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A Proposal of Quasi-Distributed WLAN MAC Protocol with High Throughput and Traffic Adaptability

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Abstract: For WLANs, the efficiency of MAC protocol is related to throughput and power saving, which is an important item for wireless communication with limited bandwidth. Much research work has been carried out and some of the proposed schemes are effective. However, most proposals were ether based on contention mode or schedule mode and neither possessed both good characters of two methods. In this paper, we propose a MAC protocol named OSRAP that Scheduled Random access Protocol for one hop WLAN. OSRAP works in two modes, i.e., schedule and contention mode, which is able to dynamically adapt to traffic load and achieves high throughput which is close to transmission capacity in saturated case. Unlike conventional hybrid protocols, every node does not have to intentionally reset any parameter according to the changing traffic load except its queue length. A distinguishing feature of this scheme is the novel way of allowing nodes 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 required in previous schemes. This makes OSRAP simpler and more reliable. Through our analysis results, we show that our scheme can greatly improve the probability of successful transmission which means a high throughput and low delay.

Keywords: WLAN, MAC protocol, CSMA/CA, throughput, delay

1. Introduction

Wireless LANs are gaining increasing popularity in recent years. MAC protocol is a fundamental element that determines the efficiency in sharing the limited communication bandwidth of wireless channels. IEEE 802.11[1], [2], [3] is the most popular MAC protocol used in wireless networks, 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 suffers collisions, which will lower the available bandwidth. In contrast to the DCF, PCF needs a control node to arrange transmissions for plural network nodes, and the polling mechanism causes significant overhead and unnecessary delay for stations under low traffic. Since DCF and PCF have different performance, research on MAC protocols based on the two methods were carried out respectively for the two different situations.

PCF is an optional access method that supports isochronous, contention-free traffic and is built on top of the DCF. PCF is implemented only in infrastructure WLANs. DCF is designed for asynchronous data transmission by using CSMA/CA. Due to inherent simplicity and flexibility, the DCF mode is preferred and is important for distributed systems such as running vehicle systems specially when $n \times n$ communication service is needed [4]. Since ratification of IEEE 802.11, DCF has attracted much research attention [5], [6], [7], [8], [9]. In Ref. [5], IEEE 802.11 MAC protocol is improved for WiFi with long distance communications since the DCF has the characters of simple, low cost and adaptability. As for the capacity of wireless networks, much of the previous works focus in computing theoretical throughput bound [10]. Cali et al. pointed out in Ref. [10] 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 than improved DCF protocol in a usual way. In Ref. [11], the binary-exponential-backoff also used in IEEE 802.15.4 is studied. In the paper, it is indicated that the performance is affected by the number of active nodes which is difficult to be confirmed in time, which becomes a problem for a mobile network systems.

Hybrid Coordination Function (HCF) [12], [13], [14] of IEEE 802.11e 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 because of transmission of coordination messages. A scheduled node may not fully utilize the allocated TXOP (Transmission Opportunity) when there is 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 distribute over the channel space after a certain time period. This becomes an overhead for HCF.

Since we expect to propose a MAC protocol which can be ex-

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panded for ad hoc networks suitable for distributed systems such as running vehicles, in this paper we propose a novel MAC protocol OSRAP (Scheduled Radom Access Protocol for one hop WLAN with high throughput and adaptability), a Quasi-DCF which can be used for distributed systems. Our proposal has a higher throughput close to that of schedule protocol in the case of high traffic, while keeping adaptability to topology change like DCF. Here, though our proposal is for WLANs in one hop area, as the final goal, we can extend it for multi-hop mobile networks by using multi frequency channels, which is left as future works. 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.

2. Scheduled Random Access Protocol for One Hop WLANs

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 OSRAP.

2.1 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). As shown in **Fig. 1**, 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 fail 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 starts the above process again. When the transmission of a packet fails for a maximum number of times, the packet is dropped.

2.2 Related Work

Considerable research efforts have been expended on either theoretical analysis or throughput improvement (Refs. [6], [7], [8], [9], [10], [15], [16], [17], [18], [19]). In Ref. [19], Bianchi used a Markov chain to model the binary exponential backoff procedure. By assuming the collision probability of each node's transmission is constant and independent of the number of retransmission, he derived the saturated throughput for the IEEE 802.11 DCF. In Ref. [15], Bharghvan analyzed and improved the performance of the IEEE 802.11 MAC. Although the contention information appended to the transmitted packets can help in collision resolution, its transmission increases the traffic load and the delay results in insensitivity to the traffic changes. Kim and Hou developed a model-based frame scheduling algorithm to improve the protocol capacity of the 802.11 [18]. In this scheme, each node sets its backoff timer in the same way as in the IEEE 802.11. However, when the backoff timer reaches zero, it waits for an additional amount of time before accessing the medium. Though this scheme improves the efficiency of medium access, the calculation of the additional time is complicated since the number of active nodes must be accurately estimated.

