QoS Control Method for W-LAN Ad Hoc Network With Automatic Contention Window Adjustment

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***Abstract*—This paper proposes a new QoS control method for the ad hoc Wireless LAN (W-LAN), which adjusts the Contention Window (CW) size dynamically based on the required and achieved bit rate. By the proposed method, a node with higher bit rates can have better chance to send the data in order to satisfy the Quality of Service (QoS) requirement. This paper also shows the effectiveness of the proposed method based on the results of computer simulations.**

Keywords-QoS; IEEE802.11b/a; Ad Hoc Network; Contention Window; Required Bit Rate

I. INTRODUCTION

With the increase in the demand of multimedia communications in the area of wireless networks, a number of studies about the Quality of Service (QoS) control have been performed [1]-[10]. Especially, Wireless LAN (W-LAN) has been expected to be an important communication technology because new high speed specifications have been realized continuously. IEEE802.11, the standard of W-LAN, has a Distributed Coordination Function (DCF) access method. DCF is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA / CA) and its outline is as follows:

(1) When the sender node attempts to transmit a frame, it first senses the channel status.
(2) If the channel is idle during the period of Distributed Inter Frame Spacing (DIFS), the sender node transmits the frame.
(3) If the channel is busy, then the sender node waits until the channel becomes idle. After the channel becomes idle, it still waits for the period of DIFS. Then, it determines the back-off time defined within the Contention Window (CW) which is necessary to reduce collisions.
(4) When the back-off time reaches zero, then the sender node starts to transmit the frame and the destination node replies with an Acknowledgment (ACK) to the sender node after waiting for the period of Short Inter Frame Spacing (SIFS).

In this procedure, all nodes have statistically equal probability to acquire transmission opportunity. So, IEEE 802.11 defines a QoS framework called Enhanced Distributed Channel Access (EDCA) which changes the CW size based on four traffic access categories, namely, Voice, Video, Best Effort Data and Background Data. Voice traffic has the smallest CW after collision or completion of previous transmission. But EDCA does not include any consideration about the difference of node's required bit rate.

There are several studies regarding QoS of IEEE802.11. The paper by L. Romdhani et al. [8] proposed Adaptive EDCF (AEDCF) for ad hoc networks, which gradually adjusts the expansion rate of the CW after collision and diminishes the rate of CW after successful transmission. DCF and EDCA are known to work relatively well when the traffic load is not so heavy, but when the medium is saturated, they no longer work effectively because EDCA does not have a mechanism to alleviate collisions. AEDCA works 25% better in high traffic load conditions than EDCA by simulation. Another paper by J. Maeda et al. [9] proposed to change the CW based on the required bit rate and frame size. This assumes the Access Point (AP) collects the required bit rates and calculates the CW for each node.

We propose a similar strategy to [9] and we introduce a required bit rate driven CW adjustment. The CW is updated dynamically by the achieved bit rate [10]. We expect this feedback mechanism to contribute to a fairness of bandwidth allocation by taking the actual network conditions into account.

The rest of this paper is organized as follows. Section II describes the proposed QoS control method. Section III shows the effectiveness of the proposed method based on the evaluation result. Section IV describes the conclusion of this paper.

II. PROPOSAL OF QOS CONTROL METHOD

In the CSMA/CA procedure, the back-off time is determined as follows:

Back-off Time = Random () * Slot Time

 ISBN: 978-1-61208-454-1

Random ( ) is the function to generate a random number of integer values based on the uniform distribution in the range [0, CW].

The main purpose of proposed method is to make the following Achievement Ratio equal, as much as possible, for nodes requiring different bit rate.

$$\text{Achievement Ratio} = \frac{\text{Achievement throughput}}{\text{Requited throughput}}$$

Let us consider the example of two nodes, where the requirement bit rate of node 1 is twice as large as the required bit rate for node 2. In case of the standard method, the Achievement Ratio of node 1 is higher than that of node 2 because the standard does not have any method to consider the difference of the node's required bit rate. So, our proposal is based on the idea that the value of CW is determined by considering the difference of the required bit rate and it is also changed adaptively based on the transmission result (e.g., successfully transmitted frame number).

