Multiple Access in MAC Layer Based on Surrounding Conditions of Wireless Stations

Makiko Matsumoto
Ochanomizu University
2-1-1, Otsuka, Bunkyo-ku
Tokyo 112-8610, JAPAN
Email: makiko@ogl.is.ocha.ac.jp

Masato Oguchi
Ochanomizu University
2-1-1, Otsuka, Bunkyo-ku
Tokyo 112-8610, JAPAN
Email: oguchi@computer.org

***Abstract*—Many parameters of wireless communications are uniquely configured, regardless of their communication environments. However, we believe that stations are able to achieve efficiency in communications using surrounding information. One of the systems that is expected to improve the performance of wireless communications is Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) in the MAC Layer. In this paper, we propose a new model to improve network performance using information about the number of stations in the backoff algorithm of CSMA/CA. Although there are already some proposals for the use of the backoff algorithm, most of them are proposed under an ideal scenario, in which the communication conditions of all the stations are the same. However, we propose a model that can adapt to scenarios in which the communication conditions of each station are different. The performance of CSMA/CA enhanced with our algorithm is extensively investigated in simulations performed under multiple scenarios. The obtained results indicate that our model can simultaneously achieve good communication performance and fairness.**

I. Introduction

In recent years, computers have made it possible to collect a wide range of information by combining sensor information and understanding the sensors' surrounding conditions. In particular, we can use the hundreds of different types of sensors installed in cars for wireless communications. In this paper, we focus on vehicle communication scenarios in which the stations are able to detect their surrounding conditions.

Recently, attempts to introduce wireless communications into new applications of ITS field have been frequently investigated, such as collision avoidance, automatic tracking traveling, and traffic information sharing. In the evaluation of such an environment, vehicle density has an impact on the condition of wireless communications. It is dynamically influenced by the temporal and spatial changes. For example, the morning and/or evening traffic congestion changes temporally, and the influx of cars from countryside to city changes spatially.

In such an environment, vehicle density is sometimes very high. It is a realistic assumption that traffic congestion has been occured on one side of a six-lane high way. When the communication range is about 300m, and the inter-vehicular distance is about 2m, the number of vehicles in the communication area is over 100. On the other hand, it is also not rare that there is just one vehicle in a communication area. Therefore, we need to grasp how the communication behaves, or should behave in various vehicle densities.

Many parameters of wireless communications are uniquely configured, regardless of their communication environments. One example is the minimum contention window (CWmin), one of the parameters in CSMA/CA that is known to have a significant impact on communication performance [1].

A station with a new packet to transmit monitors the channel activity before transmitting the packet. If the channel is idle for a period of time equal to a distributed interframe space (DIFS), the station proceeds with the transmission. If the station senses that the channel is busy, it continues to monitor the channel until it is determined to be idle for a DIFS. At this point, the station generates a random backoff interval before transmitting to minimize the probability of its collision with packets being transmitted by other stations. The random backoff interval is uniformly chosen in [0,CW-1] and used to initialize the backoff timer, where CW is the current contention window size. For the first transmission attempt, CW is set to be equal to a value CWmin. The backoff timer continues running as long as the channel is sensed to be idle, pauses when data transmission (initiated by other stations) is in progress, and resumes when the channel is sensed to be idle again for longer than the DIFS. The station transmits when the backoff time reaches zero. If a station fails to transmit, CWmin is doubled to the maximum value after each unsuccessful transmission, as shown in equation (1).

$$CW = 2^n(CW_{min}+1)-1 \tag{1}$$

n : Number of retransmissions

To reduce the probability of coinciding with the timing of other stations' transmissions at retransmission, the CW is increased after unsuccessful transmissions. The CW is also reset to CWmin after a successful transmission. In this paper, this access method is referred to as "basic CSMA/CA".

It is not a problem if a few stations exist on a channel because the probability of collision is low. However, if a large number of stations use the same channel, the probability of collision is higher because CWmin is small compared to the number of stations. It is easy to waste time encountering repeated collisions. In addition, an unnecessary latency occurs at each transmission by repeating the above process at the next transmission. This is caused by the feature of the CSMA/CA algorithm that resets the CW to CWmin after a successful transmission, even if the CW is increased to the appropriate size. For this reason, as the number of stations increases, the communication performance of the entire network may degrade.

In this paper, we discuss how to set the CWmin according to the number of surrounding stations using the surrounding information. While Bianchi's model has already proposed a method of calculating the appropriate CWmin using the number of surrounding stations, the model assumes an ideal scenario in which the communication conditions of all the stations are the same[3]. Therefore, we evaluate Bianchi's model from various viewpoints, such as the number of retransmissions, the behavior of the CW and the backoff counter, and verify their effects. Based on the results, we propose a new model that considers the different communication conditions of all the stations and evaluates them under scenarios that are closer to real environments.