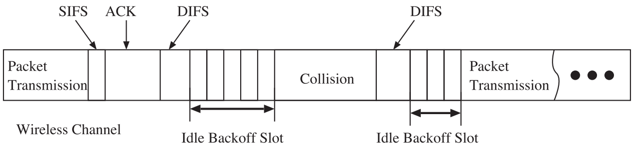


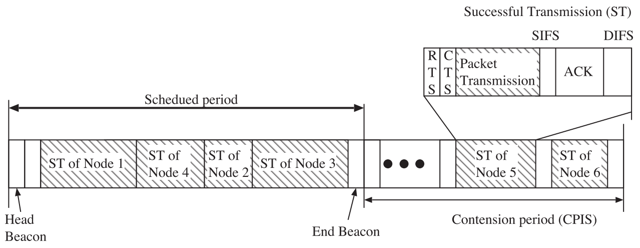
Fig. 1 IEEE 802.11 MAC mechanism.

Cali et al. [10] studied the 802.11 protocol capacity by using a p-persistent backoff strategy to approximate the original backoff in the protocol. In addition, they showed that given a certain number of active nodes and average frame length, there exists an average contention window that maximizes throughput. Based on this analysis, they proposed a dynamic backoff tuning algorithm to approach the maximum throughput. It is important to note that the performance of the tuning algorithm depends largely on the accurate estimation of the number of active nodes. However, in practice, there is no simple and effective run-time estimation algorithm due to the distributed nature of the IEEE 802.11 DCF. And proposed algorithm cannot guarantee that every node has the same CW, which may result in a poor fairness. This is because that there is no control node for DCF, every node tunes its CW according to its own view of network situation, and after some nodes changed their CWs, which leads to changes of network traffic, the other nodes may tune with different values of CW. Meanwhile, a complicated algorithm (Refs. [10], [20]) would impose a significant computation burden on each node and be insensitive to the changes in traffic load.

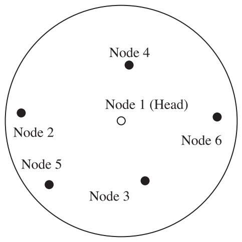
Quite a few proposals for improving MAC protocol are reported such as fast collision resolution (FCR) [6], Dynamically Optimizing the Backoff process (DOB) [21]. Though DOB in Ref. [21] preserves the advantages and overcomes the deficiencies of the work [10] and FCR, it shows the limit of improvement on pure DCF. So, in the following, we give a novel proposal in a way of scheduling random access in WLANs.

2.3 OSRAP

Based on above analysis, we propose a novel MAC protocol named OSRAP (Scheduled Radom Access Protocol for one hop WLANS). The main idea is that allowing WLAN nodes to access media with any contention-based MAC protocol such as CSMA/CA in the case of low traffic load and access media with scheduling method for high traffic load. OSRAP seems like hybrid protocol but essential different. Scheduling in OSRAP is carried out by each node individually rather than a control node. Though a head node is needed to send beacon to construct a superframe, the load added to node is almost same as that of



(a) Composition of superframe



(b) Nodes distributing arround the head in one hop

Fig. 2 Scheduled and contention based transmission in OSRAP.

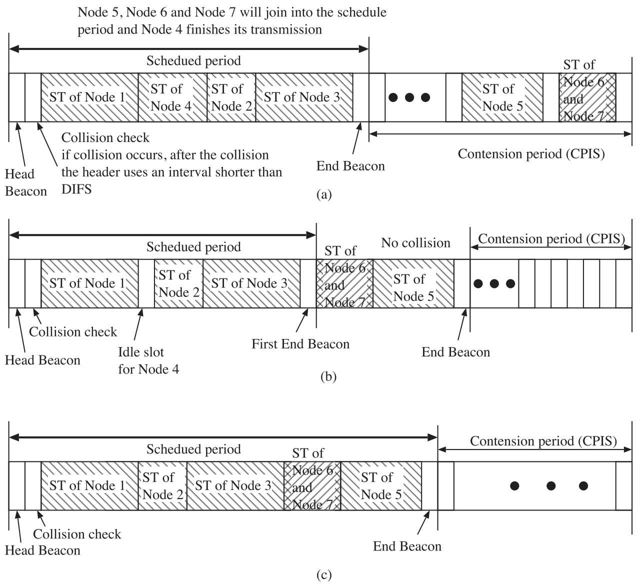


Fig. 3 Procedure of forming a scheduled queue in OSRAP.

usual node, which can be understood in the afterward explanation. Here, we just take OSRAP as a Quasi-Distributed MAC protocol which can be easily extended to be utilized to ad hoc networks.

In the following, we introduce our proposal, OSRAP, in detail. Suppose there are some network nodes in a area. Initially, each node actives according to contention-based protocol, say CSMA/CA, in the case of low traffic load. When a node finds that the traffic load arises over a certain threshold by a local index such as queue length, number of continuous collisions, then it announces to become a head which divides time into superframe by sending beacons, for example node 1 shown in **Fig. 2** (b). After hearing a beacon sent from head, the nodes in one hop area begin to active according to OSRAP.

