Frame Aggregation Size Determination for IEEE 802.11ac WLAN Considering Channel Utilization and Transfer Delay

Tomokazu Moriyama, Ryo Yamamoto, Satoshi Ohzahata and Toshihiko Kato
Graduate School of Informatics and Engineering, University of Electro-Communications,
1-5-1, Chofugaoka, Chofu, Tokyo 182-8585, Japan

Keywords: IEEE 802.11ac WLAN, MU-MIMO, Frame Aggregation, Spatial Stream.

Abstract: In order to improve the throughput over WLAN, the IEEE 802.11ac standard, which has been used recently, introduces the frame aggregation and MU-MIMO (multi-user multiple-input and multiple-output) mechanisms. The frame aggregation concatenates multiple data frames in one MAC data unit. MU-MIMO provides SDMA (space division multiple access), which allows multiple STAs (stations) to share space resources. In an 802.11ac WLAN, MU-MIMO is used in the downlink data transfer in a way that data frames to multiple STAs are aggregated separately and transmitted at the same time. When traffic loads to individual STAs are different, however, it is possible that there is a waste in space and time resources. In order to avoid this waste, several methods to control the frame aggregation size for MU-MIMO are proposed. Those methods focus mainly on increasing the channel utilization, and so they have a problem that there is a large delay in transmitting an aggregated data unit. In this paper, we propose a new method to determine the frame aggregation size considering both channel utilization and delay data frames suffer from in transmission queues. A performance evaluation result shows that our method provides high channel efficiency with keeping transmission delay in a relatively small value.

1 INTRODUCTION

One of major interests on WLAN is an improvement of data transfer throughput. IEEE 802.11ac, the latest version of WLAN standard, introduced several mechanisms to increase the throughput of individual data transfers and that of a WLAN system as a whole. They include new modulation methods, increased number of antennas, frame aggregation, and MU-MIMO. The frame aggregation is originally introduced in 802.11n (Kim, et al., 2012), and 802.11ac inherits it with expanding the maximum aggregation size from 65.5 Kbytes to 1 Mbyte (Ong, et al., 2011). Multiple data frames are aggregated into a single MAC data unit called A-MPDU (aggregation MAC protocol data unit).

As for the MIMO technology, 802.11n adopted only SU-MIMO (single-user MIMO), which is designed to increase the throughput between one sender and one receiver (Perez-Neira and Campalans, 2010). On the other hand, 802.11ac has introduced MU-MIMO, which is a technique to transmit to multiple receivers at the same time based on SDMA, in order to increase the overall throughput of a WLAN system as a whole (Gast, 2013). A separate data stream in an MU-MIMO communication is called a *spatial stream*. It should be noted that 802.11ac supports MU-MIMO only for the downlink data transfer from an AP (access point) to STAs.

In an actual data transfer, the frame aggregation and MU-MIMO are used together, and this introduces a problem that there is a waste (channel idle time) in some spatial streams when there are variations in traffic loads from an AP to STAs. More specifically, the 802.11ac standard defines a procedure that, when an AP transmits A-MPDUs over multiple spatial streams using MU-MIMO, it aggregates all data frames stored in transmission queues for individual streams. That is, the 802.11ac standard selects the maximum value among multiple queue lengths as the frame aggregation size. We call this procedure *mamimum policy* in this paper. Although this policy allows queued data frames to be transmitted immediately, spatial streams with shorter queue length will have a wasted time in data transfer.

In order to eliminate this waste in space and time resources, there are several proposals on how to determine the frame aggregation size during MU-

Moriyama, T., Yamamoto, R., Ohzahata, S. and Kato, T.
Frame Aggregation Size Determination for IEEE 802.11ac WLAN Considering Channel Utilization and Transfer Delay.
DOI: 10.5220/0006472200890094
In *Proceedings of the 14th International Joint Conference on e-Business and Telecommunications (ICETE 2017) - Volume 6: WINSYS*, pages 89-94
ISBN: 978-989-758-261-5

MIMO data transfer. (Nellalta, et al., 2012), (Nomura, et al., 2014), and (Nomura, et al., 2015) propose *minimum policy*, which uses the frame aggregation size equal to the smallest value among transmission queue lenghs used by spatial streams which are ready for MU-MIMO data transfer. (Syed and Trajkovic, 2015) proposes *average policy*, where the frame aggregation size is set to the average of transmission queue lenghs for spatial streams. These policies improve the channel utilization by decreasing a waste in space and time resoruces, but the queueing delay before data frames are transmitted becomes large.