The rest of this paper is organized as follows. In Section II, the method of setting CWmin using Bianchi's model and the related works are described. The evaluation environment is introduced in Section III. In Section IV, we discuss the simulation results and the performance of Bianchi's model. We present our proposed model and evaluate its results and performance in section V. Finally, in section VI, we provide some concluding remarks.

II. Bianchi's model and Related work

A. Setting CWmin

Bianchi's model assumes that collisions constantly and independently occur at each transmission of each station. It then defines the CWmin according to the number of stations using multiple probabilities, such as data collisions and transmissions. The CWmin is provided by equation (2) :

$$CW_{min} = N\sqrt{2T_c/SlotTime} \tag{2}$$

$T_c = MAC_{hdr} + PHY_{hdr} + Payload + DIFS + \delta$
N : Number of stations
δ : Propagation Delay

Where T_c is time spent when a collision occurs. Therefore, when we use RTS/CTS, we should use equation (3) because the data that may occur collisions is RTS packet.

$$CW_{min} = N\sqrt{2T_c/SlotTime} \tag{3}$$

$T_c = RTS + DIFS + \delta$
N : Number of stations
δ : Propagation Delay

B. Related work and Technology

The average packet delay of Bianchi's model is discussed in detail in [4]. Additionally, in [5], a new model is proposed that extends Bianchi's model to include the finite packet retry limit specified in the IEEE 802.11 standard. Nevertheless, [4] and [5] and Bianchi's model all assume an ideal scenario in which the communication conditions of all the stations are the same. In addition to Bianchi's model, Cali's model [6] is available to mathematically calculate the throughput. Cali makes the assumption that the backoff time is independent of the number of packet retransmissions and is sampled from a geometric distribution. Under these assumptions, [6] develops a mathematical model that calculates the throughput. [7] extends Bianchi's model and Cali's model, proposing a new model, which considers the effect that occurs when a station that has successfully completed a transmission seizes the channel because it has a better chance of winning in the next competition than the other stations. However, both [6] and [7] have developed complex analytical formulas utilizing several assumptions.

Of the methods proposed to optimize the CWmin, the EDCF of IEEE 802.11e is well known in [8]. EDCF is defined as a MAC protocol for QoS in wireless networks. EDCF provides differentiated services of distributed access to the wireless medium for four delivery priorities or access categories. It classifies the transmissions' priority into four categories according to the QoS required by the stations and sets a different CWmin for each category. [9] propose extending EDCF with the dynamic adaptation algorithm of CWmin, which enables each station to tune the CWmin size used in its backoff algorithm at run time. However, these approaches differ from our approach in the use of QoS when setting the CWmin.

III. Evaluation Environment

Most of the models described in the previous section have been proposed under an ideal scenario. However, it is necessary to consider various communication conditions in the evaluation of a model. This section presents the scenarios and performance criteria used in our evaluations. In this paper, we use QualNet as a simulator.

A. Scenarios

In the following simulation, each station generates CBR data streams. The packet size is 1000 bytes, and the packet interval is configured to 1ms. We assume that each station communicates with IEEE 802.11a.

In [3], Bianchi's model was only evaluated under an ideal scenario in which the communication conditions of all the stations were the same. In this paper, we evaluate the model under various scenarios in which the communication conditions of each station are different to consider scenarios that are more similar to a real environment, in addition to the ideal scenario. The primary communication conditions that may impact performance are the communication distance and

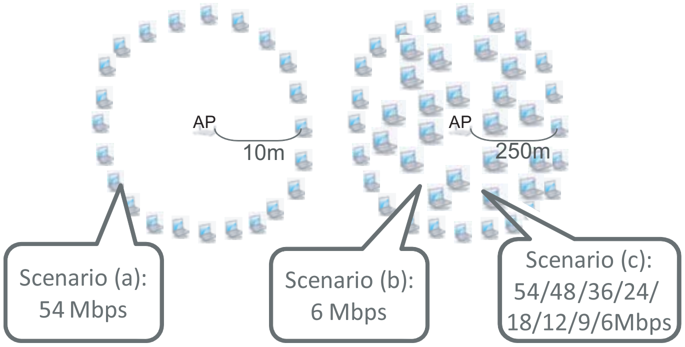

Fig. 1. Simulation scenario

TABLE I
PARAMETERS OF CISCO'S AIRONET 1130AG IEEE 802.11A/B/G AP

Distance from AP (m)	10	20	30	90	120	150	200	250
Data Rate (Mbps)	54	48	36	24	18	12	9	6

the data rate. Therefore, we consider three cases as simulation scenarios to evaluate Bianchi's model.

(a) The ideal scenario, in which the communication conditions of all stations are the same.
(b) The scenario in which the distances between each station and an access point (AP) are different.
(c) The scenario in which the data rates of each station are different.

