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A Novel Multiple Access Protocol for Multihop Mobile Ad Hoc Networks

Kai Liu, Lianzhen Cheng and Hantao Li
School of Electronics and Information Engineering
Beijing University of Aeronautics and Astronautics
Beijing 100191 China

Abstract- **Based on the concept of contention reservation for polling transmission and collision prevention strategy for collision resolution, a fair on-demand access (FODA) protocol for supporting node mobility and multihop architecture in mobile ad hoc networks is proposed. In the protocol, a distributed clustering architecture and an idea of reserving channel resources to get polling service are adopted, so that the hidden terminal (HT) and exposed terminal (ET) problems existed in traffic transmission due to multihop architecture and wireless transmission can be eliminated effectively. In addition, a fair collision prevention (FCP) algorithm is proposed to greatly eliminate unfair phenomena existed in contention access of newly active nodes and completely resolve access collisions. Finally, the performance comparison of the FODA protocol with CSMA/CA in IEEE 802.11 and polling protocols by OPNET simulation are presented. Simulation results show that the proposed protocol has better multiple access performance than CSMA/CA and polling protocols.**

Keywords: mobile ad hoc network, multiple access, on-demand, polling, fair access, collision prevention

I. INTRODUCTION

A mobile ad hoc network (MANET) is a self-organizing multi-hop mobile wireless network with no predefined infrastructure. The self-organizing features of rapid deployment and stable maintenance make MANET very attractive in military and civil applications where fixed infrastructures are not available. Such applications include fleets on oceans, armies in battlefields, disaster rescue after an earthquake and collaborative computing with laptops in a classroom. To achieve the practical benefits of MANET, one of important issues to be solved is medium access control (MAC), which ensures efficient and fair sharing of scarce wireless bandwidth. Due to multihop sharing of common channel, there are some well-known problems in the design of MAC protocol in MANET, i.e. hidden terminals (HT) and exposed terminals (ET) problems [1], which greatly lower throughput and increase delay. Currently, many proposed MAC protocols for MANET can be categorized as contention-based manner and conflict-free manner. The contention-based protocols for MANET use a variant of require-to-send/clear-to-send (RTS/CTS) handshake, carrier sensing, periodic exchanges of information among nodes, or reservations as access mechanism. Typical protocols are IEEE 802.11 distributed coordination function (DCF) [2], multiple access collision avoidance (MACA) [3], and distributed packet reservation multiple access (D-PRMA) [4] protocol, which are mostly based on random multiple access techniques. The conflict-free protocols for MANET mostly use a central control point to flexibly assign channel resources for its neighbor nodes, such as 802.11 point coordination function (PCF) [2], virtual base station (VBS) [5], and Bluetooth [6]. Random multiple access protocol can overcome the resource wastage problem existing in fixed assignment multiple access protocol. However, the probability of packet collisions increases with the increase of the number of active nodes or total offered load. These packet collisions can be avoided by adopting polling mechanism. However, polling overhead and related message delay will increase drastically when a large number of nodes have no packets to transmit. By integrating the advantages of these two methods and combining collision prevention mechanism, a novel efficient multiple access protocol based on clustering architecture is proposed, i.e. fair on-demand access (FODA) protocol, which employs the idea of reservation with random contention and perfect scheduling transmission with polling.

The rest of the paper is organized as follows. Node model and clustering architecture are presented in Section II. Section III describes the FODA protocol. In Section IV, performance evaluation is provided. Finally, some useful conclusions are given in Section V.

II. NETWORK MODEL

In MANET, each node usually has only one set of transceiver operating in half-duplex mode and a different identifier (ID). Assume that the carrier sensing range of a transceiver is adjusted to be at least twice the transmission range of data packets. In the FODA protocol, a local central access point or cluster-head (CH) is needed to be responsible for scheduling packet transmissions of its neighbor nodes, which can be achieved according to a clustering algorithm (say the clustering algorithm in [7]). By this, it can be extended to multihop networks. The distance of any two nodes in this kind of cluster is at most two hops, and all the packets, whose source and destination are not in communication range, must be relayed by CH or gateway. One or multiple gateways are selected by CH to relay intercluster traffic. Different clusters use different channels. Fig. 1 shows clustering architecture of a network topology. In the figure, node a, h and k are CHs in their own clusters, node c and f are gateways connecting two clusters, and the others are

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ordinary nodes. Communication between different nodes can be accomplished independently based on traffic relaying through multiple clusters.

