Collision-Free On-Demand Multiple Access Protocol for Mobile Ad Hoc Networks

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***Abstract*—In this paper, a collision-free on-demand multiple access (CF-ODMA) protocol for mobile ad hoc networks is proposed. In the CF-ODMA protocol, every node obtains collision-free polling service by channel reservation. In addition, a collision resolution algorithm is presented to guarantee that in the present of reservation collisions the access nodes can successfully access channel in sequence, and resolve packet collisions during the contention access period. Simulation results show that the proposed protocol can achieve better performances than the IEEE 802.11 distributed coordination function (DCF) and point coordination function (PCF) mechanisms in terms of throughput, average packet dropping rate and delay.**

Keywords— medium access control (MAC); mobile ad hoc networks; reservation; collision resolution; polling

I. INTRODUCTION

A mobile ad hoc network is a highly dynamic self-organizing network consisting of many mobile users or nodes with no predetermined topology and central control. One of its hotspots is multiple access, also known as medium access control (MAC) [1], which deals with efficient channel resource sharing for multiple nodes during communications. Many multiple access protocols have been presented to solve such common channel sharing of multiple nodes for mobile ad hoc networks. A typical example of pure random access protocols is request-to-send/clear-to-send (RTS/CTS) distribution mode of IEEE 802.11 MAC protocol, which employs RTS/CTS handshake mechanism to decrease transmission collisions from the transmission time of long data packet to that of RTS mini-packet mostly due to hidden terminal problem [2] caused by multihop architecture and the application of carrier sensing. Other typical protocols based on random multiple access techniques are IEEE 802.11 DCF [3], multiple access collision avoidance (MACA) [4] and distributed packet reservation multiple access (D-PRMA) [5] protocol, etc. 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) [3], virtual base station (VBS) [6], and Bluetooth. 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 packet delay will increase drastically when a large number of nodes have no packets to transmit.

Wang *et al* proposed a slotted MAC protocol called FD-MAC [7]. FD-MAC protocol combines random access and reservation-based access, and introduces the concept of "data flow" and a flow-driven mechanism for resource reservation. For short-duration data flows, it employs a random access protocol, while for the long-duration data flows it employs a flow-driven reservation-based access protocol. CSMAC proposed in [8] is based on the popular DCF mechanism. In the new mechanism, the AP controls the medium access by adjusting the randomly generated back-off number of the stations. In this way the AP prevents collisions in the system, and helps in the scheduling of transmissions of the stations by maintaining a list of the time-slots that have been reserved for their next transmissions.

By integrating the advantages of random access and reservation-based access, and combining collision prevention mechanism, a novel efficient multiple access protocol based on clustering architecture is proposed, i.e. collision-free on-demand multiple access (CF-ODMA) 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. Firstly, node model and clustering architecture are described in Section II. Secondly, Section III presents the CF-ODMA protocol. In Section IV, performance evaluation is provided. Finally, some useful conclusions are given in Section V.

II. NETWORK MODEL

In MANET, we assume that each node has only one set of transceiver operating in half-duplex mode and a unique identifier (ID). In the CF-ODMA protocol, a local central control node (CCN) is needed to be responsible for scheduling packet transmissions of its neighbor nodes, which can be achieved according to some certain clustering algorithm (refer to the clustering algorithm in [9]). 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 CCN or gateway. One or multiple gateways are selected by CCN to relay inter-cluster traffic. Different clusters

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use different channels. Fig. 1 shows the architecture of cluster network topology.

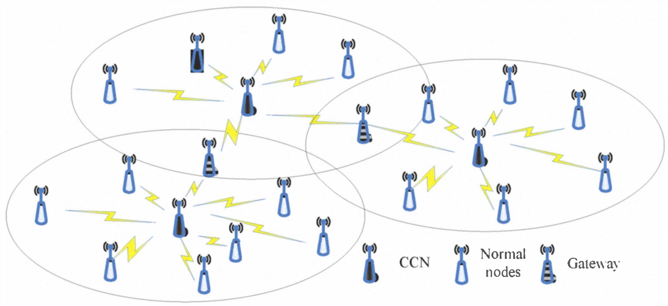

Fig. 1 Clustering architecture

III. CF-ODMA Protocol

The transmission process of the CF-ODMA 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 random contention during reservation access (RA) slots. If it accesses channel successfully, CCN will poll it during the polling phase. Otherwise, the node will make collision-free reservation with collision resolution algorithm in the conflict resolution phase.

