〈一般研究課題〉　走行中自動車群のソフト一体化を実現する
ポジティブ対応型通信に関する研究
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走行中自動車群のソフト一体化を実現するポジティブ対応型通信に関する研究

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Improving Wireless Networks to Realize Positive Communication for Transport Systems

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Abstract

The MAC protocol is important in LAN, especially in wireless LAN because of limited bandwidth. A great deal of research has been carried out and some of proposed schemes are effective. Specifically, considerable effort has been devoted to improving the IEEE 802.11 standard which is utilized widely and it seems that we cannot expect to enhance the throughput dramatically than improved proposals ether for DCF or PCF. In the meantime, besides throughput, there are some other issues for DCF such as fairness and QoS support. However, except for several hybrid protocols, most proposals were either based on contention mode or schedule mode and neither of the two modes has possessed the good characters of the other.

In this paper, we propose a new hybrid MAC scheme used for distributed system (with no control node) that dynamically adapts to traffic changes without degradation of delay in the case of low traffic load and achieves high throughput which is close to transmission capacity in saturated case. We carried out simulations focusing on throughput and delay. Through an analysis of simulation results, we show that our scheme can greatly improve the throughput with low delay.

Keywords　WLAN, MAC protocol, Throughput, Random Access, Channel Reservation.

Ⅰ. INTRODUCTION

The MAC protocol is important in LAN, especially in wireless LAN because of limited bandwidth. IEEE 802.11 standard [1], [2], [3] specifies a common medium access control (MAC) layer, which provides two functions, Distributed Coordination Function (DCF) and an optional Point Coordination Function (PCF). The basic 802.11 MAC layer uses DCF to share the medium between multiple stations. DCF will suffer collisions, which will lower the available bandwidth in the case of high traffic. In contrast to the DCF, the polling mechanism causes significant overhead and unnecessary delay for stations under low traffic.

Since DCF and PCF have different performances, research on MAC protocols based on the two methods were carried out respectively for the different situations. Due to inherent simplicity and flexibility, the DCF mode is preferred and has attracted most research attention [4], [5], [6], [9], [10], [11], [12]. Cali et al. pointed out in [7] that depending on the network configuration, IEEE 802.11 DCF may deliver a much lower throughput compared to the theoretical throughput limit after analysis and a scheme was given for achieving a throughput close to the theoretical upper bound in saturated case. It seems that we cannot expect to enhance the throughput much more for DCF in a usual way. Hybrid Coordination Function (HCF)[13],[14] of IEEE 802.11e is defined for overcoming the QoS problem by IEEE 802.11 task group. The HCF uses a superframe consisting of contention period (CP) and contention free period (CFP), which seems like a hybrid method of contention-based and schedule-based scheme. However, the CF-Schedule needs a control node as a coordinator and may waste channel capacity. A scheduled node may not fully utilize the allocated TXOP (Transmission Opportunity) when there are not enough pending data to be transmitted. On the other hand, the lifetime of each scheduled TXOP is different, so the scheduled TXOPs that are still alive may sparsely distribute over the channel space after a certain time period. It becomes an overhead for the PC to rearrange the scheduled TXOPs. HCF is a complex coordination function and EDCA appears to be gaining more early acceptance than HCF but, as indicated, cannot provide efficient channel utilization and the aggregate throughput degrades when network situation changes in the number of active nodes, traffic load and proportions among traffic of different priorities [18][19]. In this paper, we propose a novel MAC protocol for WLANs, focusing on the aggregate throughput and potential QoS support. The novelMAC scheme dynamically works in the two modes, i.e., schedule or contention mode, which is named as Scheduled Random Access Protocol (SRAP). Compared to the 802.11 MAC protocol and previous enhancement approaches, this scheme has the following distinguishing features:

- It allows WLANs to work with low delay as in the contention-based mode and achieve a high throughput as in the schedule-based mode without complicated on-line estimation as required in previous schemes[15],[16],[17].
- Unlike usual hybrid methods, SRAP dynamically works in the schedule and contention modes without the burden of complicated computing for shifting in two modes.
- SRAP suitably adapts to traffic changes, which leads to high throughput in saturated case without degradation in delay even in the unsaturated case.