To solve hidden node problem, 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. Hereafter, RTS/CTS is used in our protocol OSRAP stated afterwards. In the following, we introduce our proposal by three parts, transmission by superframe, initialization of OSRAP mode and how to keep transmission order for each node.

2.3.1 Transmission by Superframe

Not losing generality, we use example to explain OSRAP to make it easy to be understood. As shown in Fig. 2 (a), OSRAP allows channel access in terms of superframes consisting of two parts, schedule period (SP) and contention period (CP). A head, say node 1, takes charge of sending of head beacon (HB) and end beacon (EB). A flag bit is attached to HB and EB so that when a node hears beacon it can distinguish.

As shown in **Fig. 3** (a), nodes either transmit in order in SP or contend for the channel to transmit in CP but are not allowed to transmit in both of two periods in one superframe. At the beginning, a node contends for a channel in CP and after successful transmission, it is allowed to transmit in SP under a certain condition, such as that 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 SP and to escape from SP when the transmission request queue becomes empty. And then we give the procedure of initialization when there is no SP in the next section.

In Fig. 3 (a), the node ordered as the first sender, a head, in SP takes charge as the leader which sends the head beacon at the beginning of superframe and sends the EB at the end of SP period. The head begins to count idle slots after the EB. If a certain number called as contention window in term of idle slots (CPIS) has been reached, the head then sends the HB. Each of an active node also counts the idle slots and knows the end of CP, so that, in general, collision of HBs 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 HB and after waiting for a short time for example SIFS used in IEEE 802.11, it retries if there is a collision. Meanwhile, the head sends an EB after the last transmission.

2.3.2 Initialization of OSRAP

As for the initialization of OSRAP, we give the procedure as follows. 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 using DCF mode. If the node encounters no collision and detects no event related to SP, it can continue transmitting with DCF mode. A node in backoff, upon detecting no head beacon, knows that the channel is unscheduled. Then if a node needs to set up a SP in the cases such as that the number of packets in its queue or the number of collisions it encountered exceeds a threshold, it just needs to send a HB and if succeeded, after sending its packet, it sends EB. At the beginning, the only member in SP is the head itself. The head continues being head and sends in SP until it has no frame to send. When a head withdraws from SP, the next node in SP, entering the SP in a way introduced in the following section, becomes a new head automatically and takes charge of sending beacons. Each node in SP estimates when a head beacon should be sent by courting CPIS. If a node in SP could not hear expected beacon, it will send head beacon instead as new head and resets its counter of sequence in SP. In the meantime, the other nodes in SP also need to reset their counter of sequence upon checking idle slots. Here, there is a problem that the location of new head may not be the center of group. So, some member of SP may be unable to hear from new head and have to withdraw from SP, which will influence the total throughput. As a possible solution, multichannel can be used for the nodes out of the group area to construct new group with a channel different from that of neighbor, which we will discuss for some future occasion.

2.3.3 Confirming and Keeping Transmission Order in SP

OSRAP can be thought as a Quasi-DCF because each node decides its transmission order by itself rather than a central node. In OSRAP, a head and nodes with transmission requests use channel events to understand the situation of channel instead of control data, which leads to decreasing control message interchanges and computation. In the following, we give the definitions of Channel Events which is used for head and nodes to confirm the transmission reservation. One Packet Transmission event (OPT) is defined as: Used for head and nodes to confirm the number of finished packet transmissions. It can be ACK, RTS, CTS, long term transmission or noise which cannot be thought as short control message. Besides, it can be also an idle interval one or more continuous idle slots when a node escapes from SP in the case that its transmission queue becomes empty.

A node with a request before confirming the channel situation (SP or CP) is called as a New Comer and it can contend for the channel just according to DCF mode. The New Comer can understand the channel situation when hearing some events such as continuous transmissions with a short interval, head or EBs when it is in backoff. What need to do for a New Comer is that stopping backoff timer after receiving HB and resuming again after detecting an EB. In general, a New Comer has no chance to find an idle slot in SP except that a node escapes from SP and leaves an idle slot.