In this paper, we compare three aggregation policies and clarify the channel utilization and the delay including both queueing delay and transmission delay. We also propose a new procedure that determines a frame aggregation size dynamically between the minimum queue length and the average queue length, according to the variations of the queue lengths among spatial streams. The proposed methods determines an aggregation size close to the minimum queue length when the queue length variations are small, and on the other hand, it determines a size close to the average queue length when the variations are large. The rest of paper consists of the following sections. Section II shows the problem of wasted space and time resources in MU-MIMO and the conventional solutions against this problem. Section III presents the proposed method. Section IV describes the results of the computer simulation study and Section V concludes this paper with some directions for the future work.

2 PROBLEM AND CONVENTIONAL WORK

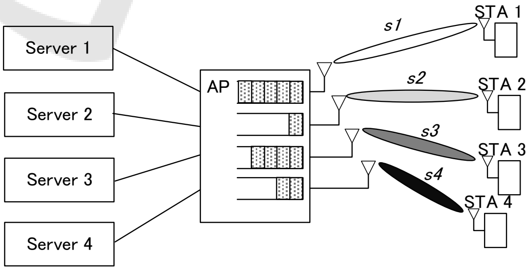
2.1 MU-MIMO and Frame Aggregation

MU-MIMO is a technology adopted by 802.11ac to improve a WLAN system level throughput. It is based on the SDMA scheme which transmits directional radio waves in parallel. In SDMA, an AP can send data frames to multiple STAs simultaneously. In an actual environment, STAs sometimes implement one or a few antennas due to the hardware scale limit, while APs can be equipped with many antennas. So, MU-MIMO is an effective way to improve the whole WLAN system throughput. Currently the 802.11ac standard regulates that the MU-MIMO downlink data transfer supports up to eight streams.

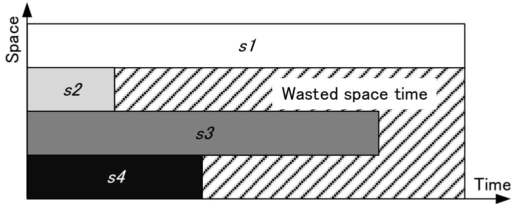
The frame aggregation technology is introduced in 802.11n and is extended in 802.11ac. It is understood commonly that the frame aggregation improves the data transfer throughput in MAC layer (Kim, et al., 2004), (Chosokabe, et al., 2015). There are two types of frame aggregation; A-MSDU (aggregation MAC service data unit) and A-MPDU. In this paper, we focus on A-MPDU, where data frames (MPDU) including MAC header and FCS (frame check sequence) are concatenated to form an A-MPDU. The error detection is performed per MPDU basis and their reception is reported independently and inclusively by a single Block Ack (block acknowledgment) frame.

2.2 Problem of Wasted Space and Time Resources

As described above, the current 802.11ac standard tries to aggregate as many MPDUs as possible in an A-MPDU during MU-MIMO data transfer. This procedure may bring a problem that there are wasted time in some spatial streams. Figure 1 shows an example. In a WLAN in Figure 1(a), AP works as an Ethernet switching hub and an 802.11ac access point. Four servers connected to AP via Ethernet are communicating with four stations, STA1 through STA4. AP establishes separate spatial streams, *s1* through *s4*. In some moment, the transmission queues for individual spatial streams contain different number of MPDUs as shown in this figure. When those MPDUs come to be transmitted using MU-MIMO, AP sends all of these frames by aggregating them into A-MPDUs for individual spatial streams. The result is given in Figure 1(b). In this case, the



(a) example of MU-MIMO data transfer



(b) status of spatial streams

Figure 1: Wasted space time problem during MU-MIMO data transfer.

maximum A-MPDU length (frame aggregation size) is the length of five MPDUs, which is equal to the largest queue length among transmission queues just before A-MPTUs are transmitted (maximum polity). This is the queue length for spatial stream *s1*. As for the other spatial streams, the queue length was not as large as *s1*, and so there are some wasted time as indicated by a shaded part in Figure 1(b). We call this part a *wasted space time*. This part will decrease the channel utilization, and, as a result, degrade the WLAN system level throughput.