(a) is the scenario considered when Bianchi's model is proposed in [3], in which the distances from the AP and the data rates of all the stations are the same. The distance from AP and the data rate are fixed to 10 m and 54 Mbps, respectively. The data rate is fixed to 6 Mbps to investigate the influence of distance alone in (b). The data rate is configured according to the distance from AP in (c). Although there are other methods of configuring the data rate [10], we use the most typical approach, configuring it according to the distance from AP. The relationship between the distance and the data rate is different at each wireless device or vendor. We use the parameters of Aironet 1130AG IEEE 802.11a/b/g AP and present the value in Table I.

B. Evaluation criteria

In [3], the evaluation criterion focuses only on the communication performance; the total throughput is used as the indicator of this performance. However, we are concerned about the potential for a lack of fairness between the stations when the communication conditions of the stations are different, as in scenario (b) or scenario (c). For example, a station may occupy the bandwidth despite the presence of other stations. Although the station only obtains high throughput when others cannot communicate at all, its result is only judged according to the evaluation of the total throughput.

Therefore, we add an indicator of fairness to avoid these problems. We use the extended Jain's fairness index as an indicator of fairness. The value (fi) of the fairness index is defined as

$$fi = \frac{(\sum_{i=i}^{N} x_i)^2}{k \sum_{i=i}^{N} {x_i}^2} \qquad (1 \leq i \leq N) \tag{4}$$

, where N is the number of stations on a channel and x_i is defined as follows:

$$x_i = \frac{Real\ Throughput\ of\ node\ i}{Expected\ Throughput\ of\ node\ i}$$

, where x_i shows the percentage that met the throughput expected when a station communicates at the data rate of node i (= Expected Throughput of node i). "Expected Throughput of node i" is defined as follows:

$$Expected\ Throughput\ of\ node\ i = \frac{Execution\ speed\ of\ d_i}{N}$$

In scenarios (b) and (c), we use this fairness index.

IV. EVALUATION OF BIANCHI'S MODEL

In order to evaluate the performance of Bianchi's model, in this section, we investigate the impact of the number of stations, the distance from AP, and the data rate and compare them to the basic CSMA/CA.

(a)Ideal scenario

We analyze the factors of the improvement of the communication performance in Bianchi's model in detail.

1) Total throughput: First, to make sure the effect of Bianchi's model, we vary the number of stations in the range of [10,100] and measure the total throughput. Figure 2 shows the total throughput for basic-CSMA/CA, CSMA/CA with RTS/CTS, Bianchi's model and Bianchi's model with RTS/CTS. As expected, the simulation result demonstrates that Bianchi's model can achieve a higher throughput than the default. Moreover, the total throughput in Bianchi's model maintains high values, even in the presence of a high number of stations. This result under the ideal scenario shows that Bianchi's model is effective in terms of throughput.

In the following subsection, we investigate the factors of the improvement of the total throughput by utilizing Bianchi's model.

2) Wasted time in retransmissions: In this subsection, we compare the time wasted in retransmissions under basic-CSMA/CA and Bianchi's model, based on the simulation results of the behavior of the CW and the probability of retransmission. Figure 3 illustrates the behavior of the CW in any node of 40 stations between 21 and 22 sec when communications are stable and where 40 is the usual maximum number of stations that can connect to an AP. The CW rises after an unsuccessful transmission and falls after a successful transmission.

