Lossless Data Transmission by means of IEEE 802.11aa GCR Block Ack with TXOP-Bursting and AIFS Control

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***Abstract*—This paper utilizes IEEE 802.11aa GCR Block Ack and TXOP-Bursting for lossless groupcast of computer data. Both mechanisms are mainly for audiovisual communications. We adopt them for computer data groupcast. We propose a dynamic control method of EDCA parameters to allow TXOP-Bursting without interfering with other traffic. We perform a computer simulation to evaluate the required time for lossless transmission. As a result, we show that GCR Block Ack using TXOP-Bursting with the dynamic control of the EDCA parameters can shorten the time needed for lossless transmission.**

***Index Terms*—Wireless LAN, IEEE 802.11aa, Groupcast, TXOP-Bursting, Computer data transmission, Lossless**

I. Introduction

The advancement of wireless LAN technologies brings us low delay and high-speed communications. It enables live streaming and multi-person teleconferencing. This kind of service is suitable for employing groupcast. The groupcast can transmit the same data to multiple receivers simultaneously. IEEE 802.11aa, which is standardized in 2012, specifies GCR (GroupCast with Retries) for reliable one-to-many communications. GCR includes two mechanisms: GCR Unsolicited Retry and GCR Block Ack.

There have been several studies on QoS (Quality of Service) and QoE (Quality of Experience) assessment of audiovisual groupcast with GCR [2],[3]. They only consider continuous media transmissions such as audio and video. On the other hand, the requirement of computer data simultaneous transmission to massive PCs or tablet terminals exists. The computer data has quite a different character from the continuous media.

Reference [4] evaluates the download completion time of the binary data transmission with the two GCR methods and the unicast method. As a result, we notice that GCR Block Ack has the shortest download completion time in many situations. In addition, Reference [5] proposes a hybrid approach of two GCR methods.

EDCA defines TXOP (Transmission Opportunity) and has the TXOP-Bursting mechanism. The mechanism allows a terminal to send frames with the same AC sequentially during the TXOP limit. References [4] and [5] do not consider TXOP-Bursting for binary data transmission.

Besides, Reference [6] proposes a channel access mechanism for video multicasting over wireless LANs. The authors introduce a new AC (Access Category) for video multicasting in the EDCA (Enhanced Distributed Channel Access) mechanism. The new AC has lower priority and longer TXOP duration than that for unicast of audiovisual streams to reduce lost packets. Although binary data transmission does not generally employ TXOP-Bursting, the mechanism can enhance transmission efficiency.

In this paper, we employ TXOP-Bursting to groupcast the binary data with GCR Block Ack. In addition, we propose a dynamic control method of EDCA parameters. This paper controls AIFS (Arbitration Inter Frame Space); it is a parameter for prioritized control in EDCA. We show the effectiveness of the proposed method through computer simulation with ns-3 [7].

We organize the remainder of this paper as follows. At first, Section II performs computer simulation with static AIFS. We then propose a dynamic control method of AIFS in Section III. Section IV concludes this paper.

II. TXOP-Bursting with fixed AIFS

In this section, we add an AC to groupcast binary data. We then perform computer simulation of the binary data transmission with GCR Block Ack and TXOP-Bursting.

A. Transmission method

This paper assumes that AP (Access Point) simultaneously transmits the same binary data to several receiver terminals over a wireless LAN. AP employs IEEE 802.11e EDCA (Enhanced Distributed Channel Access) as a QoS control mechanism. It introduces four ACs (Access Categories) to support differentiated channel access for applications with QoS requirements. A station that supports EDCA has an individual buffer for each of the four ACs, and the channel access function based on CSMA/CA is independently carried out per AC.

In this paper, we employ GCR Block Ack. We explain the transmission mechanism of GCR Block Ack with or without TXOP-Bursting below.