The CW for node i after time d (i.e., CWi (t+d)) is determined by (1).

$$CWi\ (t+d) = CWi\ (t) + (FSi - Fi)*FL\ /\ (Fi*ST) \quad (1)$$

where
FL = Transmission time of one frame
ST = Slot Time
Fi = Target transmission frame number of Node i during time d which is calculated by (2)
FSi = Successfully transmitted frame number of Node i during time d

In (1), Fi is defined as follows:

$$Fi = \sum_{J} (Tj * Ri * FSi\ )\ /\ (Rj * Ti\ ) \qquad (2)$$

where
T_i = Achieved throughput of Node i
R_i = Required throughput of Node i

Equations (1) and (2) present the algorithms used to adjust CW. Each node in the network notifies the other nodes of its values for CW/ required bit rate/achieved bit rate before starting communication. Then, all nodes determine their CW (t+d) by (1), and start communication based on CSMA / CA procedure. Therefore, by the back-off time control of the proposed method, the back-off time of the node with lower required bit rate will be longer and the back-off time of the node with higher required bit rate will be shorter.

III. Computer Simulation

A. Simulation Method

Computer simulation has been performed to evaluate the proposed method based on IEEE802.11b and 11a. Table 1 shows the network parameters. Nominal Maximum Throughput is the maximum transmission rate by the IEEE standard and any other parameters follow standard unless it is explicitly mentioned. Frame generation for each node is assumed to follow the Poisson distribution.

Two groups of nodes have been assumed, and each group has 10 nodes. All nodes in Group 1 share the same throughput requirement and Group 2 also share the same throughput which is twice higher than Group 1. Table 2 for 802.11b and Table 3 for 11a show the simulation cases from light load to very saturated load. The Required Throughput per Node is the generated throughput at each node of each group. The Total Load is the sum of these generated throughputs. In these simulations, a total of 20 nodes built one ad-hoc network. Any node is in radio ranges of all other nodes, so there are no hidden nodes and RTS/CTS are not applied. These simulations assume ideal radio environment without any interferences or background noise. Also, it does not consider free space loss of radio propagation. This simulation is intended to evaluate the proposed MAC layer mechanism.

TABLE 1 NETWORK PARAMETERS

IEEE 802.11 Standard	11b	11a
Mode	Ad-hoc	Ad-hoc
Nominal Max. Throughput (Mbps)	11	54
SIFS Period (μsec)	10	16
DIFS Period (μsec)	50	34
Slot Time (μsec)	20	9
CW Max	1023	1023
CW Min	31	15
Frame Size (byte)	1000	1000
Simulation Time (sec)	60	60

TABLE 2 SIMULATION CASES PARAMETER FOR 802.11b

802.11b		Case 1	Case 2	Case 3	Case 4
Required Throughput per Node (Mbps)	Group 1	0.2	0.3	0.36	0.5
	Group 2	0.4	0.6	0.72	1
Nominal Max. Throughput (Mbps)		11	11	11	11
Total Load (Mbps)		6	9	10.8	15
Load Ratio		0.545	0.818	0.982	1.364

 ISBN: 978-1-61208-454-1

TABLE 3 SIMULATION CASES PARAMETER FOR 802.11a

802.11a		Case 1	Case 2	Case 3	Case 4
Required Throughput per STA (Mbps)	Group 1	1	1.5	1.8	2
	Group 2	2	3	3.6	4
Nominal Max. Throughput (Mbps)		54	54	54	54
Total Load (Mbps)		30	45	54	60
Load Ratio		0.556	0.833	1.000	1.111

B. Simulation Result s

Table 4 and Table 5 show the simulation results.