A. *Reservation Access Scheme*

Ordinary nodes will send the reservation packets to reserve channel resource at the RA slots in current frame if they have packets to send. If the node accesses successfully, the CCN would record the ID number and broadcasts the result to the network, then this node will be polled later at the polling phase. Otherwise, nodes restart to reserve channel resource and the conflict resolution will be needed to avoid further conflict.

Fig. 2 shows the channel time sequence of reservation access phase under the circumstances of collision-free. The transmission frame begins with the SR (start reservation) packet sent by CCN, several RA (reservation access) slots are used to reserve channel for the normal nodes. Collision won't happen when there is only one node send RA packet to reserve channel resource. CCN broadcasts the result using RB packet and then starts the polling phase without collisions: CCN and normal nodes which access the channel successfully transmit data PKT or polling information alternately until all the polling nodes finish their transmission or a complete frame is timed out.

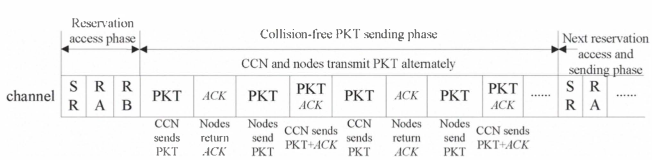

Fig. 2 Principle of CF-ODMA protocol without collisions

Fig. 3 shows the channel time sequence of reservation access phase under the circumstances of collisions. The nodes which need to send data packets fail to reserve channel resource and collision happens at the RA slot, the networks then enter the conflict resolution phase, during which the maximum number of FA and FB mini-slots is N_{VID}. Every ordinary node has a unique binary code with equal length for collision-free reservation access, which consists of its virtual ID (VID). Every active node sends mini-packet or keep sensing at the FB mini-slots depending on the binary value of each bit: if the binary value is 1, active node broadcasts mini-packet FB; if the binary value is 0, the node then keeps sensing. The collision resolution algorithm achieves conflict-free access and resolves the unfairness problem existed in contention access of newly active ordinary nodes completely.

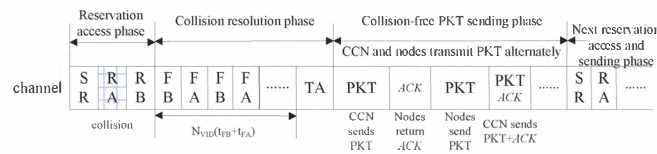

Fig. 3 Principle of CF-ODMA protocol when collision happens

B. *Conflict Resolution Scheme*

Fig. 4 provides the flow diagram of a proposed algorithm during the collision resolution phase. The algorithm consists of the following key procedures:

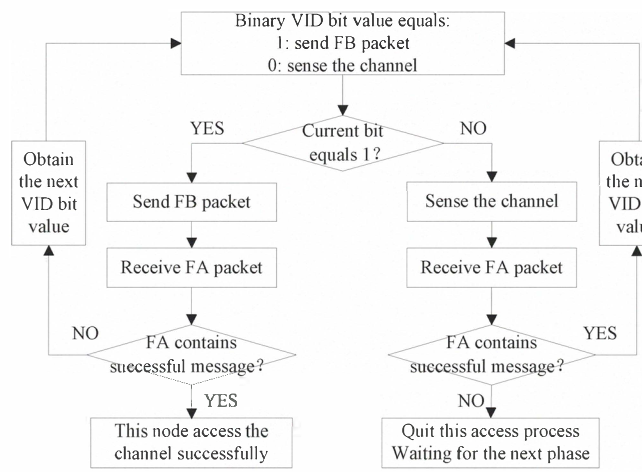

Fig. 4 Collision resolution scheme of nodes

a) Active nodes send FB packets or keep sensing at FB mini-slots depending on their binary value of VID. If the bit value is 0, then the node keeps sensing state, and executes *b)*; otherwise the node sends FB packet and executes *c)*.

b) Receive the reserve result of CCN at FA mini-slot with following three possibilities: *FA IDLE*, *FA BUSYTONE* and *FA SUCCESSFUL*. If the node receives *FA IDLE*, then obtains the next VID bit value and return to *a)*; otherwise the node quit this access process and waits for the next phase.

c) Receive the reserve result of CCN at FA mini-slot, if the node receives *FA SUCCESSFUL*, the current node cancels the transmission of remaining FB mini-packets and gets the channel resource successfully; otherwise the node obtains the next VID bit value and return to *a)*.