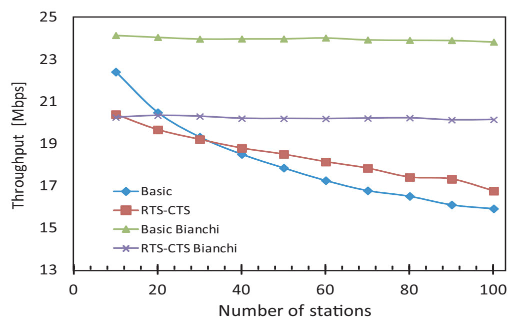

Fig. 2. Throughput for 802.11a and Bianchi's model vs. number of stations

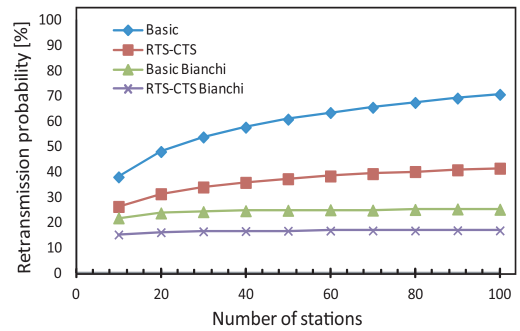

Fig. 4. Probability of retransmission

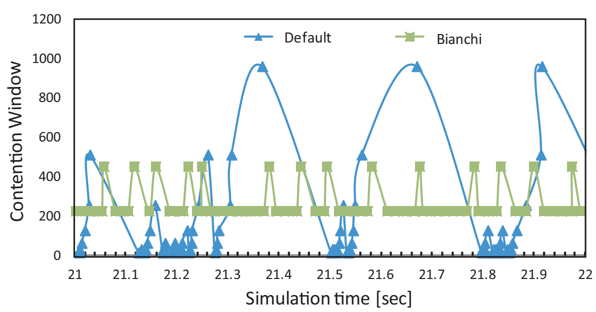

Fig. 3. Wasted time for retransmission

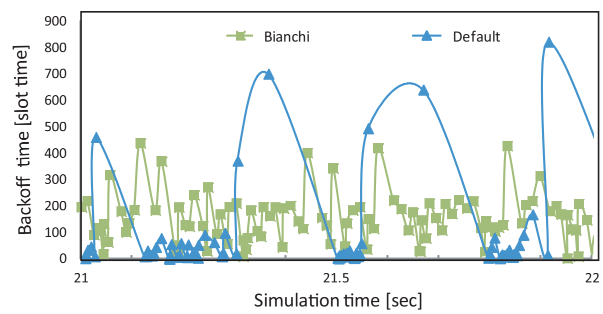

Fig. 5. Behavior of backoff time

It can be seen that the station repeats collisions up to 6 times, and up to 133 msec is wasted for each collision in the default. Furthermore, the data transmission is 34 times slower than when no collision occurs. The average amount of wasted time in the retransmissions is about 43.2% of the total simulation time. On the other hand, the number of collisions is maintained up to 2 times in Bianchi's model. Even if collisions occur, the maximum wasted time is up to approximately 15 msec, and the time of data transmission is 3 times slower than when no collision occurs. In addition, the average wasted time remains at approximately 11% of the total simulation time.

In consideration of the above, it is clear that configuring the CW using Bianchi's model limits the number of collisions and significantly reduces the amount of time wasted in retransmissions.

To investigate the effect of retransmissions on the other numbers of stations, we measured the retransmission probability at each number of stations. The result is shown in Figure 4. Figure 4 shows that the retransmission probability in the default rises as the number of stations increases. In contrast, the retransmission probability in Bianchi's model remains constant. When the CWmin is optimized, the retransmission probability is almost equal to the value of 10 stations, even with a high number of stations. Therefore, we ensured that setting the CW using Bianchi's model led to limiting the retransmission because the CWmin significantly affects the retransmission probability.

3) Time of data transmission: We investigate the impact of the CWmin using the turnaround time from the time the backoff time is set until the packet is sent out (= time taken to transmit a packet). Figure 5 illustrates the behavior of the backoff time in any node of the 40 stations between 21 and 22 sec when communications are stable.

The backoff time is almost the same between the default and Bianchi's model, at a simulation time of 21.6 sec. However, the time required for data transmission in Bianchi's model is much lower than in the default. This may be because in CSMA/CA, when the transmission of another station starts counting the backoff time, the counter is paused. After the other station's transmission is complete, the counter is restarted. Thus, the time of data transmission is different due to the different number of pauses taken when counting the backoff time, even if the same backoff time is set. In both the default and Bianchi's model, we measured the number of pauses during the backoff time; the results are shown in in Figure 6. It is clear that there is an improvement in the number of pauses at each backoff time in Bianchi's model, compared to the default.

This is because in the default, a station that has successfully completed a transmission has a better chance of winning in the next competition than other stations, as the CW is reset to CWmin after a successful transmission in the default. In contrast, the possibility of the transmission of another station during the backoff time is limited in Bianchi's model because CWmin is set according to the number of stations, even if the CW is reset to CWmin after a successful transmission. Therefore, the number of pauses during the backoff time in the default maintains a lower increase than in Bianchi's model