Figure 3 shows how nodes (Node 5, 6, 7) access the channel, get reservations in SP and escape from SP (Nodes 4). As an example, Fig. 3 expresses the channel situation that the head heard. In Fig. 3 (a), there are three nodes, Node 5, 6 and 7 succeeding in sending a frame in CP, which are candidates to have a reservation in SP of the next superframe. Node 6 and 7 send in the same time without interfering each other while the head cannot discriminate but confirm it as successful transmissions by the transmission interval longer than RTS or CTS. Since, after successful transmission in CP, a node can know the following successful transmissions till to the HB of the next superframe. In reverse order, nodes transmits in SP following the first EB of the next superframes as shown in Fig. 3 (b). If a node has no frame to transmit and escapes from SP, it need not to do anything and an idle slot appears in this position. Counting the idle slot as a frame transmission, the other nodes judge their transmission turns by the number of transmissions in SP. Suppose the sequence number of node withdrawing from SP is n, the following sequence numbers are n+1. When the node with sequence number n withdraws from SP, the next node with sequence number n+1 will not hear expected transmission and it will wait for an interval of one slot. The receiver does not need to do anything for sending order change but listens to the channel. The other nodes following the withdrawing node can also hear the idle slot and take it as a withdrawing event then adjust their sequence counter. After the transmission of the last candidate, the head sends the (Second) EB which means the beginning of CP. The useless idle slots distributing in SP are compressed in the next superframe as shown in Fig. 3 (c).

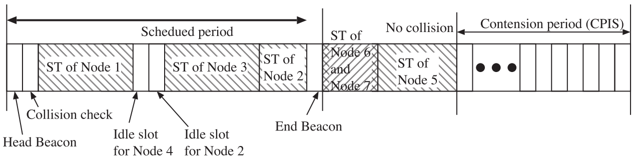


Fig. 4 Procedure of moving up in SP.

As shown in **Fig. 4**, the following nodes may use the vacant time interval which the escaped node used. Here, we need to pay attention that when an idle slot occurs in SP because of the node escaped from it, it is not always possible for the just behind node to move up. In SP, each node counts the number of OPTs till to its own turn and then begins transmission. If a node finds an idle slot in SP before its turn, it thinks there is a node escaped from SP and if it confirms the vacant time interval can be used, it will count idle slots till to detecting signal from other node or reach its turn. In the former case, the node counts the OPT as two. In the latter case, the node begins to transmit and remember the new order for the transmission in the next superframe.

A head needs to count OPTs to calculate the number of members in SP so that can send EB in right time. As for the HB, head just needs to count the number of idle slot times to CPIS after sending EB to determine when to send HB.

Since the channel is busy in SP, a node contending in CP does not need to care it. The CPIS in term of idle slot is just like an entrance to SP and the longer it is the faster a node can join to the SP; however, a long CPIS wastes bandwidth when the network becomes saturated, which will be shown in the next subsection. So CPIS is an important parameter for OSRAP. The probability of collision in SP should be very low. If unexpected collision in SP occurs because of a New Comer, the node in SP just needs to abandon the reservation and try to access from CP by IEEE 802.11 DCF.

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

2.4 Inconsistent Channel Views between Nodes in SP

In general, nodes in SP can transmit in order without collision except for special cases because of inconsistent views of transmissions in SP. In the following, we use an example to show this case. In **Fig. 5** (a), Node 2 thinks its transmission turn as second and begins transmission after Node 1. As shown in Fig. 5 (b), Node 4 thinks its transmission turn as third and begins transmission after Node 2. In the meantime, as shown in Fig. 5 (c), Node 3 decided its turn as the second in the preceding superframe provided it cannot detect signals from Node 2 and Node 4 and their receivers. In this case, Node 3 begins its transmission

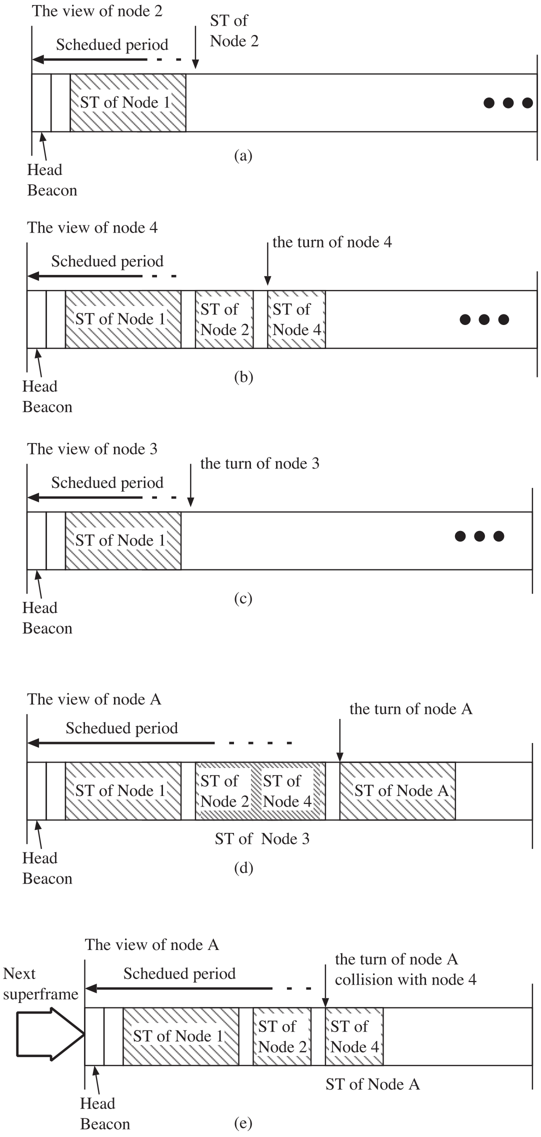


Fig. 5 Collision in SP caused by inconsistent views of channel.