TABLE 4 SIMULATION RESULT OF 802.11b

802.11b		Case 1	Case 2	Case 3	Case 4
Load Ratio		0.545	0.818	0.982	1.364
Standard CW Method					
Achieved Throughput per group (Mbps)	Group 1	1.97	2.82	2.72	2.71
	Group 2	3.70	2.96	2.76	2.75
Total Achieved Throughput (Mbps)		5.67	5.78	5.47	5.47
Achievement Ratio	Group 1	0.99	0.94	0.75	0.54
	Group 2	0.93	0.49	0.38	0.28
Jain's Fairness Index		0.9982	0.9109	0.9033	0.9034
Total Collisions		5,194	3,908	8,496	8,640
Total Successful Transmissions		42,536	43,326	41,058	40,999
Proposed CW Method					
Achieved Throughput per group (Mbps)	Group 1	1.99	2.29	2.53	2.07
	Group 2	3.90	3.66	3.28	3.95
Total Achieved Throughput (Mbps)		5.89	5.95	5.80	5.80
Achievement Ratio	Group 1	0.99	0.76	0.70	0.51
	Group 2	0.97	0.61	0.45	0.33
Jain's Fairness Index		0.9995	0.9842	0.9538	0.9974
Total Collisions		1,210	1,200	3,135	3,101
Total Successful Transmissions		44,162	44,639	43,508	45,175

TABLE 5. SIMULATION RESULT OF 802.11a

802.11a		Case 1	Case 2	Case 3	Case 4
Load Ratio		0.556	0.833	1.000	1.111
Standard CW Method					
Achieved Throughput per group (Mbps)	Group 1	10.02	13.96	14.01	14.04
	Group 2	17.47	14.00	13.91	13.87
Total Achieved Throughput (Mbps)		27.48	27.96	27.92	27.91
Achievement Ratio	Group 1	1.00	0.93	0.78	0.70
	Group 2	0.87	0.47	0.39	0.35
Jain's Fairness Index		0.9952	0.9006	0.8982	0.8969
Total Collisions		33,340	30,904	31,208	31,274
Total Successful Transmissions		206,136	209,676	209,380	209,322
Proposed CW Method					
Achieved Throughput per group (Mbps)	Group 1	10.00	14.02	14.12	13.85
	Group 2	19.99	17.66	17.57	17.82
Total Achieved Throughput (Mbps)		29.99	31.68	31.69	31.67
Achievement Ratio	Group 1	1.00	0.93	0.78	0.69
	Group 2	1.00	0.59	0.49	0.45
Jain's Fairness Index		0.9999	0.9503	0.9479	0.9542
Total Collisions		6,414	5,567	5,462	5,632
Total Successful Transmissions		224,958	237,576	237,676	237,528

The maximum achieved throughput of the entire network is about 6Mbps for 802.11b and 32Mbps for 11a after saturation or where Load Ratio is 1.0 and higher. These are considered to be reasonable with taking overhead such as DIFS, SIFS, ACK and back-off time into account. The proposed method shows definitely better throughput than the standard method. As it can be seen in the tables, the number of collisions is smaller with the proposed method. Generally, the sum of successful transmissions and collisions are similar between the proposed and standard methods. With the proposed method, a substantial amount of collisions are converted to successful transmissions.

Fig. 1 and Fig. 2 show the graphs of Load Ratio versus Achievement Ratio. In the graph, STD, PRP mean Standard CW Method, Proposed CW Method, and GP means node Group, respectively. Achievement Ratio is the ratio of Achieved Throughput to Required Throughput per Group.