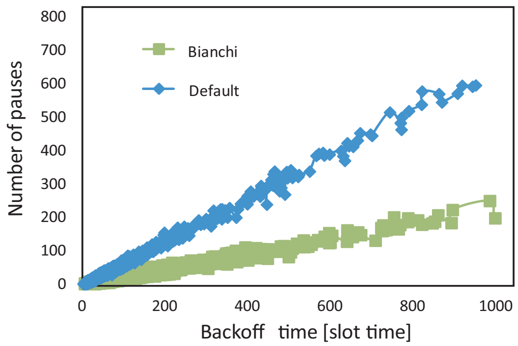

Fig. 6. Number of pauses during backoff time

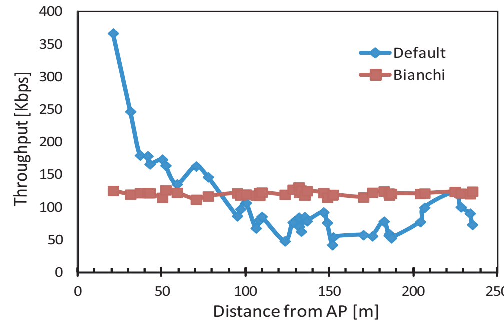

Fig. 8. Throughput at each station according to the distance from AP

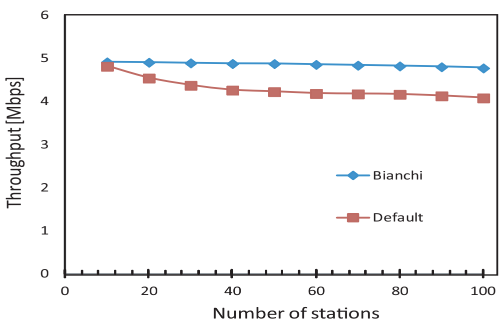

Fig. 7. Total throughput in scenarios in which the distance is different

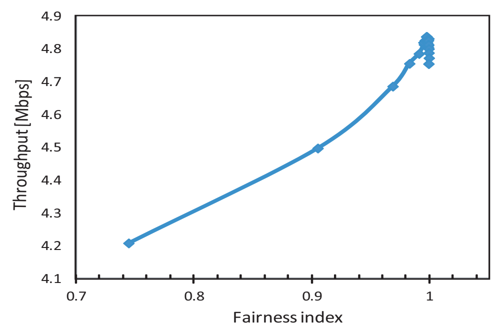

Fig. 9. Total throughput vs Fairness at each CWmin

with a long backoff time. Similar results are obtained in RTS/CTS. Therefore, we made sure that Bianchi's model is effective at considerably shortening the time of data transmission.

4) Analysis results: The results indicate that the improvement of the total throughput in Bianchi's model is the result of the combined effects of reducing the time wasted in retransmission and the time of data transmission by limiting the number of pauses during backoff time.

(b)Scenarios in which the distance is different

5) Total throughput: Figure 7 compares the total throughput of each number of stations in the default and Bianchi's model. The simulation results demonstrate that the total throughput in Bianchi's model is higher than in the default. Moreover, Bianchi's model can inhibit the decline in performance due to an increased number of stations that occurs in the default.

6) Fairness: As an example, we will discuss the issue of fairness for 40 stations. Figure 8 shows the throughput per station at each distance from AP. It shows that the farther the distance from the AP is, the lower the throughput is. However, the bandwidth in Bianchi's model is fairly shared at any distance without the effect of the distance.

Figure 9 illustrates the correlation between the total throughput and the fairness index. The value of CWim varies in the range of [15,1000]. The left endpoint, total throughput = 4.2Mbps and fi = 0.74, is CWmin = 15. The right endpoint, total throughput = 4.75Mbps and fi = 0.99, is CWmin = 1000. Furthermore, the point of the total throughput = 4.83Mbps and fi = 0.99 is the CWmin calculated by Bianchi's model. Bianchi's model is able to achieve good values for both total throughput and the fairness index.

7) Analysis results: The results indicate that Bianchi's model is effective for both communication performance and fairness, even if the distances between the stations and an AP are different. Similar results were obtained in RTS/CTS.

(c)Scenarios in which the data rates are different

In this subsection, we further evaluate 3 typical scenarios.

(c') Stations are unevenly distributed in $0m < d \leq 90m$
(c") Stations are unevenly distributed in $90m < d \leq 250m$
(c"') Stations are distributed across the communication area ($0m < d \leq 250m$)

The data rate to be used in (c') is either 54/48/36/24 Mbps. In (c"), the data rate is set to either 18/12/9/6 Mbps. As the stations are evenly distributed across the communication area in (c"'), all the 8 data rates, 54/48/36/24/18/12/9/6 Mbps, are used.

(c') Stations are unevenly distributed in $0m < d \leq 90m$

Figure 10 illustrates the correlation between the total throughput and the fairness index when the value of CWim varies in the range of [15,200] for the 40 stations. The left endpoint, total throughput = 15.17Mbps and fi = 0.966, is CWmin = 15. The right endpoint, total thoughput = 15.8Mbps

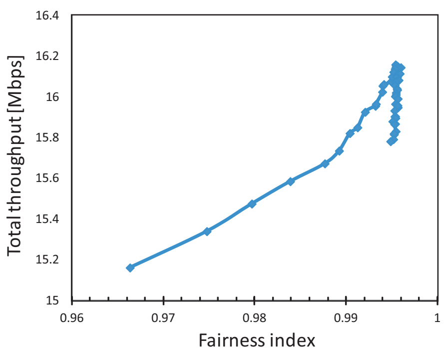

Fig. 10. Total throughput vs. Fairness Index : Stations are unevenly distributed in $0m < d \leq 90m$