1) GCR Block Ack: GCR Block Ack adopts IEEE 802.11n Block Ack to groupcast communications. Figure 1 depicts a transmission sequence in GCR Block Ack. The scheme

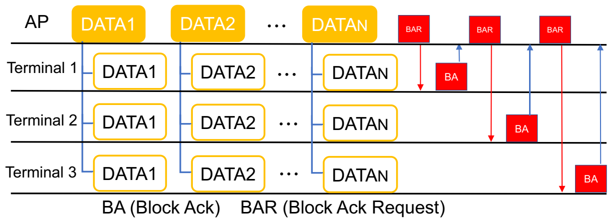

Fig. 1. Communication sequence in GCR Block Ack

exploits the Block Ack mechanism for groupcast transmission. It can acknowledge multiple MAC frames by an Ack frame.

AP transmits multiple MAC frames for a group sequentially. After the transmission, AP transmits BAR (Block Ack Request) to each terminal. When a terminal receives BAR, the terminal makes BA (Block Ack), which includes acknowledgments for received MAC frames, and transmits it to AP. AP confirms the transmission for all the terminals via BAR and BA. If a terminal cannot receive MAC frames, AP just retransmits the frames.

In the default EDCA mechanism, the binary data transmission does not adopt TXOP-Bursting. Then, GCR Block Ack in this paper needs to acquire the channel access right for every frame transmission. After the frame transmission, the terminal waits for the AIFS and backoff duration toward the subsequent frame transmission.

2) GCR Block Ack with TXOP-Bursting: In this method, we adopt TXOP-Bursting to binary data transmission with GCR Block Ack. When we employ TXOP-Bursting, AC which achieves the channel access right can send frames sequentially without waiting during AIFS or backoff.

The prioritized control of EDCA is performed by controlling four parameters. They are the minimum value of the contention window ($CW_{\min}$), the maximum one ($CW_{\max}$), AIFS, and TXOP limit. The IEEE 802.11e standard provides recommended values of the parameters as shown in Table I; it is for the IEEE 802.11a physical layer. Here, AIFSN is defined for calculating AIFS. AIFS is calculated by Equation (1). Slottime is a time unit for generating the backoff period.

$$AIFS[AC] = SIFS + AIFSN[AC] \times Slottime \qquad (1)$$

This paper defines AC_GC, which is an AC for groupcast as in [6]. AC_GC has a lower priority than the existing four ACs. AC_GC has a larger TXOP limit than 0, and then TXOP-Bursting is enabled in AC_GC.

AC_GC can avoid frame transmission of other ACs when AC_GC transmits several frames sequentially with TXOP-Bursting. Thus, AC_GC has a larger AIFSN than AC_BE, which is the category of best effort discrete media transmission. To investigate the appropriate value of AIFSN for AC_GC, we perform computer simulations with several AIFSN values. In this paper, we do not change parameters for the contention window, i.e., $CW_{\min}$ and $CW_{\max}$.

TABLE I
EDCA PARAMETERS

AC	$CW_{\min}$	$CW_{\max}$	AIFSN	TXOP limit [ms]
AC_BK	15	1023	7	0
AC_BE	15	1023	3	0
AC_VI	7	15	2	3.008
AC_VO	3	7	2	1.504

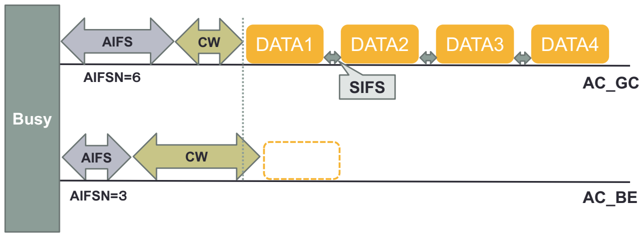

Fig. 2. Communication sequence in TXOP-Bursting

Figure 2 shows a transmission sequence with TXOP-Bursting. Here AC_GC acquires the transmission opportunity and sequentially sends frames by means of TXOP-Bursting.

B. Simulation

Figure 3 depicts the network topology. n Data Receivers ($\mathrm{DR}_1, \cdots, \mathrm{DR}_n$) and five Mobile Nodes ($\mathrm{MN}_1, \cdots, \mathrm{MN}_5$) are statically placed on a circle of r [m] distance from Access Point (AP). They consist of a Basic Service Set (BSS) of IEEE 802.11a (5 GHz band, maximum 54 Mbps) wireless LAN.