If fairness of throughput is completely achieved, Achievement Ratio of Group 1 and 2 should become the same value. But Group 1 shows higher Achievement Ratio than Group 2 in Fig.1 and 2. This is because Group 1 has a lower required throughput and the required transmission air

 ISBN: 978-1-61208-454-1

time is shorter. In a saturated network, each node competes to secure its air time. The standard method provides a homogeneous opportunity to access the channel to all nodes. Therefore this is understandable that Group 1 can have higher Achievement Ratio as Group 1 needs totally shorter air time. The proposed method adjusts the CW based on the achieved and required throughput, but, still, CW has its limitation (i.e., CWmax as 1023). So the proposed method is considered to have better fairness than the standard method, but its fairness still has certain limitation.

In order to evaluate fairness, Jain's Fairness Index [11] is selected. Fig. 3 and Fig. 4 show the graphs of Jain's Index for 802.11b and 11a, respectively. As it can be seen in Fig. 3 and 4, Jain's Fairness Index is always higher with the proposed method.

IV. CONCLUSION

In this paper, we have proposed a new QoS control method for the ad hoc W-LAN network based on the DCF which handles the communication priority in accordance with each node's required and achieved bit rate. The computer simulation shows that the proposed method has better total throughput, fairness and collision numbers. The total throughput and Jain's Fairness Index are improved by several percentages. The number of collisions is one order of magnitude smaller and the number of successful transmissions was increased by a similar number.

This time, the proposed method has the maximum limit of CW, 1023, and this limitation may cap the effect. An infinite size for the CW is not practical, but we need to find an optimized maximum CW for the proposed method. This will be the subject of future work.

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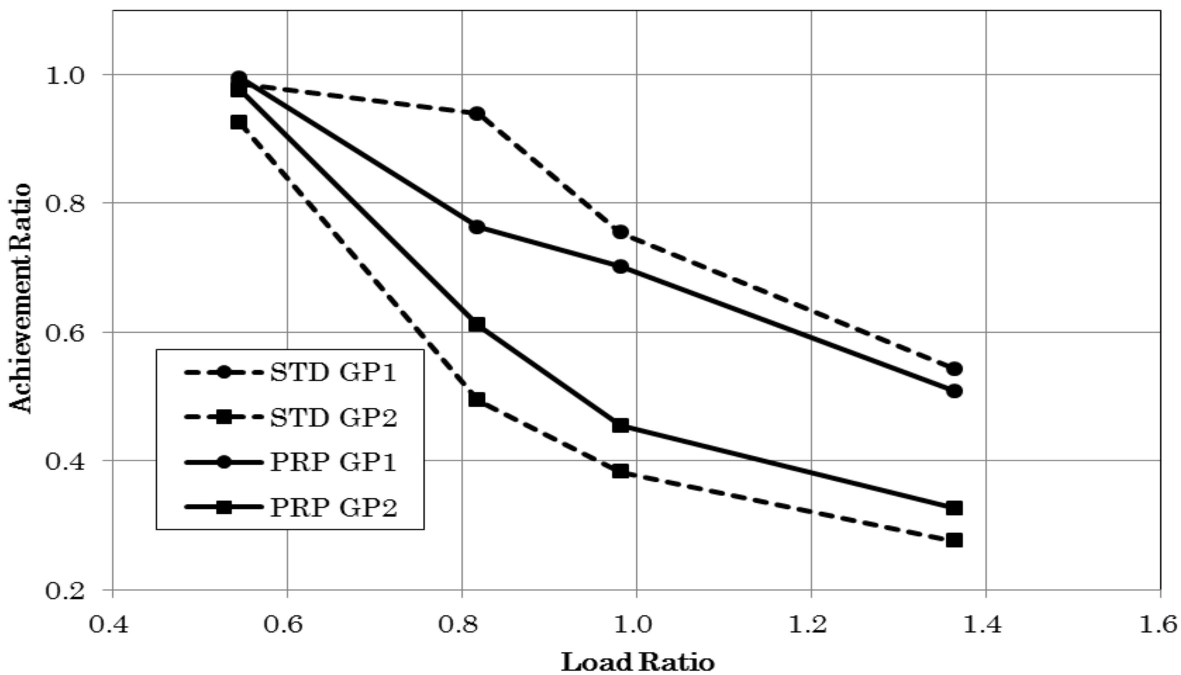