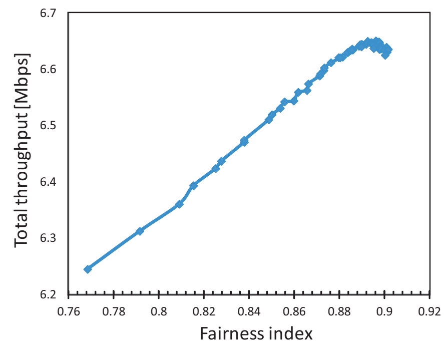

Fig. 11. Total throughput vs. Fairness Index : Stations are unevenly distributed in $90m < d \leq 250m$

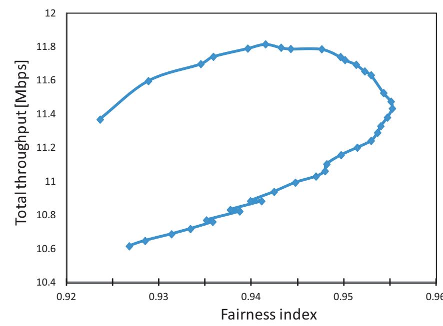

Fig. 12. Total throughput vs. Fairness Index : Stations are distributed across the communication area ($0m < d \leq 250m$)

and fi = 0.996, is CWmin =200. Furthermore, the point of the total throughput = 16.17Mbps and fi = 0.996 is CWmin, as calculated by Bianchi's model. Bianchi's model is able to achieve good values for both the total throughput and the fairness index.

(c") Stations are unevenly distributed in $90m < d \leq 250m$

Figure 11 illustrates the correlation between the total throughput and the fairness index when the value of CWim varies in the range of [15,200] for the 40 stations. The left endpoint, total throughput = 6.25Mbps and fi = 0.77, is CWmin = 15. The right endpoint, total thoughput = 6.63Mbps and fi = 0.9, is CWmin =200. Furthermore, the point of the total throughput = 6.65Mbps and fi = 0.89 is CWmin, as calculated by Bianchi's model. Bianchi's model is able to achieve good values for both the total throughput and the fairness index.

(c"') Stations are distributed across the communication area ($0m < d \leq 250m$)

Figure 12 illustrates the correlation between the total throughput and the fairness index when the value of CWim varies in the range of [15,200] for the 40 stations. The left endpoint, total throughput = 11.4Mbps and fi = 0.923, is CWmin = 15. The right endpoint, total thoughput = 10.6Mbps and fi = 0.927, is CWmin =200. Furthermore, the point of the total throughput = 11Mbps and fi = 0.945 is CWmin, as calculated by Bianchi's model. It can be observed that the throughput in $20 \leq CWmin \leq 40$ is higher than in the default. However, there are other CWmin sizes in which the throughputs are higher than in $20 \leq CWmin \leq 40$. Conversely, the fi in $20 \leq CWmin \leq 40$ where the CWmin size calculated by Bianchi's model is included are higher than in the default. However, there are other CWmin sizes in which the fi are higher than in $95 \leq CWmin \leq 200$. Therefore, the CWmin sizes in $20 \leq CWmin \leq 40$ and $95 \leq CWmin \leq 200$ are not the optimum values, and the optimization of CWmin used Bianchi's model is not effective. Moreover, there are no CWmin sizes able to achieve the maximum of both the total throughput and fairness index because the communication performance and fairness are tradeoffs $45 \leq CWmin \leq 90$. Therefore, no CWmin sizes enable both performance and fairness to achieve their maximum values in the scenario in which the stations are distributed across the communication area.

8) Analysis result: From the results of (c'), (c") and (c"'), we determined the following. In the scenario in which the stations are unevenly distributed, it is effective for the communication performance and fairness to use Bianchi's model, even if multiple data rates are combined. However, it is impossible to calculate the appropriate size of CWmin with Bianchi's model when stations exist across the communication area and all the data rates are combined. Therefore, we propose extending Bianchi's model to support any arrangement of stations in the following section.

V. Proposed model

It is generally the case that stations are arranged across the communication area, as in (c"'). However, we ensured that using Bianchi's model is ineffective for communication performance and fairness if the stations are distributed across the communication area, as described in section IV-7. Furthermore, no appropriate CWmin size exists to achieve the maximum value of both criteria. Therefore, we propose a new model to optimize the CWmin size in any scenario.

A. Method overview

We propose setting the different sizes of CWmin according to the communication condition of each station, rather than setting the same size for all the stations. We believe that this approach is able to set an appropriate size for both communication performance and fairness. The characteristics of our model are as follows.

- Stations are classified into groups, in which the appropriate CWmin can be calculated using Bianchi's model.
- Based on the number of stations in each group, CWmin is optimized using Bianchi's model for each group.
- To avoid a confusion in communications between the groups, AP determines the opportunities for communication between the groups and distributes them depending on the ratios of the number of stations in each group.