after Node 1 while Node 2 and Node 4 transmit in parallel, which is not collision since Node 3 and its receiver, Node 2, Node 4 and their receivers do not hear eachother. The following transmitter is Node A which thinks its turn as third and cannot distinguish transmissions from those of Node 3, 2, 4 and takes this interval as one OPT as shown in Fig. 5 (d). The problem is that when Node 3 finished its transmission and withdraws from SP in the next superframe, Node A will detect the end of transmission from Node 2 and begin its transmission at the same time as Node 4, which results in a collision in SP as shown in Fig. 5 (e). Fortunately, the probability of this case is very low, which can be found by the simulation results which will be given afterward. To solve this problem, we use a simple method that all nodes which encountered collsions just withdraw from SP and continue to transmit in CP. This method may result in a slight reduction in throughput. The same thing also occurs when head sends end beacon in the case of time lag.

In SP, sender of communication pair need to know the situation of preceding transmissions listening RTSs, CTSs. However, there is a possibility that only the receiver of a communicaiton pair can hear RTS or CTS from another communication pair. The possible scenario is that the receiver knows when corespondent sender should begin transmission when its turn comes but the sender does not. To solve this problem, we use a control packet named as RRTS which allows a receiver to inform the sender to begin transmission if scheduled transmission did not begin when transmission turn comes. Certainly, if both of sender and receiver cannot detect RTS and CTS sent from other transmission, they need do nothing and can carry out their transmission in parallel with other transmission. In fact, from simulation results shown afterward, obvious difference between using RRTS or not is not found, which means the probability of using RRTS is not so high under general circumstances.

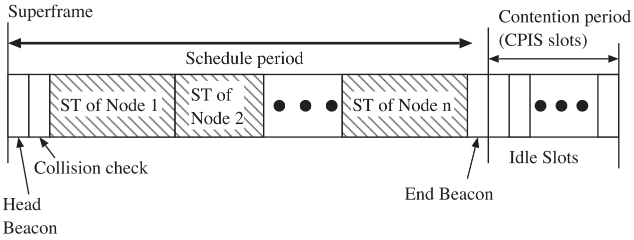


Fig. 6 Channel of OSRAP in saturated case.

2.5 Approximately Analysis and Discussion

In this section, we evaluate the performance of our OSRAP approximately through comparing with usual protocols. Here we show that OSRAP achieves a higher throughput for the saturated traffic load and then in the next section, we discuss the performance including the unsaturated case by simulation. In fact, we can apply any improved DCF protocols such as Refs. [10], [21] in the CP and a higher throughput can be expected. However, for the convenience, we suppose OSRAP use IEEE 802.11 DCF in CP.

The saturated traffic load means every node always has a frame to send. In other words, every node's queue is never empty.

If ignoring low probability events such as parallel transmissions and order mistakes, we can understand the throughput of OSRAP reaches the maximum and the wireless channel are utilized effectively as shown in **Fig. 6**.

In this case, we can express the throughput as follows:

$$\rho = \frac{\sum_{i=1}^{n} T_i}{\sum_{i=1}^{n} T_i + CPIS \cdot T_{slot}} \qquad (1)$$

where T_i is the transmission time of the frame sent from node i and n is the number of active nodes. As shown above, we can enhance aggregate throughput by decreasing CPIS. We can understand that OSRAP 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 Ref. [10]. For the saturated case, OSRAP 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.

2.6 Effects of different contention-based MAC protocols used in CP

OSRAP defines how to change access method between contention-based and schedule methods. Generally, any contention-based MAC (media access control) protocol can be used as a part of our proposal. Different contention-based protocol used in CP will result in different throughputs. The throughput of OSRAP is completely decided by the throughput of contention-based protocol used in CP, in the case of low traffic. When the traffic increases, OSRAP will change to schedule mode finally and the throughput is decided by Eq. (1), which is superior to that of any contention-based protocol. For example, if IEEE 802.11e is adopted as the protocol in CP, OSRAP will act just like IEEE 802.11e in the case of low traffic, so will its throughput. When the traffic increases, OSRAP will change to schedule mode. We can compare the throughput of OSRAP with that of pure IEEE 802.11e approximately. In Ref. [22], performance of IEEE802.11e is analyzed in detail. According to this paper, the maximum total throughput (including two ACs) reaches 67% with the condition that, number of nodes: 15, frame-length: 1,000 byte, Data Rate: 11 Mbps, Time Slot: 20 us, Two ACs: AC1 and AC3. Under the same condition, setting CPIS as 15, we can obtain the throughput up to 89% by Eq. (1). As for the change threshold, though it depends on different policy of QoS, the length of sending queue is suitable and effect because queue length exceeding a certain value means contention-based protocol could not deal with the current traffic and OSRAP needs to change to schedule mode.