Figure 1. Achievement Ratio of 802.11b

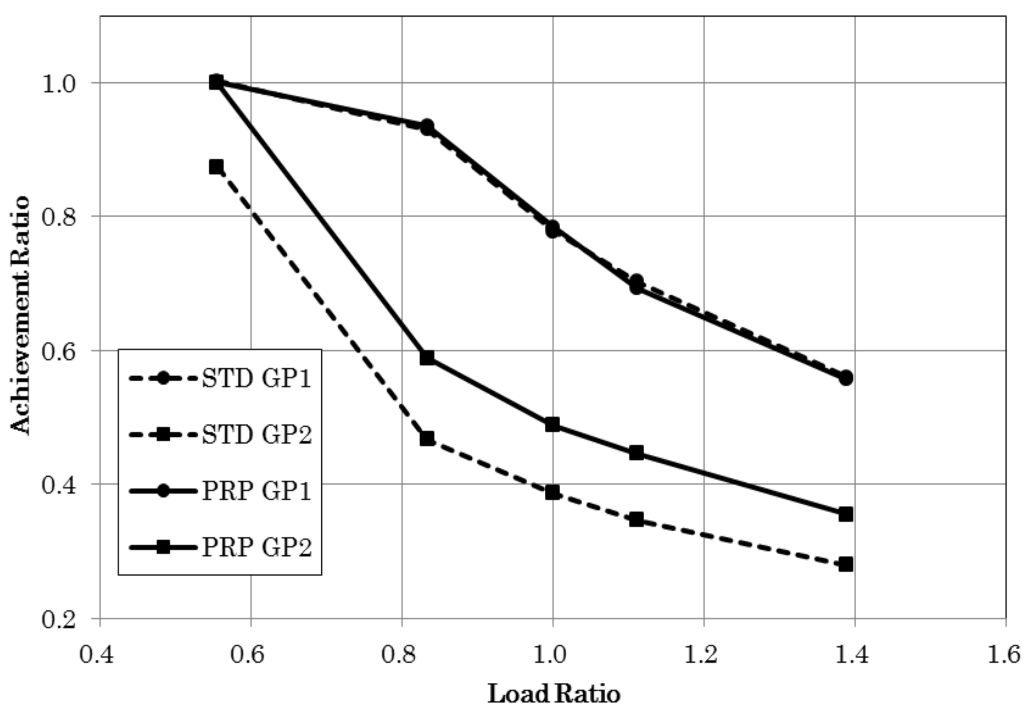

Figure 2. Achievement Ratio of 802.11a

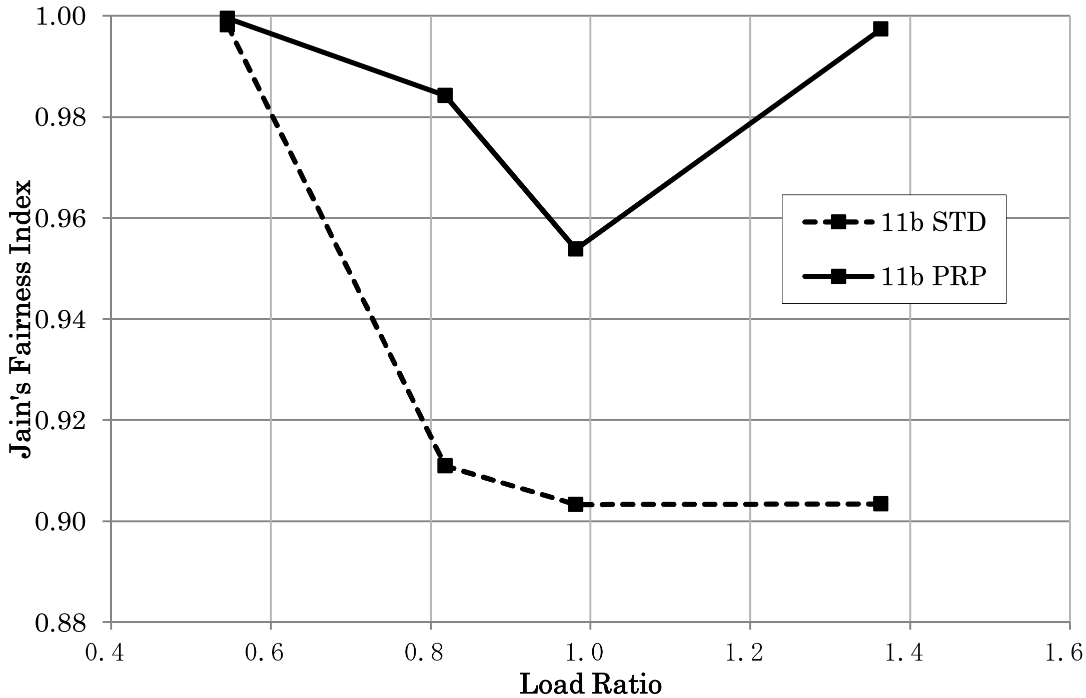