・Unlike HCF, SRAP is simple and can be easily adapted to support QoS as a distributed function, which can be expected to be used for improving other protocols such as EDCA.

The remainder of this paper is organized as follows. In Section 2, we present in detail our proposed SRAP scheme. Then we analyze SRAP approximately. In Section 3, we give the simulation results and discussions. Finally, concluding remarks are given in Section 4.

Ⅱ. SCHEDULED RANDOM ACCESS PROTOCOL

To better understand our scheme, in this section we first briefly introduce the DCF of original version of the IEEE 802.11 utilized broadly in WLANs, a distributed contention based medium access control protocol. Then, we give our proposal SRAP.

A. Operations of the IEEE 802.11 MAC

The IEEE 802.11 DCF is based on a mechanism called carrier sense multiple access with collision avoidance (CSMA/CA). In DCF mode, a node with a packet to transmit initializes a backoff timer with a random value selected uniformly from the range [0, CW − 1], where CW is the contention window in terms of time slots. After a node senses that the channel is idle for an interval called DIFS (DCF interframe space), it begins to decrease the backoff timer by one for each idle time slot. When the channel becomes busy due to other nodes' transmissions, the node freezes its backoff timer until the channel is sensed idle for another DIFS. When the backoff timer reaches zero, the node begins to transmit. If the transmission is successful, the receiver sends back an acknowledgment (ACK) after an interval called SIFS (short inter-frame space). Then, the transmitter resets its CW to CWmin. In case of collisions, the transmitter fails to receive the ACK from its intended receiver within a specified period, it doubles its CW subject to a maximum value CWmax, chooses a new backoff timer, and start the above process again. When the transmission of a packet fails for a maximum number of times, the packet is dropped.

To improve channel efficiency for long packet transmissions, the IEEE 802.11 protocol can also use a short Request To Send (RTS) control frame and a short Clear To Send (CTS) frame to reserve access to the channel. RTS/CTS is valid to relieve the interference from collisions. Hereafter, RTS/CTS is used only in contention period of our protocol SRAP stated afterwards.

B. SRAP

As shown in Fig. 1 (a), SRAP allows channel access in terms of superframes consisting of two parts, schedule period and contention period. Nodes either transmit in schedule period without collision or contend for the channel to transmit in contention period but are not allowed to transmit in both of two periods in one superframe. At the beginning, a node contends for a channel in contention period and after successful transmission, it is allowed to transmit in scheduled period if its queue is not empty or it has a sending request coming in time, or the queue length exceeds a certain threshold. Here, firstly we give the procedure for nodes to reserve channels in schedule period and to escape from schedule period when the queue become empty in the normal case shown as Fig. 1. And then we give the procedure of initialization when there is no schedule period.