III. FODA PROTOCOL

The transmission process of the FODA protocol can be divided into two phases in channel, i.e., reservation access phase and polling phase without collisions. The node with packets to send makes reservation in random contention (RC) slot during reservation access phase. If it accesses channel successfully, its CH will poll it during the polling phase. Otherwise, the node will make collision-free reservation with fair collision prevention (FCP) algorithm in the conflict-free (CF) slot started immediately.

A. Polling Transmission Scheme

In the case of clustering architecture shown in Fig. 1, the principle of the FODA protocol is shown in Fig. 2. Each cluster operates in its own local transmission frame and can work in an asynchronous fashion. After each beacon (B) packet sent by CH, there is a slot for an accepted active node to send data packet. After the node finishes its transmission, CH will send its B packet again, which poll another accepted node to send data packet.

The transmission frame begins with the start packet (ST) sent by CH. The CH in each cluster polls gateways in its cluster after ST (ST can be used to poll a gateway) in a fixed order and polls accepted ordinary nodes by round-robin rule. A gateway will send transmission insertion (TI) mini-packet in the basic slot that is reserved for it by the CH when it has just switched to this cluster from another cluster and has no packet to send. If the gateway has packets to send just at the moment, it can send data packet with TI flag in the packet slot, which can also announce its switching to this cluster. After its announcement, other nodes in this cluster can send packets to this gateway. A gateway can send a packet at the beginning of the basic slot reserved for it or just leave the basic slot idle according to whether it has data packets to send at that moment. In order to guarantee more transmission chances for gateways, a CH polls gateways again after it has polled several (say M) ordinary nodes, which is very important to the cluster with a large number of active nodes. A gateway sends transmission termination (TT) mini-packet or data packet with TT flag when it wants to leave current channel. For example, gateway f in Fig. 1 switches between cluster a and h as shown in Fig. 2. A gateway or an active node accepted by CH attaches a continuous transmission indicator (CTI) to its data packet to indicate its intention of continuous transmission for more than one packet in a frame. If the CH permits this, it will send continue transmit (CT) packet in succeeding slot, e.g. node j sends a data packet with CTI in cluster h shown in Fig. 2. When the maximum number of data packets allowed in a frame is achieved, the CH sends a reservation access (RA) mini-packet to indicate the start of RC slot for contention access of new active nodes.

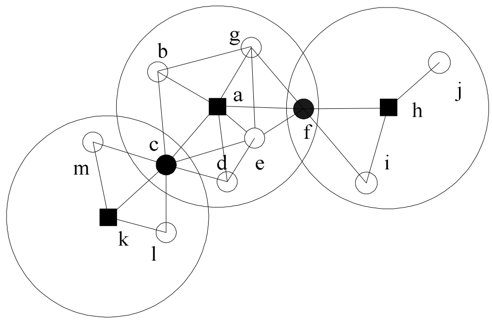

Figure 1. Clustering architecture.

When CH sends control packet, such as ST, B, CT, RA and collision prevention beacon (CPB) mentioned in the following, it can piggyback data packet with related control information if its packet queue is not empty. If an active node accepted by CH ends its packet transmission session, it will piggyback its last data packet with TT flag. Then CH does not poll this node since next frame.

If the polling queue of a CH is full, it will cancel reservation access phase as shown in Fig. 2. Considering the fairness problem of nodes in channel usage, if the polling queue of CH is full, all the successfully accessed nodes must exit the polling queue after they end the transmission of current session, and need to make