Figure 3. Jain's Fairness Index of 802.11b

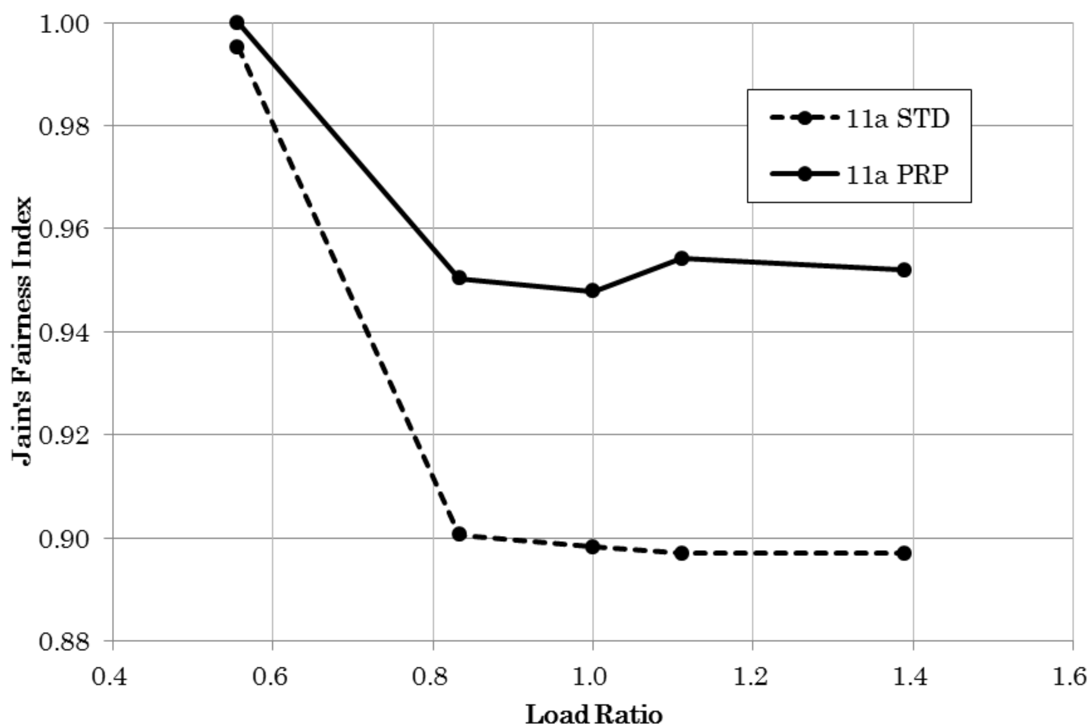

Figure 4. Jain's Fairness Index of 802.11a