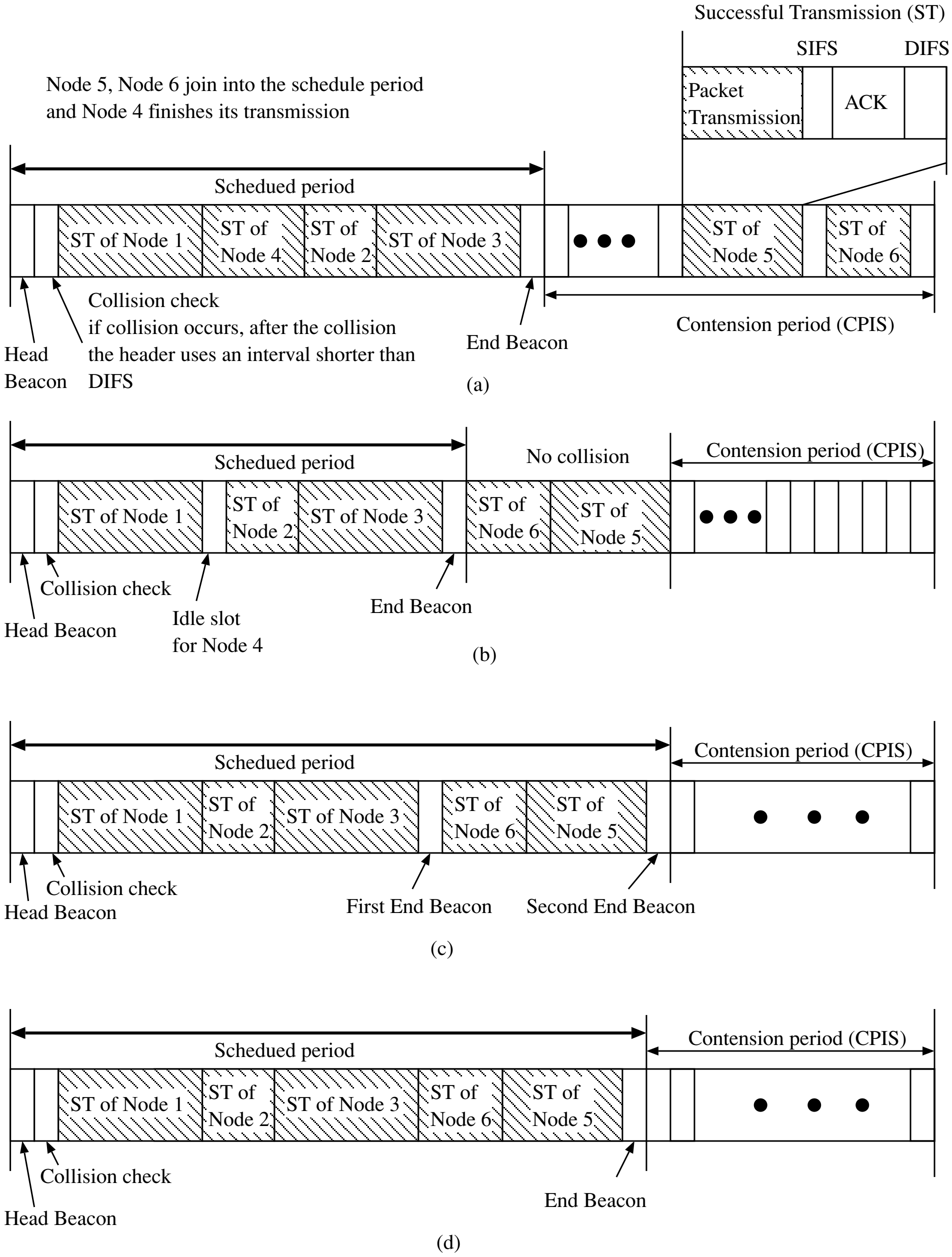

Fig. 1 Procedure of forming a scheduled queue in SRAP

In Figure 1 (a), the node ordered as the first sender in schedule period takes charge as the leader which sends the head beacon at the beginning of superframe. In the meantime, the node ordered as the last sender in schedule period takes charge as the tail which sends the end beacon at the end of superframe. The leader begins to count idle slots after the end beacon. If a certain number called as contention window in term of idle slots (CPIS) has been reached, the leader then sends the head beacon. For an active node, it also counts the idle slots and knows the end of contention period, so collision with the head beacon can be avoided. But for a new comer, it may begin to transmit immediately if the channel is idle. To deal with this case, the leader waits for one more slot after sending a head beacon and it uses SIFS to retry if there is the collision. Meanwhile, the tail sends an end beacon after its transmission. The tail can know if it is a tail, which will be explained below.

A node with a request before confirming the channel situation (schedule or contention period) is called as a new comer and it can contends for the channel just according to DCF mode. A new comer can understand the channel situation by listening to the channel for some events such as continuous transmissions with a short interval, head or end beacons when it is in backoff. In general, a new comer has no chance to find an idle slot in schedule period except that a node with a reservation in schedule period has no frame to transmit and leaves an idle slot after escaping. If unexpected collision in schedule period occurs because of a new comer, the new comer will back off and the node with reservation will retry again with a short SIFS.

Figure 1 shows how nodes (node 5, 6) access the channel, get reservations in schedule period and escape from schedule period (nodes 4). As shown in Fig. 1 (a), there are two nodes, node 5 and 6 succeeding in sending a frame in contention period, which are candidates to have a reservation in schedule period of the next superframe. Since, after successful transmission in contention period, a node can know the following successful transmissions till to the head beacon of the next superframe, in reverse order, nodes transmits in schedule period after the first end beacon of the next superframes as shown in Fig. 1 (b).