2.3 Conventional Work

In order to avoid this waste, two types of approaches have been proposed as mentioned above. One is the minimum polity based approach. The frame aggregation size will be the smallest queue length among non-empty queues for spatial streams. In the example in Figure 1, the frame aggregation size corresponds to one MPDU length, which is the queue length for spatial stream *s2*. Another is the average policy based approach. The frame aggregation size is the average queue length of non-empty queues. In Figure 1, the frame aggregation size will be the length of three MPDUs, which is the average of five, one, four and two MPDUs.

It is expected that these policies improve the channel utilization, because they can reduce wasted space time. On the other hand, data frames queued in a transmission queue will suffer from longer delay until they are actually transmitted. Actually, as for the MPDU transmission time itself is the same for three policies, that is, shorter A-MPDUs require only shorter MPDU transmission time. But, shorter A-MPDUs will increase the PHY and MAC overheads introduced in 802.11 WLAN. They include a PLCP (physical layer convergence protocol) header, RTS (request to send)/CTS (clear to send) exchanges, and Block Ack Req/Block Ack exchanges. These overheads occupy time and space resources and introduce delay for data frames.

3 PROPOSAL

The minimum policy is the most effective in the channel usage. However, as the traffic variation among multiple spatial streams becomes large, the queueing delay becomes large. On the other hand, the average policy is expected to decrease the queueing delay compared with the minimum policy even if the traffic variation becomes large. However, the channel usage of the average policy is worse than the minimum value policy.

We propose a method to control the aggregation size in response to the traffic variation among spatial streams. When the traffic variation is small, the frame aggregation size is set according to the minimum policy. When the traffic variation is large, the aggregation size is set according to the average policy. For this purpose, it is necessary to recognize the traffic variation by consulting the amount of data in transmission queues. In our method, the time stamp when a data frame arrives at the queue is kept with the data itself.

Figure 2 shows a status of an AP establishing multiple spatial streams with N stations, STA 1 through STA N. A transmission queue is allocated for each STA, and Figure 2 shows that the queue for STA i has the longest queue length and that for STA j has the shortest length. For each data frame, the time stamp is associated. In the longest queue, they are $T_{max}(1)$ through $T_{max}(I_{max})$, where I_{max} is the number of data frames in the longest queue. Similarly, the time stamps in the shortest queue are $T_{min}(1)$ through $T_{min}(I_{min})$. The total data size in the longest and shortest queues is D_{max} and D_{min}, respectively

The proposed method uses the throughput variation to represent the traffic variation among spatial streams. Specifically, the throughput for the longest queue and the shortest queue (S_{max} and S_{min}, respectively) is given by the following equations.

$$S_{max} = \frac{D_{max}}{T_{max}(I_{max}) - T_{max}(1)} \tag{1}$$

$$S_{min} = \frac{D_{min}}{T_{min}(I_{min}) - T_{min}(1)} \tag{2}$$

The frame aggregation size in the proposed method, D_{prop}, is defined in the following way.

If $S_{max} - S_{min} \leq PHY\_DATA\_RATE$, then

$$D_{prop} = D_{min} + (S_{max} - S_{min}) \times \frac{D_{ave} - D_{min}}{PHY\_DATA\_RATE}. \tag{3}$$

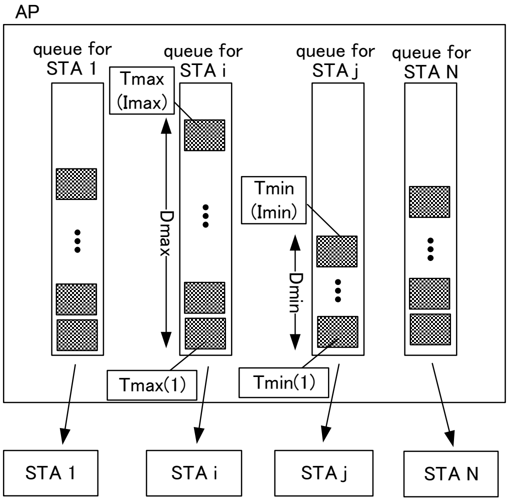


Figure 2: Status of transmission queues in AP.

Otherwise,

$$D_{prop} = D_{ave}. \tag{4}$$

Here, D_{ave} is the frame aggregation size for the average polity. It is given by the following equation.

$$D_{ave} = \frac{1}{N}\sum_{k=1}^{N} D_k. \tag{5}$$

When the traffic variation is small, D_{prop} is set to a value close to D_{min} in order to increase the channel utilization. When the traffic variation is large, D_{prop} is set to a value close to D_{ave} in order to decrease the delay. Note that the frame aggregation size is not larger than D_{ave}.