- To determine the opportunities for communication between groups, we propose an extended RTS/CTS.

The size of CWmin is most correctly calculated when the stations are classified into eight groups according to data rates, as multiple rates will not be combined in the same channel. Using the proposed algorithm, it is possible for our model to classify the stations into eight groups according to the data rate of each station. However, we will classify the stations into two groups (Group1 : $0m < d \leq 90m$, Data rate = 54/48/36/24Mbps. Group2 : $90m < d \leq 250m$, Data rate = 18/12/9/6Mbps). This ensures that the CWmin size can be adjusted appropriately using Bianchi's model in scenarios such as (c') and (c"), described in the previous section. Two groups communicate in parallel by distinguishing the opportunities for transmission between the groups and communicating independently. At this time, the CWmin size is optimized for each group. We believe that the process described above enables the stations to communicate optimally as whole network because both groups can communicate appropriately. In addition, the opportunities for communication are shared fairly in any ratio of the number of stations between the groups because AP distributes it according to the number of stations in each group.

B. Extended RTS/CTS

To distinguish the opportunities for transmission between the groups, we propose to use an extended RTS/CTS. We extended RTS/CTS to distribute the opportunities stochastically at APs based on the number of stations of each group and implemented it under the network simulator. The characteristics of our extended RTS/CTS are as follows.

- A new-state NAVS to prohibit transmissions (including backoff) indefinitely until stations receive the transition command of CTS packet is defined.
- AP distributes NAV or NAVS according to the number of stations of each group.
- The group name that should transition to NAV is described into the CTS packets.
- If a station that sent an RTS packet to AP receives the transition command to NAVS, it transitions to NAVS after the successful transmission.

Based on the above characteristics, Figure 13 illustrates the process of our extended RTS/CTS.

Stations with a new packet to transmit monitor the channel activity for DIFS and backoff time before transmitting the packet. The station (STA 1) in which the backoff time is shortest transmits an RTS packet to AP. AP determines the group given the transition command to NAV according to the probability calculated based on the number of stations of each group, and it describes the group's name (Group 2) and the period to use the channel into a CTS packet. The CTS packet is broadcast to all stations. The group (STA 3) given the transition command to NAV transitions to NAV and halts transmission for the period described into the CTS packet. The group (STA 2) that is not given the command transitions to NAVS and halts transmission completely. On the other hand,

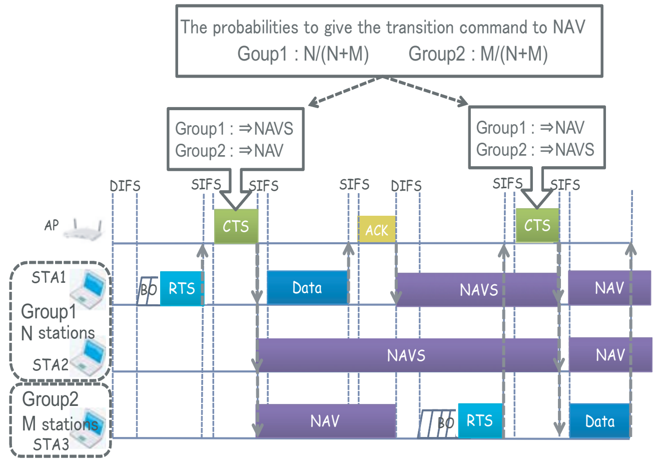

Fig. 13. Extended RTS/CTS

the station that sent the RTS packet to AP transmits a data packet after it receives the CTS packet. After a successful transmission, the group (STA 3) that was given the transition command to NAV starts the backoff and transmits an RTS packet to AP. The AP receiving the RTS packet determines the group given the transition command to NAV according to the probability and broadcasts a new CTS packet. The group (Group 1) whose state is NAVS will be able to escape from that state to NAV only if the group receives the transition command to NAV.

C. Evaluation of our model

We evaluate our model using the same scenarios as described in Section IV-7. Although Bianchi's model has already achieved good values for both total throughput and the fairness index in (c') and (c") as described in Section IV-7, we discovered that our model also achieves the same value in the simulations. This can be explained by considering the nature of the algorithm of extended RTS/CTS. When the stations are unevenly distributed to one group, the stations communicate with the same behavior as the normal RTS/CTS because the transmission rights are always given to that group. Because the CWmin size is also adjusted by Bianchi's model at this time, the simulation results are equal to the results when CWmin is optimized by Bianchi's model in the normal RTS/CTS. In (c"'), we determined that it is impossible to achieve good values for the total throughput and fairness index at the same time, even if the CWmin size is set to the value of the default specified in 802.11a or is calculated by Bianchi's model. Nevertheless, the simulation result shows that our model can simultaneously improve both the total throughput and fairness index in Figure 13. Figure 14 shows the effect of our model on 40 stations in (c"'). There are two reasons that both performance and fairness are simultaneously improved in our model. One reason is that the fairness of each station has been improved by distinguishing the rights of transmission between each group. The other is that the number of throughputs per station has been improved by setting the