If a node has no frame to transmit and escape from schedule period, it need not to do anything and an idle slot appears in this position, or certainly, sends a signal of one slot to keep the reservation if necessary. Counting the idle slot as a frame transmission, the other nodes judge their transmission turns. After the transmission of the last candidate, the tail sends the second end beacon which makes the last candidate to become the tail instead from the next superframe. The useless idle slots distributing in schedule period are compressed in the next superframe as shown in Fig. 1 (c) and (d).

Since the channel is busy in schedule period, a node contending in contention period just needs to set backoff according to the situation of contention period without caring the schedule period. The contention period CPIS in term of time slot is just like an entrance to the schedule period and the longer it is the faster a node can access the channel; however, a long CPIS wastes bandwidth when the network becomes saturated. So CPIS is an important parameter for SRAP.

As for the initialization, we give the procedure as follows. We assume that a node without transmission request is not active and does not listen to the channel, so when a request arrives at a node it begins to contend for the channel with no information related to neighbor nodes and channel situations. The node contends for the channel just as DCF mode. If the node encounters no collision and detects no event related to schedule period, it can continue transmitting. A node in backoff, upon detecting no head beacon after CPIS, knows that the channel is unscheduled. Then the node just needs to send a head beacon and end beacon to announce itself as the leader and tail.

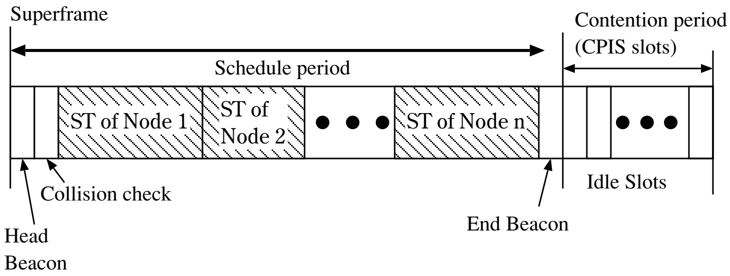

Fig. 2 Channel of SRAP in saturated case

From above, we can see that the number of nodes in schedule period increases as traffic load rises. On the other hand, SRAP behaves like pure DCF when traffic load becomes extremely low.

C. Approximately Analysis and Discussion

In this section, we evaluate the performance of our SRAP approximately through comparing with usual protocols. After showing that SRAP achieves a higher throughput for the saturated traffic load, we discuss the performance besides throughput in the unsaturated case and then we give potential option to support QoS. In fact, we can apply any improved DCF protocols such as [7],[8] in the contention period of SRAP and a higher throughput can be expected. However, for the convenience, we suppose our SRAP use IEEE 802.11 DCF in contention period.

1. Throughput in saturated case.

The saturated traffic load means every node always has a frame to send. In other words, every nodes' queue is never empty. In this case, we can understand the throughput of SRAP reaches the maximum and the wireless channel are utilized effectively as shown in Fig. 2

If we ignore the overhead in schedule period such as head beacon, we can express the throughput as follows:

$$\rho = \left(\Sigma_{i=1}^{n} Ti\right) / \left(\Sigma_{i=1}^{n} Ti + CPIS \cdot T_{slot}\right) \quad (1)$$

where Ti is the transmission time of the frame sent from node i, n is the number of active nodes. As shown above, we can enhance aggregate throughput by decreasing CPIS. And we can understand that SRAP with a small CPIS can achieve a higher throughput than original and improved IEEE 802.11 DCF schemes whose throughput is close to the theoretical upper bound indicated in [7]. For the saturated case, SRAP has a higher throughput close to that achieved by schedule-based scheme and also dynamically adapts to the changes in traffic load and the number of nodes in WLANs.

2. Mean waiting time in unsaturated case.

Like most research on IEEE 802.11 focusing on improving throughput for the saturated case, we showed every node of SRAP transmits frames in a way of reservation with a higher throughput in the saturated case. In the following, we approximately discuss performance related to the average queue length and mean waiting time for unsaturated case.

Generally, any scheme based on DCF can be used in the contention period of SRAP, such as IEEE 802.11+ proposed in [7] that claimed to achieve a throughput close to theoretical upper bound in the saturated case. We assume SRAP uses the same protocol in contention period when compared with a reference DCF protocol.