We assume transmission of a Windows Update file of 40.5 MB from AP to DRs. The data is packetized to 43838 packets in which the maximum payload size is 988 bytes. The data is transmitted sequentially without a time structure. The physical transmission rate is 12 Mbps. A frame is retransmitted until all the receiver terminals successfully receive the frame.

In the simulation, we employ RTP/UDP as the transport protocol for data transmission. Usually, this kind of data transmission does not utilize RTP/UDP because RTP is a protocol for continuous media transmission. On the other hand, for reliable data transmission, we need to check the sequential arrival. In addition, for performance evaluation, we measure delay. For these purposes, we employ RTP/UDP here.

MNs are used to handle background traffic flows. Each MN sends the traffic to AP and receives the traffic from AP. The nodes generate fixed-size IP datagrams of 1500 bytes each at exponentially distributed intervals. AP also generates traffic for each MN. The amount of traffic is adjusted by changing the average of the interval. We refer to the average amount of the traffic from AP to each load terminal as the *average load*. Each MN sends half the amount of the average load. The transport protocol for the background traffic is UDP, and ARF (Auto Rate Fallback) [8] controls its physical bitrate.

This paper does not utilize flow control mechanisms at the application layer or the transport layer. We set AP's buffer size to a sufficiently larger value than the total number of binary

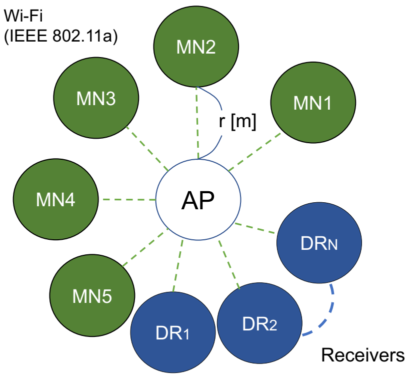

Fig. 3. Network topology

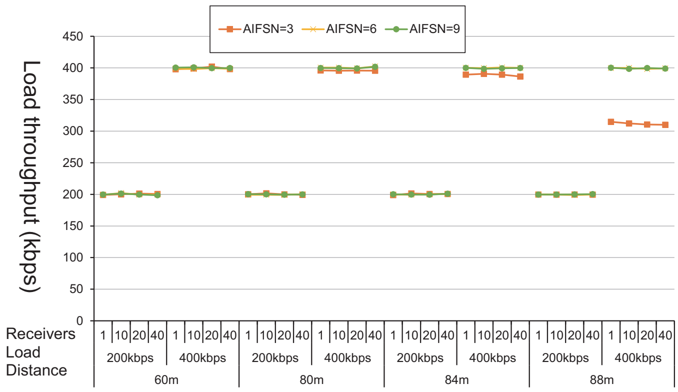

Fig. 4. Average interference traffic throughput (TXOP limit 3.008 ms)

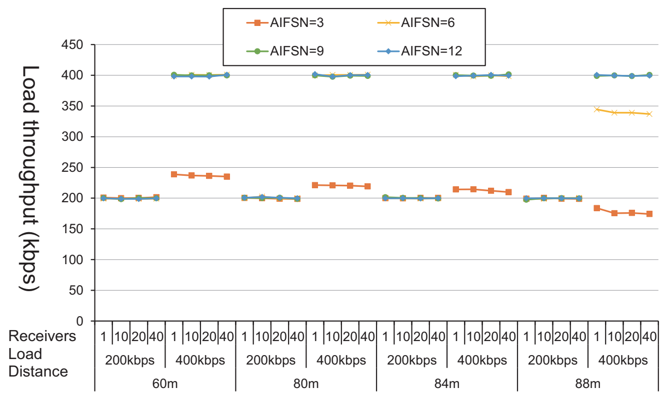

Fig. 5. Average interference traffic throughput (TXOP limit 6.016 ms)

data packets. Just after a frame is successfully transmitted, the next frame is ready to send. In this setting, the binary data occupies the transmission queue. If we consider the background traffic with the same priority, the traffic cannot be sent. Hence, we employ another AC with the same priority setting for the background traffic.

