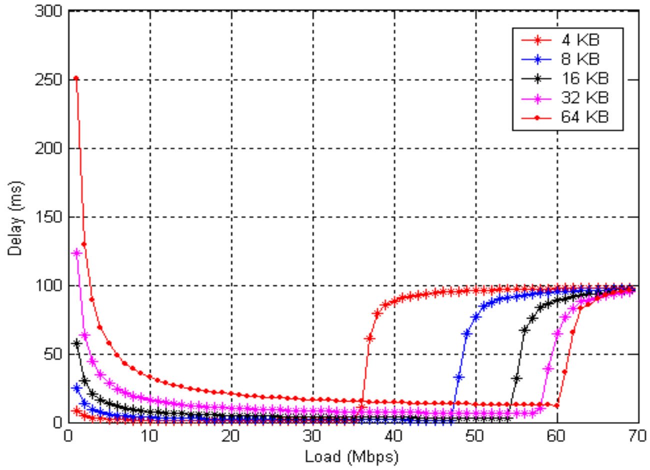

Figure 5. Aggregation size vs delay in A-MPDU scheme

In figs 4 and 5, we compare the throughput and delay with various frame aggregation thresholds for the A-MPDU scheme. Throughput linearly increases with load and finally reaches saturation point. The throughput with lower aggregation threshold saturates earlier than in the higher threshold case. Aggregation threshold of 4 KB saturates at 36 Mbps and the aggregation threshold of 64 KB saturates at 60 Mbps. When the aggregation threshold is doubled, i.e, from 4 to 8 KB, the achieved throughput is not increased by 2 times but the average delay is doubled. Average delay is reduced when the load is increased due to the presence of more frames but it increases once the load increases past the saturation value.

In the second phase, video AC with two TIDs is considered. Traffic load is generated from 1 Mbps to 30 Mbps for each TID. The resulting throughput values are cumulative of both traffic TIDs and the delay is the mean value of these TIDs. Other parameters are the same as mentioned earlier.

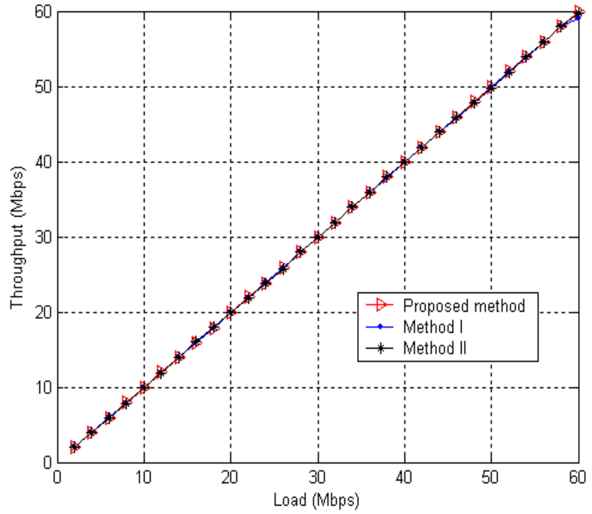

Figure 6. Throughput comparison of fixed size aggregation vs proposed method

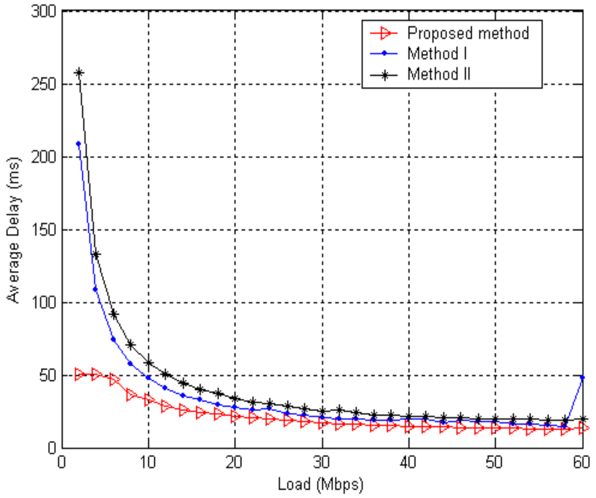

Figure 7. Delay comparison of fixed size vs proposed method

We compared the performance of proposed method with the following fixed size aggregation schemes.

- Method I (A-MPDU with the size of 64 KB)
- Method II (Two level with the size of 64 KB)

In fig. 6, we compared the MAC layer throughput with different aggregation methods. In the proposed method the maximum size of the aggregated frame is decided based on the delay requirements. Throughput linearly increases with load due to the unsaturated traffic. Since we are focusing on unsaturated traffic, the difference is only with respect to delay rather than the throughput among the aggregation methods. Fig. 7 compares the average delay with different aggregation methods. Even though the throughput is same in all the methods, the average delay is different. For instance consider a load of 2 Mbps, the delay for method II and method I is around 257 ms and 208 ms, respectively. However, in the proposed method the delay is around 50 ms. Method II always reaches higher delay than the other schemes due to aggregating more number of frames. Thus it will wait much more time to get the packets. Average delay decreases when the traffic load increases. This is due to the presence of more frames in the queue. For the above results, noiseless environment is assumed (BER = 0) and hence the above presented results shows the impact of TID mapping and the estimation of deadline alone.