Fig. 5 shows an example for collision resolution algorithm. Each node has a unique binary code. Here we set N_{VID}=4, and the virtual ID of node A, B, C is $VID_A = 0110$, $VID_B = 0101$, $VID_C = 0010$ respectively.

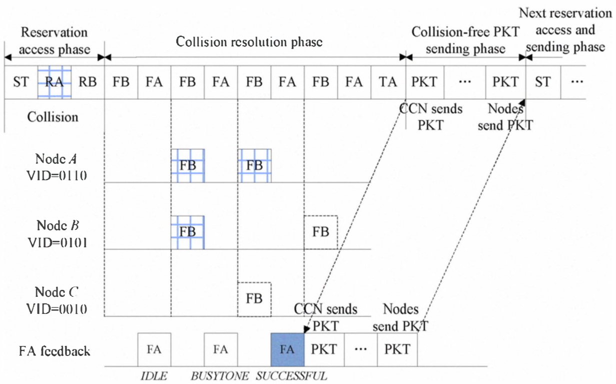

Fig. 5 Example of collision resolution algorithm

In the first FB slot, nodes A, B and C all keep sensing the channel for the first bit value of every node is 0. Therefore, CCN broadcasts *FA IDLE* signal at the following FA slot to inform normal nodes that they can continue the contention; in the second FB slot, nodes A and B send FB packet to reserve channel and CCN returns the *FA BUSYTONE* signal. At this time node C which only senses the channel receives the *FA BUSYTONE* and then quit the contention because it realizes there are some other nodes have been participated in reserving channel before itself; during the third slot, only node A's third bit value is 1, thus node A finally finishes the whole competition and obtains the channel resource successfully. CCN sends *FA SUCCESSFUL* signal to the whole network to announce this result, node A cancels the fourth FB-FA competing slot and adds to the queue of polling.

C. *Polling Transmission Scheme*

After the reservation access phase and the conflict resolution phase, the nodes get the channel resources successfully start the polling phase without collisions. Different from traditional Round-Robin method, there is not specific polling packet. CF-ODMA protocol uses the relay data PKT in CCN to transmit polling tags. When the number of polling nodes reaches the threshold of setting in one frame, the CCN skips the phase of reservation access and directly starts the polling transmission in the next frame until there are idle channel resources. All of these strategies could significantly reduce the polling overhead and improve channel throughput.

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 packet generation process follows Poisson process with average arrival rate λ, and the maximum number of nodes polled in a frame is N_{node}. The transmission length of a data packet is L_{PKT}, and the interval of SR, RA and RB slot is L_{SR}, L_{RA}, L_{RB} respectively. The mini-slot intervals in collision resolution algorithm are T_{FA} and T_{FB}. The size of receiving buffer of data packets in every node is 8Mbits, then the length of node queue is 500, 1000, 2000 respectively when L_{PKT}=16kbits, 8kbits, 4kbits. Simulation time is 10000s, and the parameters in simulation are set in Table I. We evaluate the performance of CF-ODMA by throughput, average packet delay and average packet dropping rate. The formulations are listed as follow:

Throughput: $$S_{TCU} = \frac{t_{PKT} \times N_{received\_PKT}}{t_{sim}} \tag{1}$$

Average packet delay: $$D = \frac{\sum_{i=1}^{N_{received\_PKT}} D_i}{N_{received\_PKT}} \tag{2}$$

Average dropping rate:

$$P_{drop} = \frac{N_{dropped\_PKT}}{N_{dropped\_PKT} + N_{received\_PKT}} \tag{3}$$