3. Simulation

In this section, we focus on evaluating the performance of the OSRAP including throughput, delay, retransmission rate related to power saving and instantaneous throughput related to adaptability to traffic changes through simulations carried out on OPNET. For comparison purpose, we also present the simulation results for the IEEE 802.11 DCF with RTS/CTS option. Though some improved protocols [21] of higher throughputs have been proposed, we use IEEE 802.11 DCF as the access protocol in CP of OSRAP and we can understand straightly that the OSRAP 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, CSMA/CA. The DCF-related parameters are shown in **Table 1** and are also used in OSRAP when it behaves in the mode of CSMA/CA.

Network nodes in simulation are set as **Fig. 7**. Though single data channel is assumed, since, as future work, we expect to extend OSRAP for multi-hop wireless networks with multi-channels, 13 nodes 1 hop away from the head are set as source nodes which can be senders and receivers, and the other 12 nodes expressed as black circles just act as receivers which can be thought as using other channels in the case of multi-hop networks. The source nodes generate Poisson traffic and each node has a random variable to generate sending request with the same arrival rate then traffic from each node will be the same. This case is disadvantageous for OSRAP which allows a node with bursty traffic to transmit in a reservation mode. Thinking WLAN used in a usual way, we set nodes at the intersection points of grid with 150 m interval and assume transmission distance as 330 m. Each

Table 1 Simulation parameters.

Parameter	Value
$MinCW$	31
$MaxCW$	1,023
SIFS	10 μsec
DIFS	50 μsec
Slot Length	20 μsec
Basic Bit rate	1 Mbps
Bit rate	11 Mbps

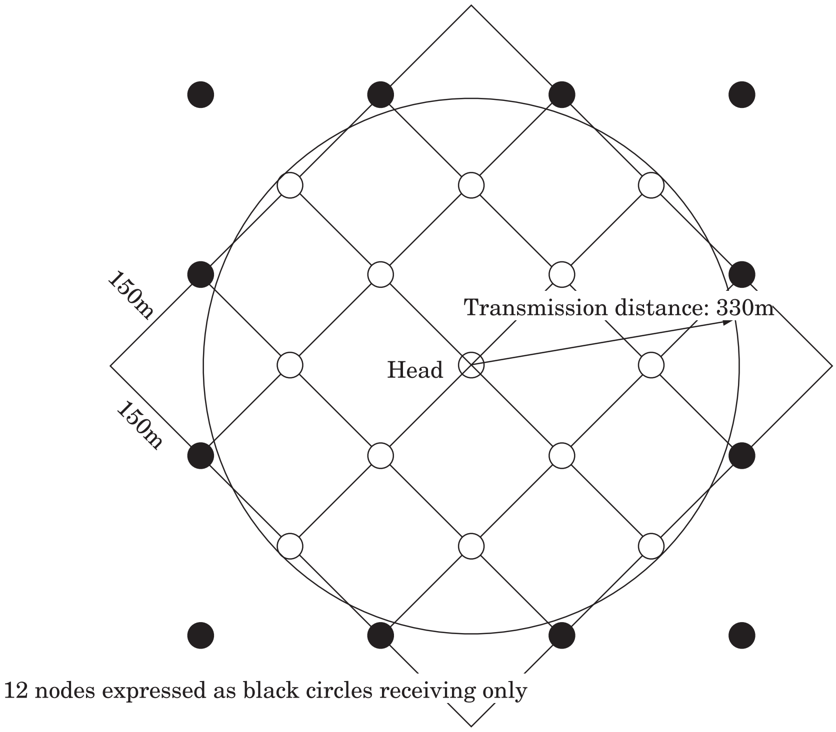


Fig. 7 Topology of Simulation models with 25 nodes.

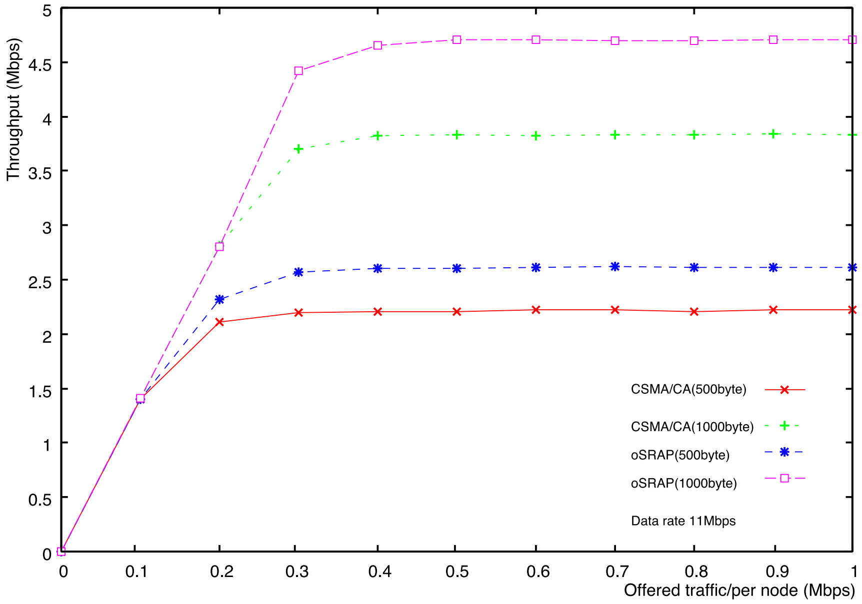


Fig. 8 Throughput of OSRAP with 25 nodes.