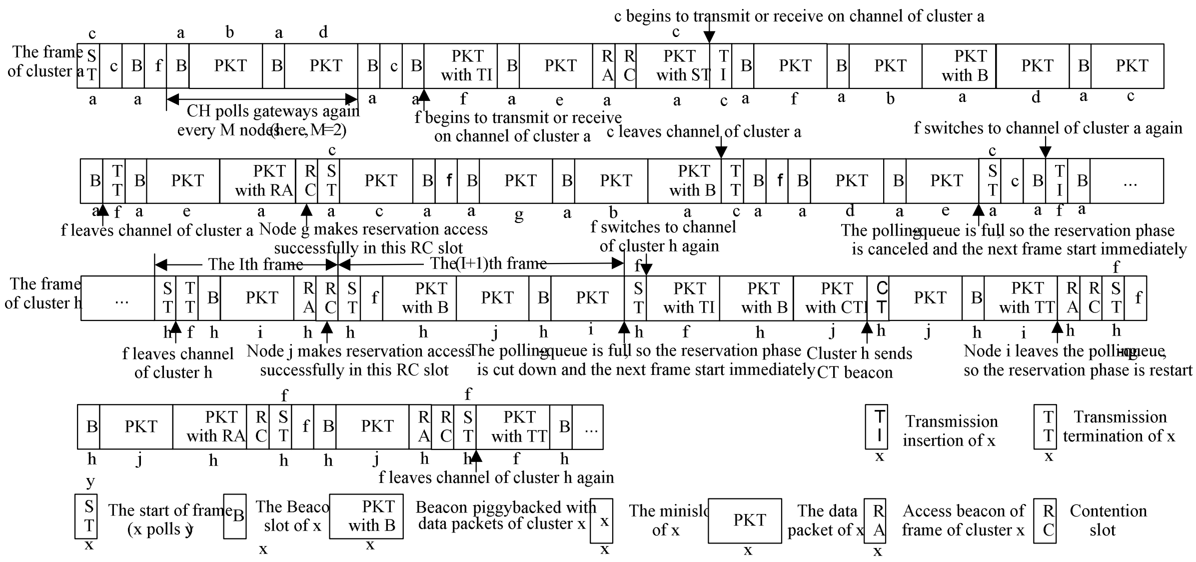

Figure 2. Principle of FODA protocol.

reservation again for their new session.

B. *Reservation Access Scheme*

An ordinary node will send a transmission access (TA) mini-packet in the RC slot to access the channel if it has packets to send. If its TA transmission is successful, the CH will take it as the first node to be polled in the next frame. If not, it will use FCP algorithm to contend for access in the CF slots started in current frame. The process of reservation access scheme is shown in Fig. 3.

(1) General Reservation Access Scheme

Usually, there is only one RC slot in a frame. If the collisions occur in the RC slot, the CH will send CPB to announce the beginning of collision-free reservation access phase (i.e. the start of the CF slot) in current frame immediately. In the following frames, the CH continue to send CPB instead of RA until it knows that collisions are completely eliminated when it finds that there is no TA mini-packet to be sent in some CF slot as shown in Fig. 3. All the nodes that failed to access use FCP algorithm to make collision-free reservation in the CF slots started in current frame and those of the following frames. In order to guarantee the larger probability of successful access, a CH initializes the number of CF slots to N_{CF} when collisions occur for the first time. N_{CF} is announced in CPB packet by CH and kept the same in subsequent frame or increased in subsequent frame if all the collisions are not eliminated after several continuous frames. Once there is no new node access in CF slot, the CH will cancel the following CF slots at once and send ST packet to enter next frame, in which it restarts to send RA mini-packet.

(2) Fair Collision Prevention Algorithm

Based on binary countdown algorithm [8] and the concept of collision prevention [9], an FCP algorithm is proposed, which can achieve conflict-free access and resolve the unfairness problem existed in contention access of newly active ordinary nodes completely.

As shown in Fig. 4(a), each CF slot is partitioned into a series of equal length mini-slots for binary countdown and a longer slot for the winner of binary countdown to send TA mini-packet. Every ordinary node has a unique binary code with equal length for collision-free reservation access, which consists of a priority value and its virtual ID. When an active ordinary node tries to access for the first time for a new session, the value of priority is minimal (say 00). Then it increases the value by one as it fails to access each time. When the priority value reaches the maximum, the node will keep it until its successful access. A CH assigns each node in its cluster a unique virtual ID. The bit number of virtual ID is determined by the number of nodes in the cluster. For example, the bit number of virtual ID is n if the number of nodes in cluster ranges between $2^{n-1}+1$ and 2^n. Considering fairness problem, a CH piggybacks CPB with virtual IDs that are reassigned for all the nodes in its cluster every several frames. The less chances a node has to send packets, the bigger virtual ID is assigned for it by its CH. The quality of service (QoS) of different services can be supported by integrate QoS priority into current unique binary code.