In GCR Block Ack, when the number of successively transmitted MAC frames is 64, or when AP has no MAC frame in the queue and has unacknowledged MAC frames, AP transmits BAR. This is the same as the Block Ack implementation for unicast communications in ns-3. After the exchange of BAR and BA for all the receivers, AP retransmits lost frames. After the retransmission, the successive new frames with no larger sequence number than the smallest sequence number of the retransmitted frame plus 63 are transmitted before BAR transmission; this is also based on the unicast implementation. Then, AP moves to the BAR and BA exchange sequence.

We consider four distances from AP to each receiver terminal: 60 m, 80 m, 84 m, and 88 m. The numbers of receiver terminals are 1, 10, 20, and 40. We apply two average load values: 200 kbps and 400 kbps. We utilize three values of the TXOP limit: 1.504 ms, 3.008 ms, and 6.016 ms. The three AIFSN values (3, 6, and 9) and an additional AIFS value (12) for TXOP limit 6.016 ms are employed. For each combination, we carry out 15 simulation runs. We call traditional GCR Block Ack "GCR-BA," while the GCR Block Ack with TXOP-Bursting is called "TXOP-GCR-BA."

We evaluate the duration from starting the data transmission at the application layer in AP until the completion of data reception without error in the application layers of all the receiver terminals. We call it the *download completion time*.

C. Results

1) Interference traffic throughput: Figures 4 and 5 show the interference traffic throughput for the TXOP limit of AC_GC 3.008 ms and 6.016 ms, respectively. We do not show the throughput for TXOP limit 1.504 ms because the groupcast transmission merely affects the throughput. This is owing to the small TXOP limit. On the other hand, as the TXOP limit increases, the throughput of interference traffic degrades. In such situations, large AIFSN can mitigate the bad influence of the groupcast transmission.

2) Download completion time: The download completion time for the traditional GCR-BA is shown in Table II. In addition, Figs. 6, 7, 8, and 9 show the reduction ratio of download completion time of TXOP-GCR-BA against GCR-BA. The purpose of this study is to shorten the download completion time without degradation of interference traffic throughput. Thus, we do not show the cases in which the interference traffic throughput degrades in Figs. 6 to 9.

We find in Figs. 6 to 9 that TXOP-GCR-BA can shorten the download completion time against GCR-BA in all the cases. The maximum reduction ratio under TXOP limit 6.016 ms is about 15 %. In Fig. 6, AIFSN = 3 has the shortest download completion time. Besides, in Fig. 7, AIFSN = 6 is almost the best when the average load is twice from the case in Fig. 6. In Figs. 8 and 9, as the interference traffic increases, AIFSN which achieves the shortest download completion time increases. We see in Figs. 7 and 9 that AIFSN which has the shortest download completion time increases as the TXOP limit increases. The number of internal collisions among ACs affects the appropriate AIFSN for the given TXOP limit.

TABLE II
DOWNLOAD COMPLETION TIME OF GCR-BA

Load (kbps)	Distance (m)	Receivers	GCR-BA (ms)
200	60	1	42062
		10	43935
		20	46148
		40	50489
	80	1	44481
		10	47377
		20	51174
		40	59442
	84	1	45280
		10	54706
		20	64709
		40	83176
	88	1	54884
		10	99946
		20	125138
		40	159156
400	60	1	48891
		10	51610
		20	54253
		40	59678
	80	1	56294
		10	60218
		20	65128
		40	75582
	84	1	58057
		10	70244
		20	83019
		40	106581
	88	1	77506
		10	142340
		20	178156
		40	226069

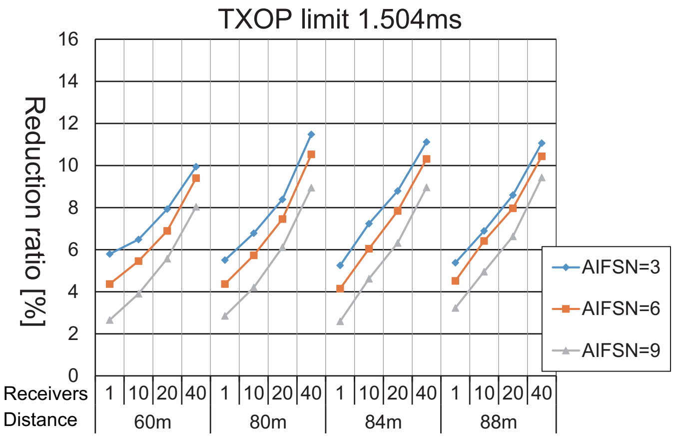

Fig. 6. Reduction ratio of TXOP-GCR-BA (TXOP limit 1.504 ms, 200 kbps)