Obviously, if each node does not enter schedule mode when traffic load is extremely low, SRAP becomes a pure DCF scheme used in contention period and certainly its waiting time and queue length are same as those of the DCF scheme. On the other hand, pure DCF scheme will reach saturation as arrival rate increases, for example at λ th. Assume SRAP with the same number of nodes in network reaches saturation at λ_{ths}, we have $\lambda_{ths} \geq \lambda_{th}$ if we set CPIS small enough. In this case, when the arrival rate is near or greater than λ_{th}, SRAP will have a shorter average waiting time and average queue length than pure DCF scheme. So, at least, we can find a value, $\lambda_0(\leq \lambda_{th})$ from which SRAP behaves with a shorter average waiting time and queue length than pure DCF scheme. To achieve better performances of average waiting time and queue length as well as a higher throughput, we can simply keep nodes not to enter schedule mode until their arrival rates increase beyond the λ_0. Thinking of practical applications, we have a very simple index, queue length, which is suitable for a node to decide whether to enter into schedule mode. When the queue length of a node exceeds a threshold value, it means the traffic load of the node is beyond capability of DCF scheme or many frames are accumulated occasionally, both of which result in a long waiting time. In this case, it is very natural for a node to enter into schedule mode to transmit accumulated frames more quickly. By this way, a node announces if it will not enter to keep a reservation in schedule period after successful transmission in contention period otherwise it enters into schedule period. In fact, according to the simulation without no limitation for a node to enter schedule period, shown in the next section, we find that SRAP has no obvious drop around the point at which the throughput of SRAP exceeds that of IEEE 802.11 DCF.

3. Potential options for supporting QoS

The latest version of wireless protocol, EDCA, is developed to provide QoS in the MAC layer. In EDCA, fixed CWmin[AC] and CWmax[AC] can guarantee the differentiation among different priority classes, but it cannot provide an efficient channel utilization and the throughput degrades when network situation changes in the number of active nodes, traf- fic load and the proportions among traffic of different priorities. In contrast, SRAP has several possible options to support QoS without degradation in throughput when the network situation changes. For example, SRAP can transmit high priority frames in schedule period, which means that a node can enter into schedule period to transmit high priority frames no matter how long its queue length is. In this way, a node of SRAP can realize if the QoS of high priority frame is satisfied through the schedule period interval and if necessary, a node can halt the transmission of low priority frames. Furthermore, if necessary, SRAP can use EDCA in contention period, so a node with a high priority frame can access the channel faster and then send the other high priority frames in schedule period. With this method, SRAP can support QoS and achieve a high throughput no matter how network changes in the total traffic load or the proportion of high and low priority traffic loads.

Ⅲ. SIMULATION

In this section, we focus on evaluating the performance of our SRAP including throughput and delay, through simulations carried out on ns2. For comparison purpose, we also present the simulation results for the IEEE 802.11 DCF. Though some improved protocols [8] of higher throughputs have been proposed, we use IEEE 802.11 DCF as the access protocol in contention period of SRAP and we can understand straightly that the SRAP should have a much higher throughput if using improved IEEE 802.11 from analysis as shown in the above section. Here, we just give the simulation results of IEEE 802.11 which is a well known protocol. In contention period of SRAP, the RTS/CTS mechanism is used, which is not necessary in schedule period. The DCF-related parameters are shown as follows:

MinCW: 31, MaxCW :1023, SIFS: 10 μ sec, DIFS: 50 μ sec ,Slot Length: 20 μ sec, Basic Bit rate: 1 Mbps , Bit rate: 11 Mbps

We carry out simulations with the model shown in Fig. 3. There is a sink node which only acts as a receiver. There are also 8 source nodes and 24 source nodes respectively for the two cases simulated. All source nodes generate Poisson traffic with the same arrival rate, which is a disadvantageous case for SRAP which allows a node with burst traffic to transmit in a reservation mode. Thinking a WLAN used indoors, we set nodes at the intersection points of grid with 5-10m interval.