4 PERFORMANCE EVALUATION

4.1 Simulation Model

In this section, we show the results of performance evaluation for three conventional methods and the proposed method using the Monte Carlo simulation. Figure 6 shows the simulation model. In the simulation, each server sends packets to the corresponding STA through a single AP. AP aggregates MPDUs and transmits an A-MPDU to an individual STA using MU-MIMO data transfer. The traffic load from a server to AP is uniformly random between 0 and *x* Mbps. AP has eight antennas and STA has two antennas. The simulation parameters are shown in Table 1. With these parameters, the physical layer data rate per STA is 360 Mbps.

As for the evaluation index for the channel utilization, we use the wasted space time ratio defined in the following equation.

$$wasted\ space\ time\ ratio\ = \frac{\text{wasted space time}}{\text{add data transmission time}} \tag{6}$$

As for the delay, we use the period from the time a packet arrives at the AP to the time it reaches the corresponding STA. We call it *delay time* in the following subsections.

4.2 Results of Two STA Case

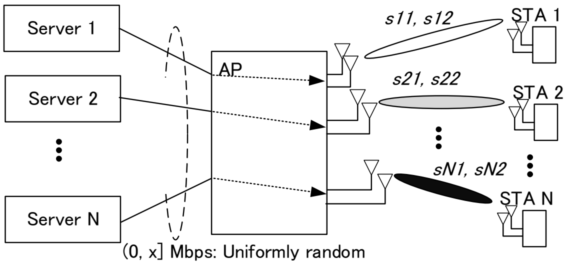


Figure 3: Simulation model.

Table 1: Simulation parameters.

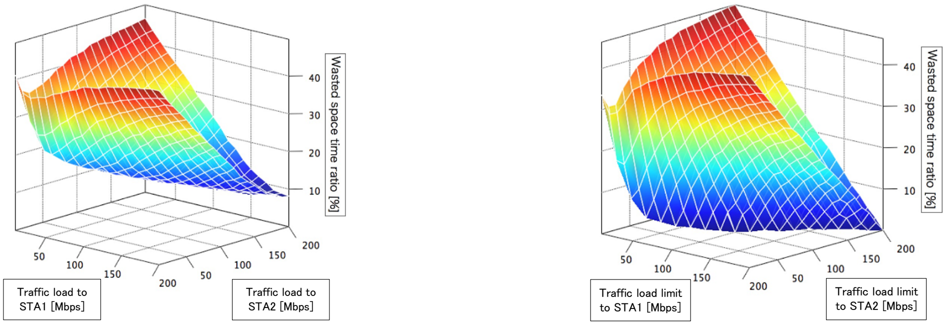
Parameter	Value
Number of STAs	N (2 or 4)
Modulation	256-QAM
Channel width per STA	40 MHz
Number of spatial stream per STA (N_{SS})	2
Coding rate (R)	5/6
Guard interval (GI)	0.8 μsec
Packet transmission duration from sever	1 sec
MPDU size	1500 byte
PHY header transmission duration	42 μsec
RTS transmission duration	40 μsec
CTS transmission duration	28 μsec
SIFS	16 μsec
DISF	34 μsec
Slot time	9 μsec
Cwmin	15
Bock Ack transmission duration	290 μsec

Figures 4 and 5 show the results when there are two STAs using MU-MIMO with two spatial streams. The horizontal axes indicate the upper limits of traffic load (*x* in Figure 3) of two STAs. The results of the wasted space time ratio shown in Figure 4 indicate that, for conventional policies, the smaller the aggregated size, the better the channel utilization. The proposed method shows the good characteristics, which is similar to the minimum policy.