III. GCR BLOCK ACK WITH ADAPTIVE AIFS

When we set appropriate AIFSN, TXOP-GCR-BA can get a shorter download completion time than GCR-BA. However, the appropriate AIFSN varies according to the TXOP limit and the amount of interference traffic. Thus, this section proposes an adaptive control of AIFSN.

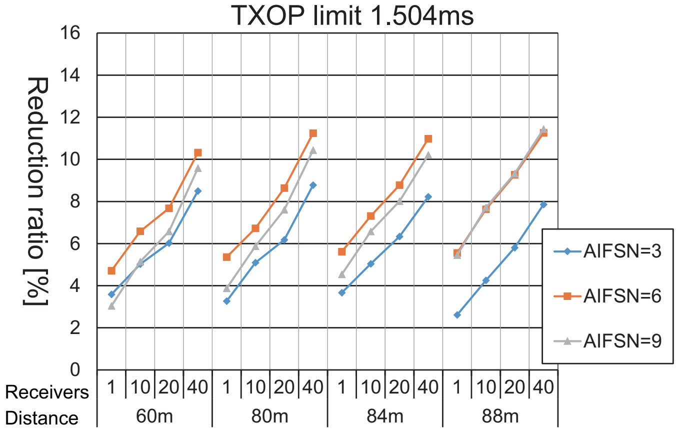

Fig. 7. Reduction ratio of TXOP-GCR-BA (TXOP limit 1.504 ms, 400 kbps)

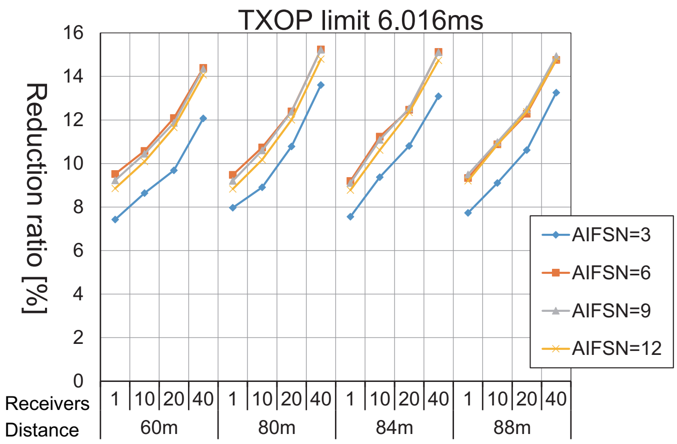

Fig. 8. Reduction ratio of TXOP-GCR-BA (TXOP limit 6.016 ms, 200 kbps)

A. *Transmission mechanism*

This paper employs the number of internal collisions among ACs for the adaptive AIFSN control. This is because the amount of internal collisions varies according to the TXOP limit and the amount of interference traffic.

Table III represents the number of internal collisions per second for the shortest download completion time in TXOP limit 1.504 ms, 3.008 ms, and 6.016 ms. In this table, we do not show the case when the throughput of interference traffic for TXOP-GCR-BA decreases against that for GCR-BA.

In Table III, we notice that the number of internal collisions for the appropriate AIFSN is about 8 to 14 in TXOP limit 1.504 ms, 5 to 12 in TXOP limit 3.008 ms, and 3 to 6 in TXOP limit 6.016 ms. The number of internal collisions is in inverse proportion to the TXOP limit.