When the CH sends CPB to announce the start of CF slots, every active node will send its ORDER reservation signal or senses the channel according to its binary code, where it sends ORDER reservation signal in i-th mini-slot if its i-th bit is 1, otherwise it senses the channel. If a newly active ordinary node senses the channel busy, it stops competing. If a newly active ordinary node completes entire competition, it becomes the only winner within its sensing range because of unique binary code. Then it can send its TA mini-packet without collisions.

Fig. 4(b) shows an example for fair collision prevention algorithm. The part 1, 2, 3 and 4 in Fig. 4(b) reflect the continuous CF slots in Fig. 3. Each node has a unique binary code as shown in Fig. 4(b). The binary codes in parenthesis represent the priority of newly active ordinary nodes. In the first CF slot, nodes a, b and c are competing for channel access. All the nodes failed to access at first time, so their priority values become 01. Therefore, all the nodes sense channel in slot 1 and send ORDER reservation signal in slot 2. During slot 3, node a and b send ORDER reservation signal, while nodes c senses channel and decide to quit. Nodes a and b continue to compete, and both of them send ORDER reservation signal during slot 4. During slot 5, node b sends ORDER reservation signal, while node a senses channel and quits. At last, only node b continues and finishes whole competition period. Thus it gets the right to sends its TA mini-packet during slot 8 and successfully access channel. In the second CF slot, nodes a and c are competing for channel access, and their priority value is 10 because they failed to access twice. In the third CF slot, the priority value of node c increase to 11, and the priority value of node d is 00 because it tries to access channel for the first

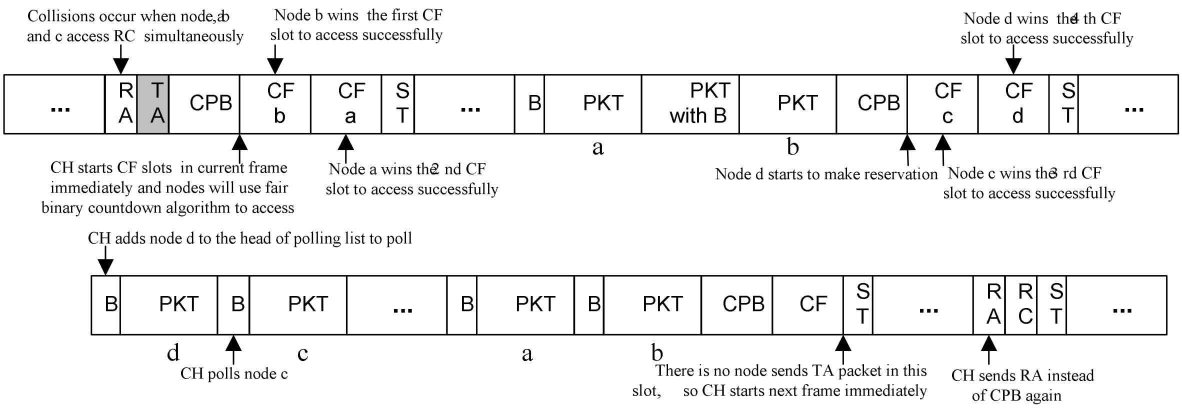

Figure 3. Reservation access scheme.

time. In Fig. 4(b), the virtual IDs of node c and d are randomly reassigned in CPB packet, and CH assigns a bigger virtual ID for node d because it has fewer chances to send packets.

Two mechanisms are proposed to improve the fairness existed in contention access of newly active ordinary nodes. First, priority value increases the priority of the nodes with more failure accesses. Second, the virtual IDs of newly active nodes are reassigned according to the transmission condition of nodes in CPB packet for several frames by CH, and the node that has fewer chances to send packets will get bigger virtual ID.

IV. PERFORMANCE EVALUATION

A. Simulation Environment

In the simulation, one cluster with the number of nodes N and communication range R is adopted. Assume that message generation process follows Poisson process with average arrival rate λ_0, and the number of data packets per message follows truncated geometric distribution with the maximum number of data packets per message L_M and probability parameter q. The maximum length of polling queue of CH is N_p. The number of nodes polled in a frame is N_{node}. The transmission interval of a data packet (i.e. packet slot) T_{PKT} is N_{slot} times of the interval of a basic slot (T_{slot}). The interval of CF slot is T_{CF}. The number of binary code in fair collision prevention algorithm is N_{bianry}, which includes the number of priority code $N_{priority}$ and the number of virtual ID N_{vid}. The mini-slot in fair collision prevention algorithm is T_{ORDER}. The parameters in simulation are set in Table I. We evaluate the performance of FODA, carrier sense multiple access with collision avoidance (CSMA/CA) in IEEE 802.11 DCF [2] and polling protocols by throughput (S), average message dropping rate (P_{drop}) and average message delay (D).