To investigate the performance in a noisy environment, we considered a BER of 2e-5. Other parameters are same as mentioned earlier. Corrupted frames due to channel effects are retransmitted until the expiry time of a frame.

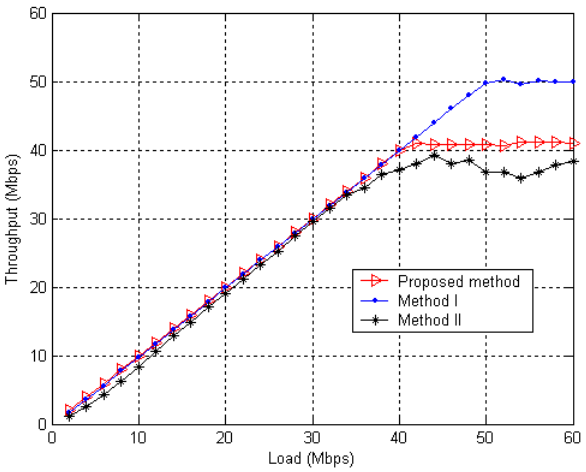

Figure 8. Throughput comparison with BER 2e-5

From figs. 8 and 9, we can observe, that the performance of method II is very poor in error prone environment when compared with other schemes. Consider a load of 40 Mbps, the method II fails to score the throughput of given load due to dropped packets and the average delay is very high due to more retransmission attempts. The proposed scheduler and method I reach the same throughput with marginal difference in average delay in the unsaturated traffic condition. Although the proposed scheduler also uses A-MSDU it has not dropped any frames. Our proposed method works well in lightly loaded network.

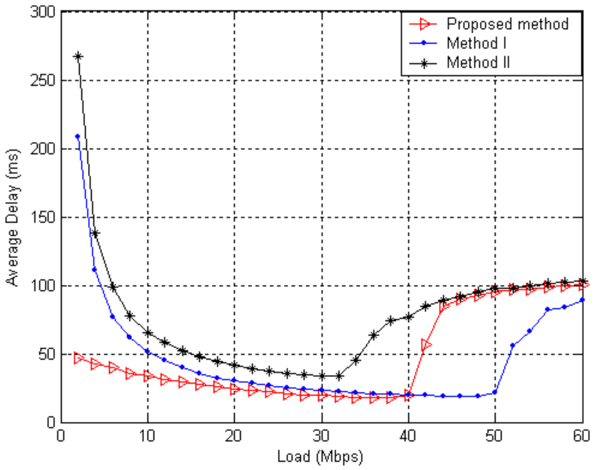

Figure 9. Delay comparison with BER 2e-5

V. CONCLUSION

In this paper, we have presented a simple frame aggregation scheduler. The frame aggregation techniques have to be effective even in unsaturated throughput. The proposed method will estimate the time deadline for frame transmission. In addition, we also outline a method for selecting the frame aggregation type. Comparisons are made with fixed size aggregation schemes and results indicate that the proposed method is superior in lightly loaded conditions as compared to the fixed size A-MPDU methods. Future work extends this to support for multiple access category.

VI. REFERENCES

[1] http://www.wi-fi.org/ retrieved on 25/09/2009

[2] IEEE 802.11n, Draft 4.0 - Wireless LAN Media Access Control (MAC) and Physical Layer (PHY) Specifications: Enhancements for Higher Throughput, IEEE, March 2008.

[3] IEEE 802.11n, Draft 2.0 - Wireless LAN Media Access Control (MAC) and Physical Layer (PHY) Specifications: Enhancements for Higher Throughput, IEEE, February 2007.

[4] http://standards.ieee.org/announcements/ieee802.11n_2009amendment_ratified.html retrieved on 25/09/2009

[5] G. Bianchi, “Performance analysis of the IEEE 802.11 distributed coordination function,” IEEE J. Select. Areas Commun., vol. 18, no. 3, pp. 535–547, Mar. 2000.

[6] Yuxia Lin and Vincent W.S. Wong “Frame Aggregation and Optimal Frame Size Adaptation for IEEE 802.11n WLANs”, Proc. IEEE GLOBECOM-2006, pp. 1-6.

[7] Dionysios Skordoulis, Qiang Ni, Hsiao-Hwa Chen, Adrian P. Stephens, Changwen Liu, Abbsa Jamalipour “IEEE 802.11n MAC Frame Aggregation Mechanisms For Next Generation High Throughput WLANs”, IEEE Wireless Commun., vol. 3, no.1, pp. 40-47, Feb. 2008.

[8] Sebastien Simoens, Pietro Pellati, Jeremy Gosteau, Karine Gosse “The evolution of 5 GHz WLAN toward higher throughputs”, IEEE Wireless Commun., vol. 10, no.6, pp. 6-13, Dec. 2003.