From the above observation, we adopt AIFSN according to the number of internal collisions. We monitor the number of internal collisions and check the number is fit into the range observed above. When the number of internal collisions exceeds/is below the range, we increase/decrease AIFSN by

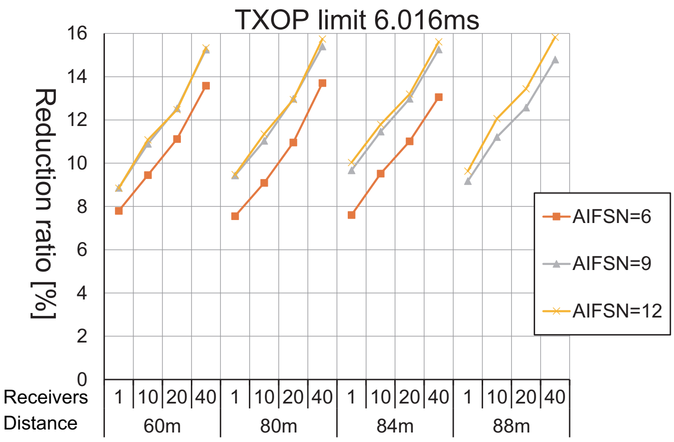

Fig. 9. Reduction ratio of TXOP-GCR-BA (TXOP limit 6.016 ms, 400 kbps)

TABLE III
COLLISION COUNT AMONG ACs PER SECOND

Load (kbps)	Distance (m)	Receivers	TXOP limit 1.504 ms	TXOP limit 3.008 ms	TXOP limit 6.016 ms
200	60	1	9.97	10.07	6.16
		10	9.94	10.30	6.05
		20	9.79	5.95	6.02
		40	9.81	5.75	5.97
	80	1	10.28	6.11	6.06
		1	10.29	6.18	6.08
		10	10.18	5.90	6.28
		40	9.98	6.00	5.94
	84	1	10.13	5.96	5.97
		10	10.14	5.94	6.10
		20	10.11	6.06	3.79
		40	10.10	6.08	6.11
	88	1	11.32	6.93	4.31
		10	11.29	6.82	4.22
		20	11.34	6.84	4.32
		40	11.45	6.94	4.30
400	60	1	12.09	12.21	7.35
		10	11.70	12.08	4.73
		20	11.94	7.29	4.57
		40	11.92	12.15	4.63
	80	1	12.08	7.48	7.13
		10	12.11	7.41	4.63
		20	12.09	7.46	4.58
		40	11.98	7.48	4.63
	84	1	12.44	7.66	4.52
		10	12.45	7.59	4.78
		20	12.27	7.49	4.72
		40	12.31	7.59	4.65
	88	1	14.21	8.64	5.51
		10	8.80	8.58	5.52
		20	8.77	8.84	5.58
		40	8.77	8.68	5.50

one. The initial and the minimum AIFSN is 3. For TXOP limit 1.504 ms, we increase AIFSN for the number of internal collisions no less than 24 and decrease AIFSN for the number of internal collisions no more than 8. When the number of collisions is not larger than 4 and not smaller than 12, we decrease and increase AIFSN, respectively, for TXOP limit 3.008 ms. For TXOP limit 6.016 ms, we increase AIFSN for the number of internal collisions equal to or larger than 6 and decrease AIFSN for the number of internal collisions equal to or smaller than 2.

TABLE IV
DOWNLOAD COMPLETION TIME FOR THE BEST SETTING OF AIFS

Load (kbps)	Distance (m)	Receivers	TXOP limit 1.504 (ms)	TXOP limit 3.008 (ms)	TXOP limit 6.016 (ms)
200	60	1	39625	38706	38059
		10	41086	39988	39289
		20	42492	41316	40570
		40	45468	44049	43224
	80	1	42034	40964	40265
		10	44165	43001	42290
		20	46881	45566	44832
		40	52617	51232	50386
	84	1	42903	41787	41117
		10	50747	49454	48562
		20	59022	57424	56602
		40	73930	71945	70595
	88	1	51934	50636	49673
		10	93056	90367	88972
		20	114383	111090	109502
		40	141545	137422	135391
400	60	1	46587	45071	44560
		10	48210	46708	45890
		20	50087	48377	47451
		40	53518	51548	50532
	80	1	53277	51673	50961
		10	56170	54465	53385
		20	59503	57679	56675
		40	67084	64982	63685
	84	1	54796	53152	52234
		10	65111	62973	61959
		20	75731	73204	72046
		40	94882	91515	89938
	88	1	73201	70769	69952
		10	131356	126665	124762
		20	161545	156570	153741
		40	200209	192878	189905

We call the adaptive AIFSN method "Adaptive AIFS," while the fixed AIFSN which achieves the smallest download completion time is called "Appropriate AIFS."