B. Performance Evaluation of FODA Protocol

The throughput, average message dropping rate and average message delay of FODA protocol with the variation of λ_0 (i.e., Lamda shown in figures) and N_p are shown in Fig. 5, 6 and 7.

As Fig. 5 shows, when λ_0 is less than 0.2, the throughput S increases lineally with the increase of λ_0. When λ_0 is bigger than 0.2, S begins to increase slowly, and becomes smooth. While λ_0 reaches 0.5, the polling queue of CH is full and S reaches maximum. This can be explained in Fig. 6 and 7. When λ_0 is smaller than 0.2, the system can accommodate the offered load. There is only a very small amount of message dropping, and the average message delay D is very small. When λ_0 is larger than 0.2, the system cannot accommodate much more offered load,

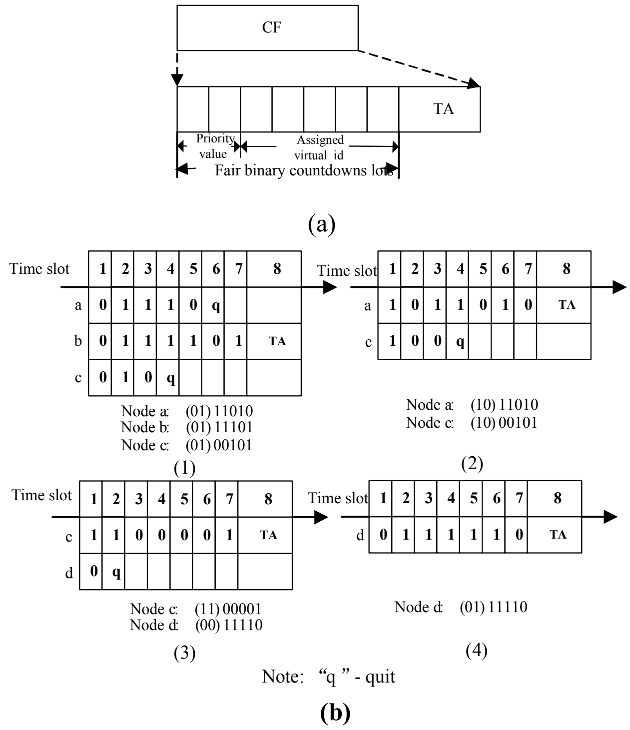

Figure 4. Example of fair collision prevention algorithm.

which results in slower increasing rate of S, higher average message dropping rate P_{drop}, and a little D. While λ_0 reaches 0.5, D increases rapidly with the increase of λ_0 and P_{drop} becomes very high.

From these figures, S does not change with the increase of N_p when λ_0 is smaller than 0.2. When λ_0 increases to a certain value, S will increase as N_p increases. N_p does not have much influence on P_{drop}. However, N_p plays a key role on D. This is because at higher offered load, the longer queue length, and the longer interval of a node to be polled one time in a frame results the longer D.

C. Performance Comparison

The performance comparison of FODA protocol with CSMA/CA and polling protocols is shown in Fig. 8, 9 and 10. For CSMA/CA protocol, the lengths of data and ACK packet are 4 kbits and 40 bits, respectively. For polling protocol, CH polls all the nodes in its cluster one by one. From the figures, we can see that at low offered load, the S of FODA, CSMA/CA and polling protocols increase lineally with the increase of λ_0. The S of FODA and polling protocols are almost the same, and larger than that of CSMA/CA protocol due to existing slight packet collisions and retransmissions in CSMA/CA protocol.

When offered load becomes larger, the S of FODA protocol becomes a little lower than that of polling protocol because of contention access collisions. However,

TABLE I Simulation parameters of FODA protocol.

Scenario		Channel	Message		Service					Interval of slot			
N	R (km)	Data rate (Mbps)	L_M	q	N_{node}	N_{CF}	N_{slot}	$N_{priority}$	N_{vid}	T_{PKT} (ms)	T_{slot} (ms)	T_{CF} (ms)	T_{ORDER} (ms)
80	10	10	40	0.95	20	2	8	3	8	2	0.25	1.0	0.8

the D of polling protocol is much higher than that of FODA protocol because CH polls many nodes, which do not have packets to send. Due to frequent packet collisions and retransmissions, the S of CSMA/CA is much smaller than that of FODA protocol and its P_{drop} is higher than that of FODA protocol.