TABLE I. SIMULATION PARAMETERS OF CF-ODMA

Parameter	**Value**	**Parameter**	**Value**
Data Rate	2Mbps	*Node Number*	30
SR RA RB TA	112bits	*Tx Range*	100m
FA FB	40bits	*SIFS*	10μs
CTS	112bits	*DIFS*	50μs
RTS	160bits	*Mini-Slot Time*	20μs
ACK	112bits	T_{prop}	1μs
CW_{min}	32	CW_{max}	1024

B. *Performance Evaluation of CF-ODMA*

The cases that L_{PKT}=16kbits, 8kbits and 4kbits with the transmission range of R=100m are considered respectively in the scenario. Fig. 6, 7 and 8 show the throughput, average packet delay and average packet dropping rate with the variation of offered load and packet length.

As Fig. 6 shows, at the low offered load, the throughput increases lineally with the increase of offered load. When offered load becomes larger, throughput begins to increase slowly, and becomes smooth. While offered load reaches saturated state, the polling queue of CCN is full and throughput reaches maximum. This can be explained in Fig. 7 and 8. When offered load is low, the system can accommodate the offered load, there is only a very small amount of packet dropping, and the average packet delay is very small. When the offered load reaches the upper limit of the networks, the system cannot accommodate much more offered load, which results in slower increasing rate of throughput, higher average packet dropping rate and a little packet delay. With the increase of offered load, packet delay increases rapidly and the packet dropping rate becomes high. In Fig.6, the maximum value of throughput becomes larger with the increase of data packet size, which we can get the analytical results from Eqs.(1), for t_{PKT} increases with the increase of L_{PKT}.

From these figures, throughput does not change with the increase of offered load when it reaches a stable state. The length of L_{PKT} has a significant influence on dropping rate and packet delay. Because CF-ODMA protocol avoids the collisions during the PKT transmission period, and the buffer size of nodes is the unique element on dropping rate. In the situation of fixed buffer size, longer L_{PKT} results shorter length of queue. Fig.7 and Fig.8 show that when the throughput reaches saturate, the networks with longer queue length have a higher delay because of the large number of waiting packets; whereas the networks with shorter queue length have higher dropping rate and lower delay, for the nodes directly drop the packets that newly generated.

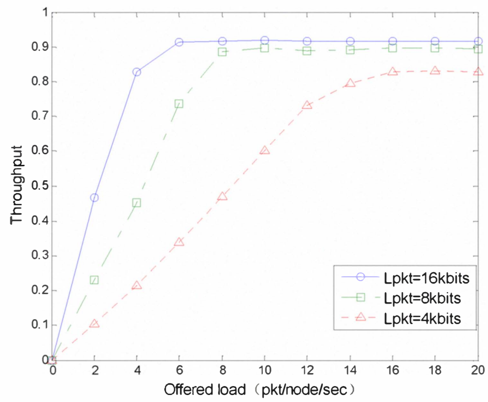

Fig. 6 Throughput of CF-ODMA protocol

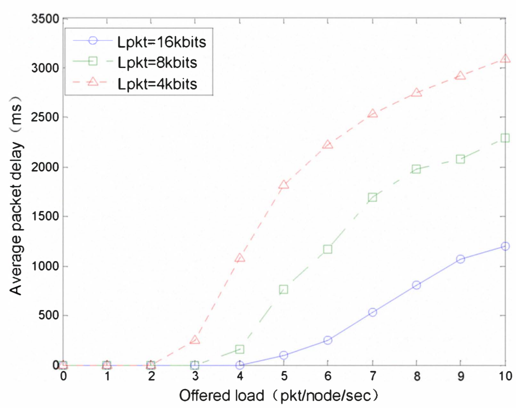

Fig. 7 Average packet delay of CF-ODMA protocol

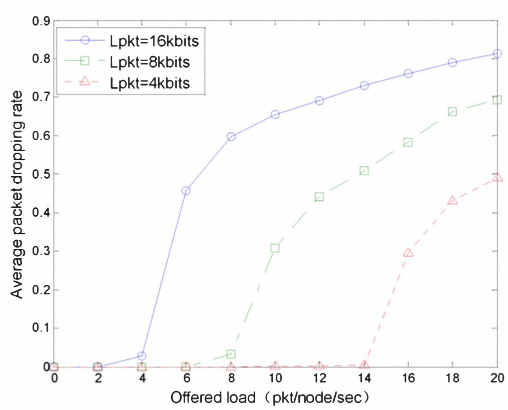

Fig. 8 Average packet dropping rate of CF-ODMA protocol

C. *Performance Comparison*

The performance comparison of CF-ODMA protocol with IEEE 802.11 DCF and PCF mechanism is shown in Fig. 9, 10 and 11. For CF-ODMA protocol, the number of network nodes is 30. For 802.11 PCF, CCN is considered as the AP to polls all the nodes in its cluster.