Figure 4 shows the throughput results of 8 source nodes. The horizontal axis expresses the node traffic which is set as the same value on each node, while the vertical axis expresses obtained total throughput of network whose datarate is 11Mbps. As shown in Fig. 4, the throughputs of SRAP increase with arrival rate (Mbps/per node) till reaching saturation either in the case of packet size 500byte or 1000 byte. Around saturated points of IEEE 802.11, the throughputs of two protocols almost have no difference and when traffic continues increasing, the throughputs of the SRAP increase. On the contrary, the throughputs of IEEE 802.11 get a little down because of increasing collisions. In

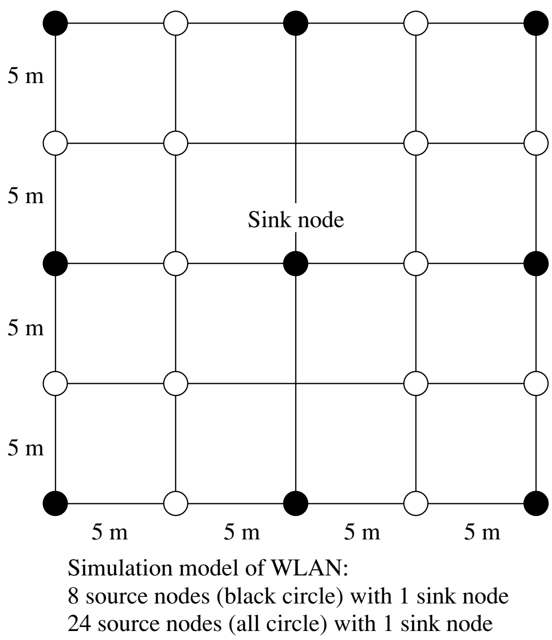

Fig. 3 Simulation models of 8 nodes and 24 nodes

comparison to IEEE 802.11, SRAP gives significantly better performance, the throughputs are improved 57% and %71 respectively for the case of 1000byte and 500byte, which means the SRAP is more effective in avoiding collisions.

Figure 5 shows the throughput results of 24 source nodes. As shown in Fig. 5, we can find the same characters shown in the case of 8 source nodes. The saturated points are not so clear as the case of 8 nodes. Since all source nodes are set with the same Poisson arrival rate under the condition of same data rate 11Mbps, when the total traffic rises close to saturation, the traffic per node is lower than that of 8 source nodes, so the probability that a node sends a packet in reservation mode for SRAP is lower than the case of 8 source nodes. Then, the throughputs of 24 nodes increase for a period before reaching saturation. In practice, many cases are such that some nodes have heavy traffic and the others have comparatively light traffic, in which SRAP is advantageous. From the simulation results, we find the throughput of SRAP could not reach the throughput evaluated in the previous section because of overhead and transmission error.

Figure 6 shows delay results of 24 source nodes. Here, the delay is defined as the average time for a packet from joining into queue to being received. In Fig. 6, the horizontal axis expresses traffic load on each node and the corresponding total traffic load becomes 8 times since there are 8 nodes in network. As well Known, under the condition of a constant data rate, the higher the throughput is, the lower the average delay, which can be found from Fig. 4 and 6. As shown in Fig. 6, when total traffic in network is under 1.6Mbps with constant packet size 500 bytes, the delay of SRAP is lower or almost same as that of IEEE 802.11. When the total traffic exceeds 1.6Mbps, the delay of SRAP becomes obviously lower than that of IEEE 802.11. As increasing of traffic, the delay reaches a constant value since the throughput stop increasing because of packet abandonment. Comparing the case of 500bytes with 1000bytes, we can find that the delay of 1000bytes is lower than 500byte at low traffic either for SRAP