When offered load is very high, the FODA protocol cancels the reservation access phase in the case of the full polling queue of CH, thus its S is the same as that of polling protocol. However, the D of polling protocol is much longer due to long interval of polling all the nodes in a cluster at a time.

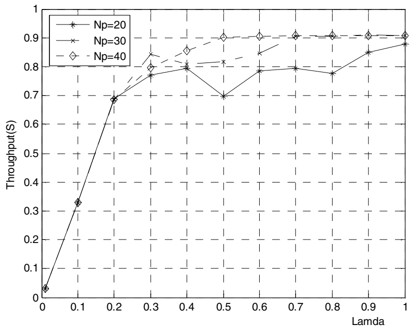

Figure 5. Throughput of FODA protocol.

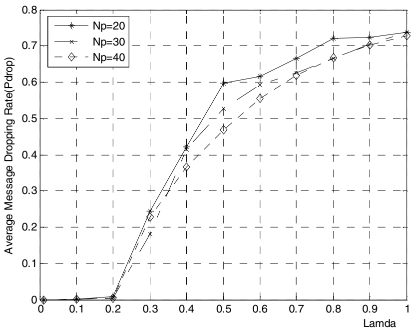

Figure 6. Average message dropping rate of FODA protocol.

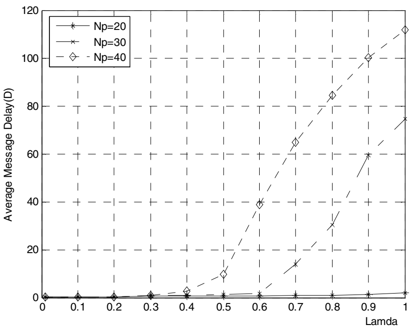

Figure 7. Average message delay of FODA protocol.

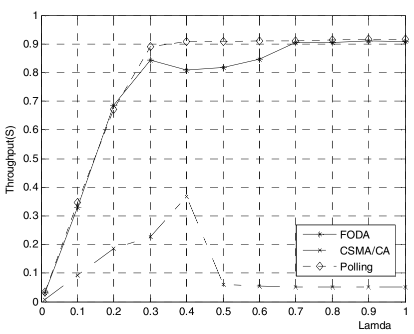

Figure 8. Throughput of FODA, CSMA/CA and polling protocols.

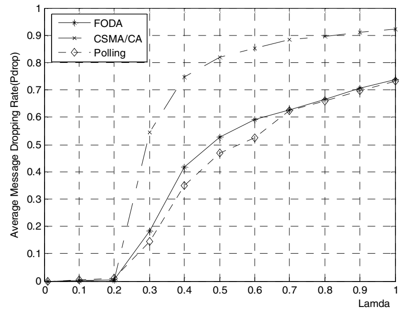

Figure 9. Average message dropping rate of FODA, CSMA/CA and polling protocols.

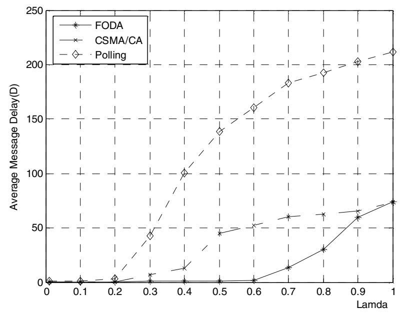

Figure 10. Average delay of FODA, CSMA/CA and polling protocols.

V. CONCLUSIONS

An efficient and dynamic on-demand FODA protocol is proposed for MANET, which integrates the concepts of fair contention, collision-free reservation access and on-demand polling service. It supports continuous transmission and cancels reservation access phase at high offer load to improve channel usage efficiency. Therefore, it overcomes the disadvantages of CSMA/CA and polling protocols, avoids packet collisions, decreases unnecessary overhead, and greatly improves throughput and the access efficiency of nodes with data packets to send. In addition, the proposed FCP algorithm completely resolves the unfairness problem. Simulation results show that the proposed protocol can provide efficient channel sharing.

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