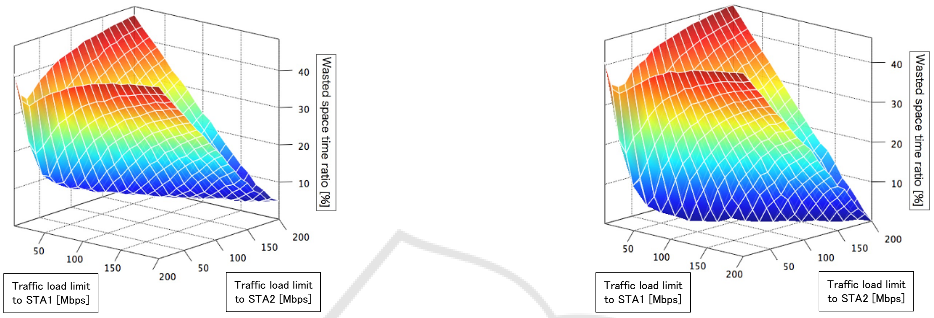
In the result of the delay time shown in Figure 5, the maximum policy gives the smallest value among four schemes. The average policy also gives small delay time, which is comparable with the maximum policy. On the hand, the minimum policy provides very large value (hundreds of mili seconds in the worst case). Although the delay time of the proposed method is higher than the maximum and average policies, the value is up to 25 msec and seems to be tolerable for actual communication.

4.3 Results of Four STA Case

Figure 6 shows the wasted space time ratio when the number of STAs is four. Each STA uses two spatial steams with AP. The horizontal axis indicate the upper limits of traffic load (*x* in Figure 3) for four STAs. As described above, the traffic is generated in a uniform random manner in the area of (0, *x*] Mbps. It is clear that maximum policy has the worst characteristics and the minimum policy provides the best performance. The average policy is located in the middle of the maximum and minimum policies. In the proposed method, when the traffic variation is small, the improvement is small. However, when the traffic variation gets large, the performance of the proposed method becomes closer to that of the minimum policy.

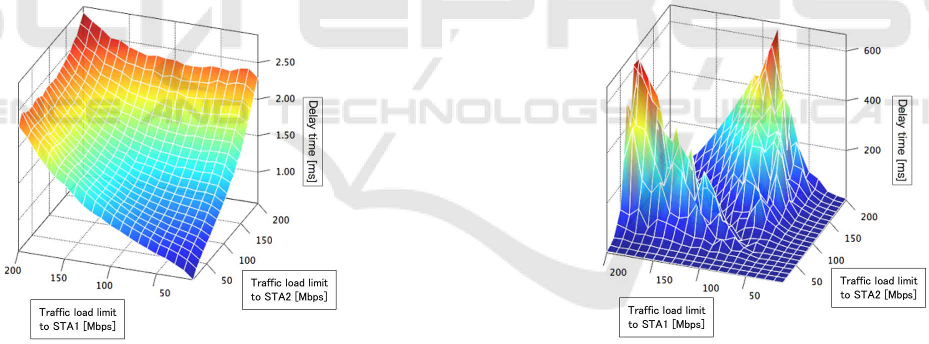


(a) Maximum policy (b) Minimum policy

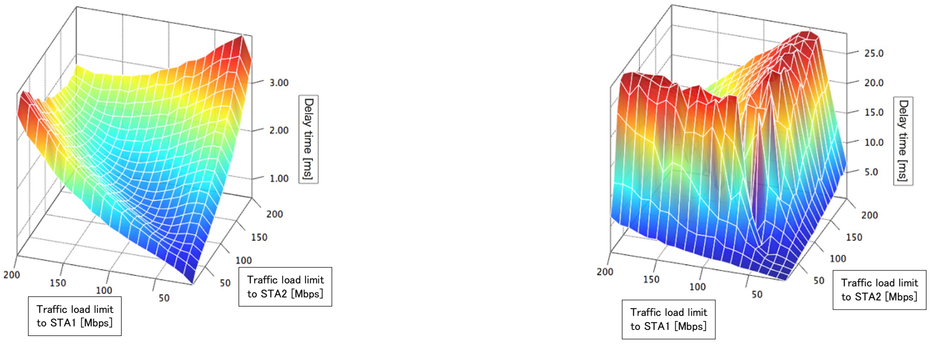


(c) Average policy (d) Proposed method

Figure 4: Results of wasted space time ratio with two STAs.



(a) Maximum policy (b) Minimum policy



(c) Average policy (d) Proposed method

Figure 5: Results of delay time with two STAs.

Figure 7 shows that the delay time from AP to STAs. The delay time of the maximum policy is the smallest, and that of the average policy is slightly larger than the maximum policy. The delay time of minimum policy is vastly large, and when x exceeds 250 Mbps, the delay time becomes more than 1 sec. Although the proposed method has larger delay time than the minimum and average policies, it is less than one tenth of the delay time of minimum policy over 250 Mbps.