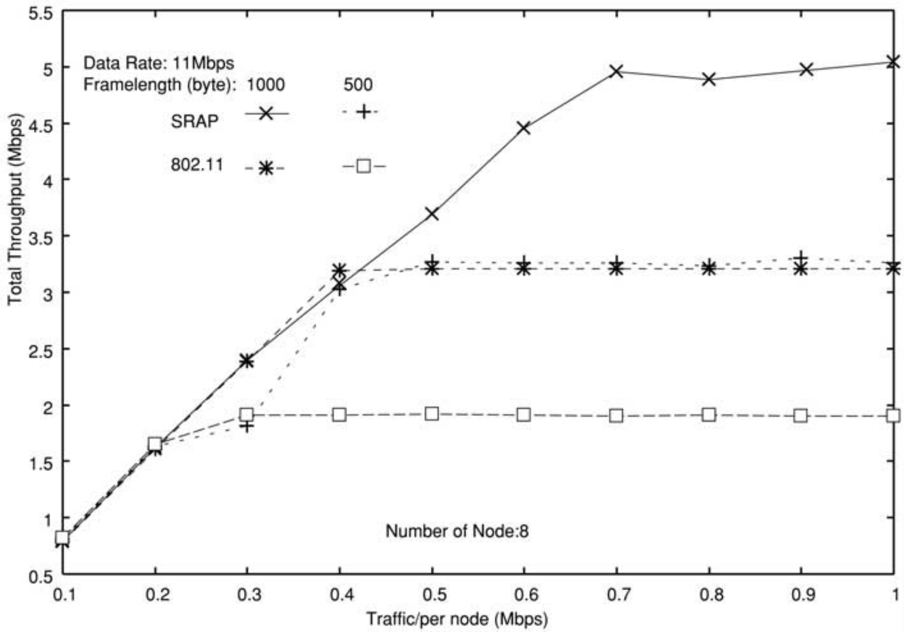

Fig. 4 Throughput of SRAP with 8 nodes

or IEEE 802.11 but becomes higher in the case of saturation because the delay includes the transmission time which of 1000byte is longer than that of 500byte.

In Fig. 7, we can find same characters shown in the case of 8 nodes in Fig. 6. In Figure 7, the delay of packet in SRAP is decreased dramatically and lower than that of IEEE 802.11 when traffic exceeds a certain value and the difference of delay between srap and IEEE 802.11 becomes more bigger because SRAP can avoid collisions which getting worse in the case of more node members.