B. Results

We show the download completion time for Appropriate AIFS in Table IV. Figs. 10, 11, and 12 depict the reduction ratio of the download completion time against GCR-BA (i.e., without TXOP limit) for Adaptive AIFS and that for Appropriate AIFS.

We notice that the reduction ratio of Adaptive AIFS is almost the same as that of Appropriate AIFS. This implies that Adaptive AIFS can select the best AIFSN according to the interference traffic condition for the given TXOP limit.

IV. CONCLUSIONS

This paper has evaluated the download completion time with IEEE 802.11aa GCR block Ack and TXOP-Bursting for lossless groupcast of computer data. We then have proposed an adaptive AIFS control method. We have confirmed that TXOP-Bursting and the adaptive AIFS control method can shorten the download completion time from the simulation result.

In future work, we need to evaluate the effect of the binary data size.

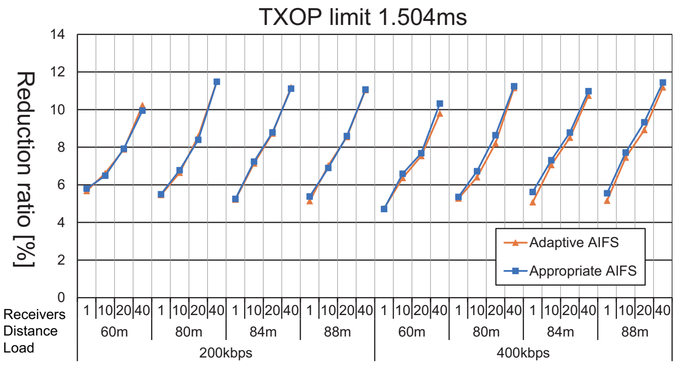

Fig. 10. Reduction ratio of adaptive AIFS (TXOP limit 1.504 ms)

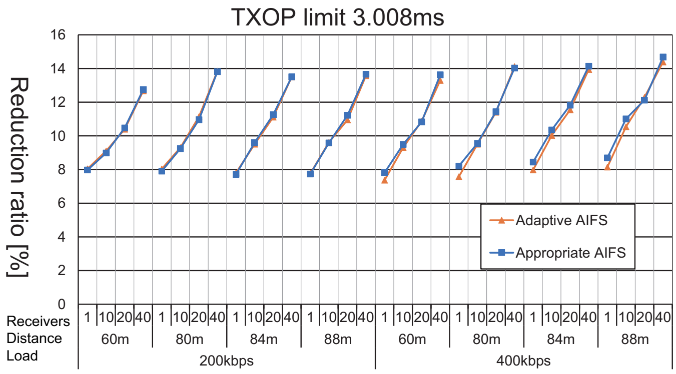

Fig. 11. Reduction ratio of adaptive AIFS (TXOP limit 3.008 ms)

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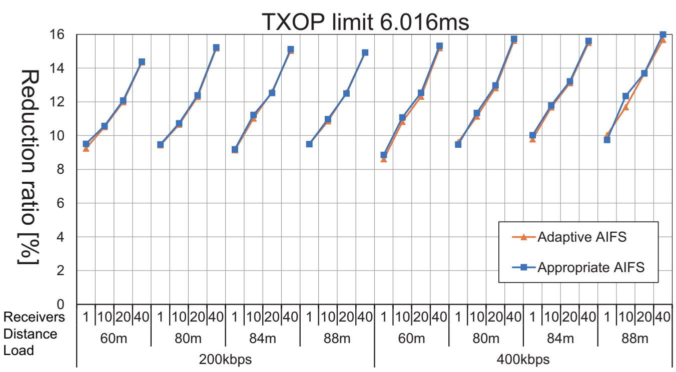

Fig. 12. Reduction ratio of adaptive AIFS (TXOP limit 6.016 ms)