From the figures, we can see that at low offered load, the throughput of CF-ODMA, 802.11 DCF and PCF protocols increase lineally with the increase of offered load. The throughput of CF-ODMA and 802.11 PCF protocols are almost the same, and larger than that of 802.11 DCF protocol due to existing slight packet collisions and retransmissions in 802.11 DCF protocol. However, the average packet delay of 802.11 PCF protocol is much higher than that of CF-ODMA protocol because CCN polls many nodes, which do not have packets to send. Due to frequent packet collisions and retransmissions, the throughput of 802.11 DCF is much smaller than that of CF-ODMA protocol and its average packet dropping rate is higher than that of CF-ODMA protocol. When offered load is very high, the CF-ODMA protocol cancels the reservation access phase in the case of the full polling queue of CCN, thus its throughput is the same as that of 802.11 PCF polling mechanism. However, the average packet delay of 802.11 PCF protocol is much longer due to long interval of polling all the nodes at a time.

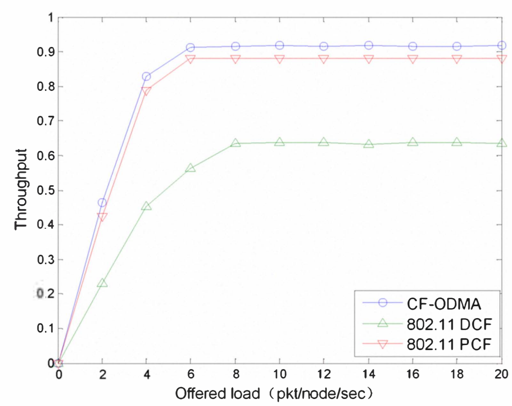

Fig. 9 Throughput of CF-ODMA, 802.11 DCF and PCF protocols

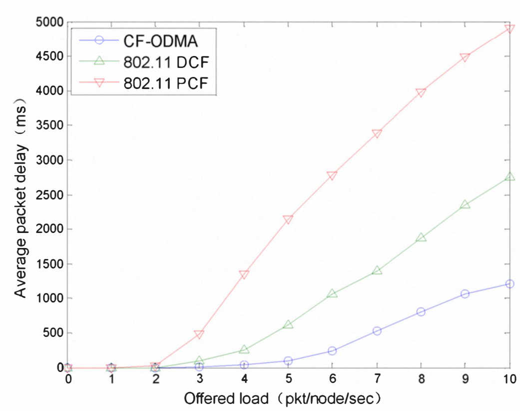

Fig. 10 Average delay of CF-ODMA, 802.11 DCF and PCF protocols

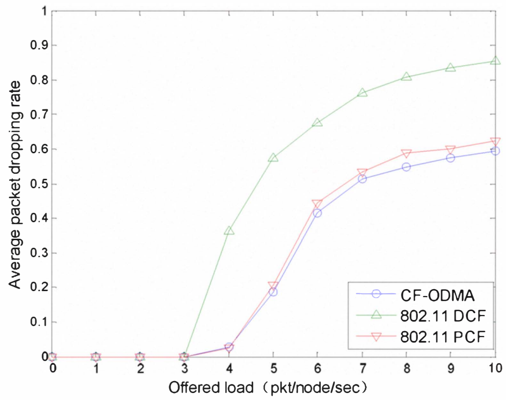

Fig. 11 Average packet dropping rate of CF-ODMA, 802.11 DCF and PCF protocols

V. CONCULSION

An efficient and dynamic CF-ODMA 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 802.11 DCF and PCF 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 collision resolution algorithm completely resolves the unfairness problem. Simulation results show that the proposed protocol can provide efficient channel sharing.

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