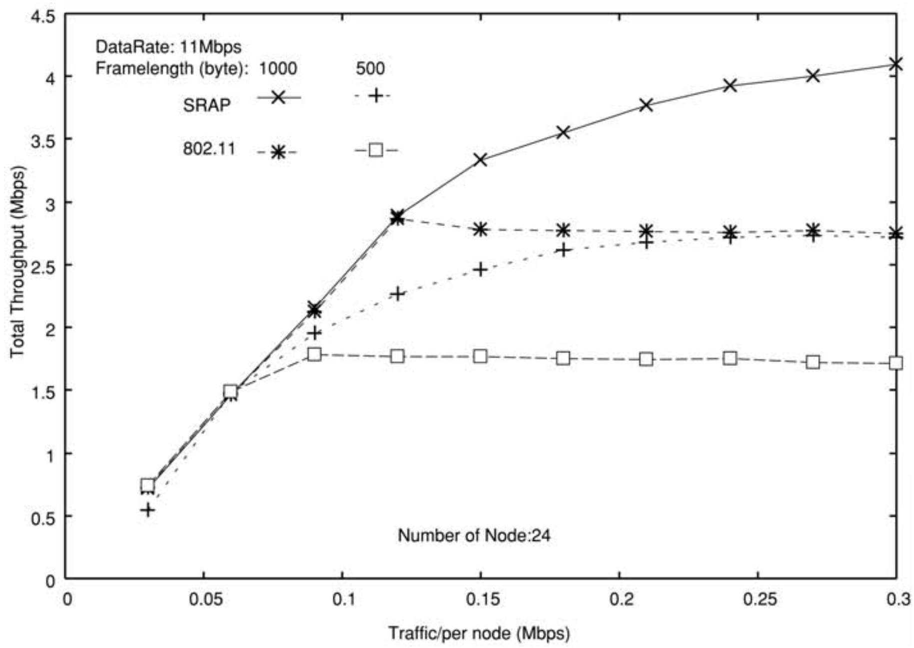

Fig. 5 Throughput of SRAP with 24 nodes

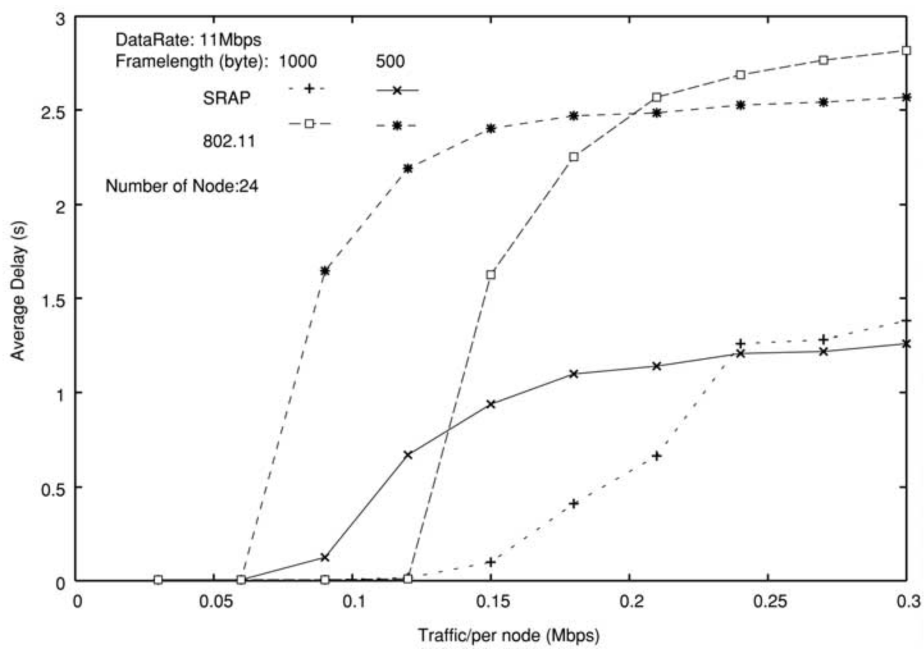

Fig. 6 Delay of SRAP and 802.11 with 9 nodes

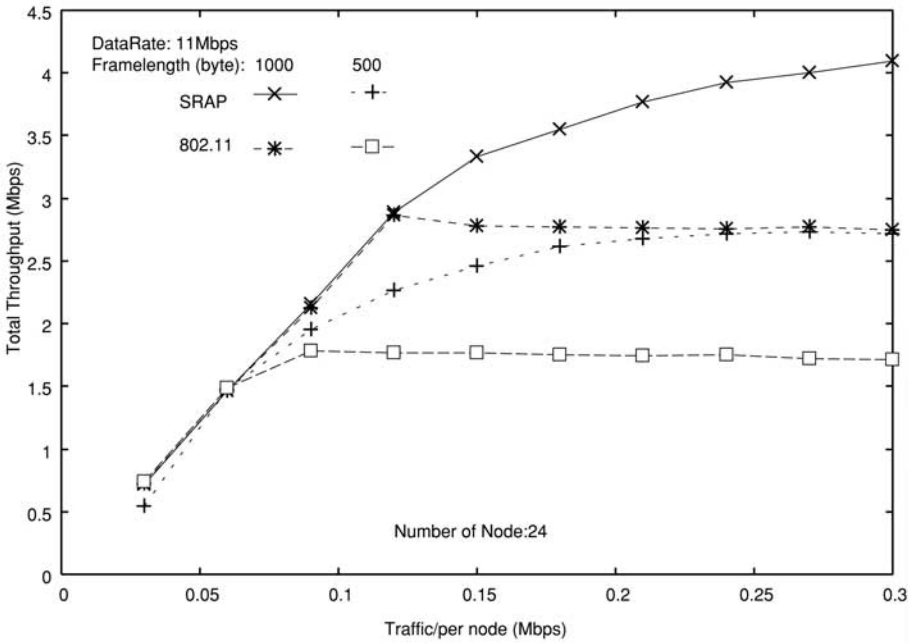

Fig. 7 Delay of SRAP and 802.11 with 24 nodes

Ⅳ. CONCLUSIONS

In this paper, we proposed a novel MAC protocol called SRAP, which achieves high throughput in saturated case without degradation in delay before saturation. SRAP is a distributed protocol whereby a central control node is not necessary. SRAP utilizes schedule period as well as contention period to achieve a throughput higher than the upper bound of pure DCF protocol given in the prior research. Meanwhile, SRAP does not need complicated configuration parameters. A node of SRAP just adjusts itself to enter into schedule period according to its own queue length. Thinking practical applications of nodes in network with unbalanced traffic, it is a good character using index of queue length and waiting time which are easily obtained. Besides high throughput, SRAP can reach a low packet delay shown as simulation results. SRAP also can be expected to achieve a low jitter and need to be evaluated in future works.

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