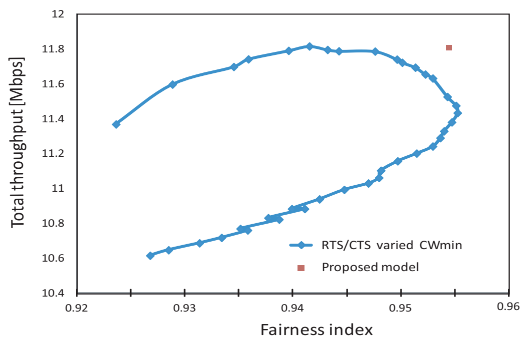

Fig. 14. Total throughput vs. Fairness index for normal RTS/CTS with changed CWmin and our model

appropriate CWmin size for each station. Using the above evaluation, we determined that our model is effective in any scenario.

VI. Conclusion

Radio equipment has made it possible to collect a wide range of information by combining the sensors' information and understanding the surrounding conditions. However, because the existing CSMA/CA does not assume a scenario in which wireless stations are able to understand the surrounding conditions, many parameters of wireless communication are uniquely configured regardless of their communication environment. Therefore, if a large number of stations communicate at the same time, they experience repeated collisions and are unable to achieve good performance.

In this paper, we assumed scenarios in which stations are able to obtain information about the surrounding conditions and considered how to set CWmin according to the number of surrounding stations. We first focused on Bianchi's model and evaluated it in the scenarios in which distance and data rate are considered. We clarified the scenario in which Bianchi's model is effective and the scenario in which it is not. Based on these results, we proposed a new approach to enable optimization of the CWmin size in any scenario and evaluated it. The result showed that our model can simultaneously improve both the total throughput and fairness index.

Acknowledgment

The authors would like to thank to Dr. Onur Altintas in TOYOTA InfoTechnology Center, Co. for the conscientious advice and help for this research work.

References

[1] M.Matsumoto, O.Altintas, M.Nishibori, M.Oguchi: "A Study of Multiple Access Using Environmental Information," *The 73th Annual Convention IPS Japan* , Tokyo, Japan, March 2011.

[2] IEEE802.11 MAC, http://standards.ieee.org/getieee802/download/802.11-2007.pdf

[3] G. Bianchi: "Performance Analysis of the IEEE 802.11 Distributed Coordination Function," *IEEE J.Selected Areas in Communications* , Vol.18, No.3, pp.535-547, Mar 2000.

[4] Chatzimisios P, Vitsas V, Boucouvalas AC: "Throughput and delay analysis of IEEE 802.11 protocol," *Proc. of IEEE International Workshop on Networked Appliances (IWNA)* , Liverpool, U.K., 2002.

[5] Wu H, Peng Y, Long K, Cheng S, Ma J: "Performance of reliable transport protocol over IEEE 802.11 wireless LAN: analysis and enhancement," *Proc. of IEEE INFOCOM* , VOL. 2, pp. 599-607, New York, U.S.A., 2002.

[6] Cali F, Conti M, Gregori E: "Dynamic Tuning of the IEEE 802.11 Protocol Achieve a Theoretical Throughput Limit," *IEEE/ACM Transactions on Networking* , VOL. 8, NO. 6, pp. 785-799, December 2000.

[7] Vishnevsky VM, Lyakhov AI: "IEEE 802.11 Wireless LAN: saturation throughput analysis with seizing effect consideration," *Cluster Computing* , Vol. 5, pp.133-144, 2002.

[8] IEEE WG, Draft Supplement to Standard for Telecommunication and Information Exchange Between Systems LAN/MAN specific requirements -Part 11: Wireless Medium Access Control (MAC) and Physical Layer Specification: Medium Access Control (MAC) Enhancements for Quality of Service (QoS), IEEE 802.11e /Draft D5.0, July 2003.

[9] Lassaad Gannoune: "A Non-linear Dynamic Tuning of the Minimum Contention Window (CWmin) for Enhanced Service Differentiation in IEEE 802.11 Ad-hoc Networks," *Proc. of IEEE VTC*, 2007.

[10] S.Biaz, Shaoen Wu: "Rate adaptation algorithms for IEEE 802.11 networks: A survey and comparison," *IEEE Symposium on Computers and Communications* , pp.130-136, Marrakech, July 2008.

[11] Cisco Aironet 1130AG IEEE 802.11a/b/g AP, http://www.cisco.com/web/JP/product/hs/wireless/airo1130/prodlit/1130ag_ ds.html