Considering these two performance results, we confirmed that the proposed method improves the channel utilization and reduces the delay time.

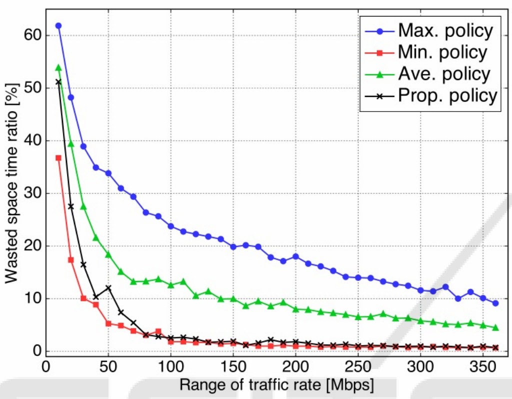


Figure 6: Wasted space time ratio with four STAs.

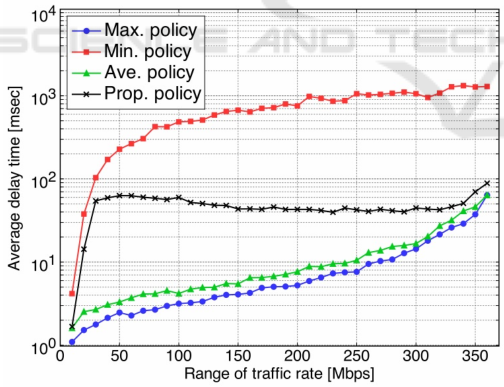


Figure 7: Delay time with four STAs.

5 CONCLUSIONS

In this paper, we proposed a method of determining the frame aggregation size in MU-MIMO data transfer. Monte Carlo computer simulation showed that the difference in the aggregation size provides a trade-off between the channel utilization and the transfer delay. By appropriately determining the aggregation size according to the traffic variation for individual spatial streams, the delay time can be reduced. The result is that the proposed method provides 10% of the delay time in the worst case of the conventional methods, and the channel utilization of the proposed method is close the best of the conventional methods. However, these are results in an early stage. We need to revise our method and elaborate performance evaluation in more realistic communication environment.

REFERENCES

Kim, Y., et al., 2012. Adaptive two-level frame aggregation in IEEE 802.11n wlan. In *Proc. IEEE Asia-Pacific Conference on Communications (APCC 2012)*.

Ong, E. H., et al., 2011. IEEE 802.11ac: Enhancements for very high throughput WLANs. In *Proc. IEEE Personal Indoor and Mobile Radio Communications (PIMCR 2011)*.

Perez-Neira, A. I., Campalans, M. R., 2010. *Cross-Layer Resource Allocation in Wireless Communications: Techniques and Models form PHY and MAC Layer Interaction*. Elsevier Science.

Gast, M. S., 2013. *802.11ac: A Survival Guide: WI-Fi at Gigabit and Beyond*. O'reilly Media.

Nellalta, B., et al., 2012. On the performance of packet aggregation in IEEE 802.11ac MU-MIMO WLANs. *IEEE Commun. Lett., vol. 16, no. 10*.

Nomura, Y., et al., 2014. High efficient packet aggregation scheme for multi-rate and voip packet transmissions in next generation mu-mimo wlans. In *Proc. IEEE 2014 International Conference on Advanced Technologies for Communications (ATC '14)*.

Nomura, Y., et al., 2015. Efficient frame aggregation with frame size adaptation for next generation mu-mimo wlans. In *Proc. 9th International Conference on Next Generation Mobile Applications, Services and Technologies*.

Syed, A. U., Trajkovic, L., 2015. Improving vht mu-mimo communications by concatenating long data streams in consecutive groups. In *Proc. IEEE Wireless Communications and Networking Conference Workshops (WCNCW 2015)*.

Lin, Y., Wong, V. W. S., 2006. Frame aggregation and optimal frame size adaptation for ieee 802.11n wlans. In *Proc. IEEE Global Telecommunications Conference 2006 (GLOBECOM '06)*.

Kim, Y., et al., 2004. Throughput enhancement of ieee 802.11 wlan via frame aggregation. In *Proc. IEEE Vehicular Technology Conference 2004 (VTC2004-Fall)*.

Chosokabe, Y., et al, 2015. A channel adaptive hybrid aggregation scheme for next generation wireless lan. *In Proc. IEEE Wireless Communications and Networking Conference Workshops (WCNCW' 2015)*.