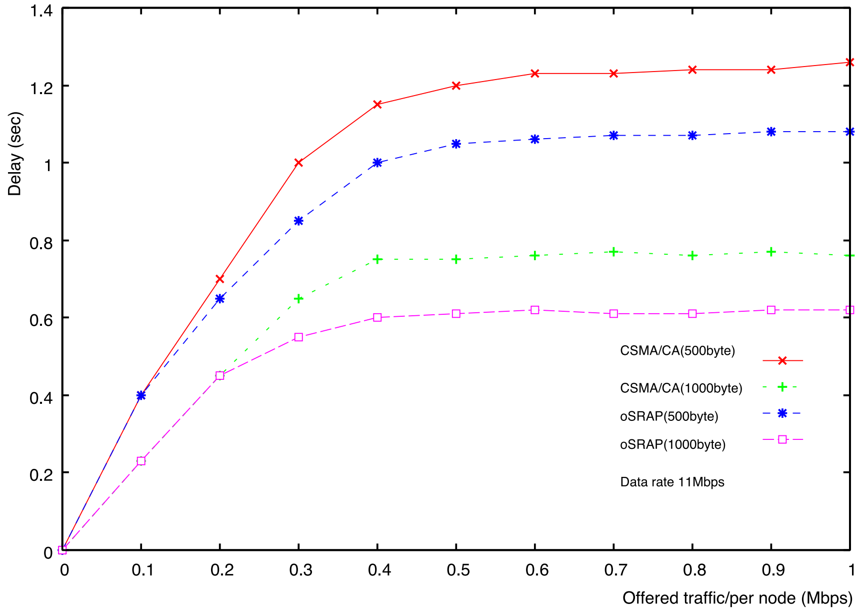


Fig. 9 Average delay.

node selects a receiver randomly from 1 hop neighbors.

Figure 8 shows the throughput results. 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 11 Mbps. As shown in Fig. 8, the throughputs of OSRAP increase with arrival rate (Mbps/per node) till reaching saturation either in the case of packet size 500 byte or 1,000 byte. Around saturated points of IEEE 802.11, the throughputs of the two protocols almost have no difference and when traffic continues increasing, the throughputs of the OSRAP becomes higher. In comparison to IEEE 802.11, OSRAP gives significantly better performance. The throughputs are improved 23% and 18% respectively for the case of 1,000 byte and 500 byte, which means transmissions in SP of OSRAP is more effective. For CSMA/CA, the throughputs do not fall down like CSMA/CD in Ethernet, which means the threshold of CW (1023) is big enough for 25 nodes.

Figure 9 shows the results of the delay. Since delay is related to throughput, we can find OSRAP has lower delays in all cases, which is consistent with the results of throughput shown in Fig. 8. As shown in Fig. 9, delays arise with traffic load and finally reaches a constant value respectively, which means network traffic gets saturated.

Figure 10 shows the results of retransmission times per packet, which is a meaningful index for wireless communication. The lower it is, the lower the energy consumption is. In Fig. 10, the horizontal axis expresses traffic and the vertical axis expresses average transmission times for one frame transmission. As shown in Fig. 10, in the case of OSRAP, in range of low traffic, there are not obvious difference between OSRAP and IEEE 802.11. With arising of traffic, after a peak, average transmission times of OSRAP begin to lower. This is because OSRAP begin transmitting

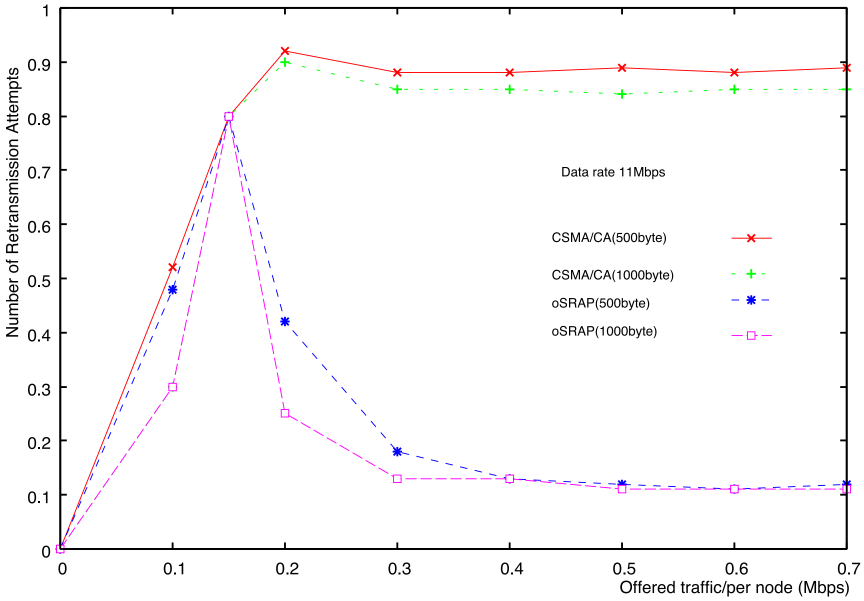


Fig. 10 Number of retransmission attempts.

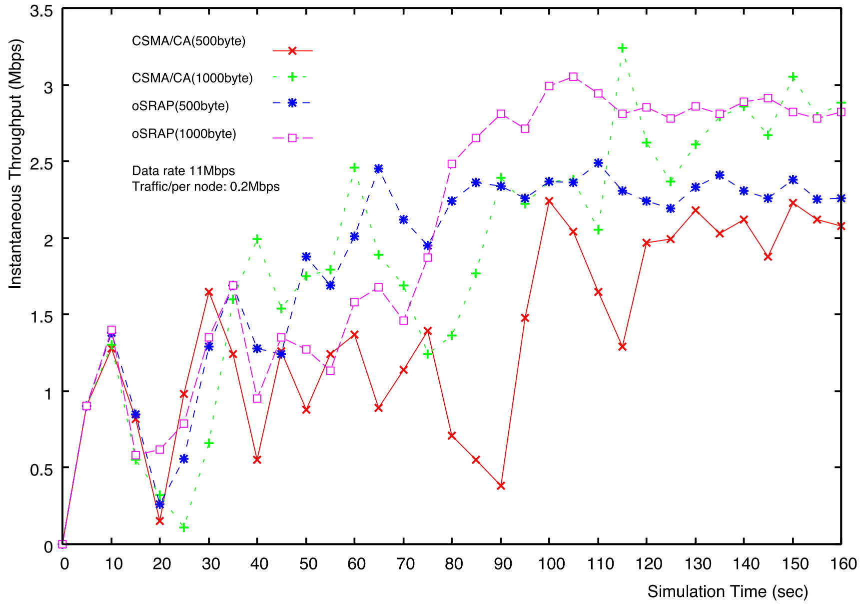


Fig. 11 Instantaneous throughput of OSRAP with traffic load 0.2 Mbps.

in scheduling mode. We see the results are quite different from IEEE 802.11. Low average transmission times can result in saving battery of wireless nodes.

Figure 11 shows how instantaneous throughput changes after a traffic load is imposed to network nodes. The horizontal axis expresses time-lapse and the vertical axis expresses instantaneous throughput obtained by average throughput in 5 s interval with the traffic load set as 0.2 Mbps per node. In our simulation, equal traffic load is set for each node at the same time. In practice, many cases are such that some nodes have heavy traffic (bursty traffic) and the others have comparatively light traffic, in which OSRAP is advantageous. From Fig. 11, we can find that, from beginning of simulation when traffic load is attached to each node, throughputs of OSRAP arise and reach a comparatively stable state from time 80 s, which is faster than that of IEEE 802.11. IEEE 802.11 will suffer a longer process of collision for nodes to distribute transmitting timings by setting different CWs and even after enough time, finally it cannot reach a stable state like OSRAP. This result expresses that OSRAP has better adaptability to bursty traffic and lower jitter.

4. Conclusions

In this paper, we proposed a novel MAC protocol called OSRAP, which achieves high throughput with lower delay. OSRAP is a Quasi-Distributed protocol whereby a central control node is not necessary, which can be applied on distributed system. OSRAP utilizes SP as well as CP to achieve a throughput higher than the upper bound of pure DCF protocol given in the prior research. Meanwhile, OSRAP does not need complicated configuration parameters. A node of OSRAP just adjusts itself to enter into SP according to its own queue length, which is a simple and directly obtained index. This character is meaningful for

OSRAP applications in network of nodes with unbalanced traffic. Besides high throughput, OSRAP can achieve a low packet delay shown as simulation results by scheduling transmissions and has potential options for supporting QoS such as low delay, low jitter. While saving battery of wireless nodes by low retransmission times, OSRAP has a better adaptability to traffic changes.

In this paper, we proposed a MAC protocol for one hop WLAN. It is possible to further extend to multihop ad hoc networks by using multi-channels. Consequently, we need to solve the problems such as channel selection, SP member changes. Those are left as future works.

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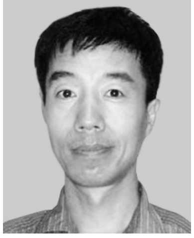

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