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RESEARCH ARTICLE

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A distributed synchronous reservation multiple access control protocol for mobile Ad hoc networks

Abstract This study proposes a new multiple access control protocol named distributed synchronous reservation multiple access control protocol, in which the hidden and exposed terminal problems are solved, and the quality of service (QoS) requirements for real-time traffic are guaranteed. The protocol is founded on time division multiplex address and a different type of traffic is assigned to different priority, according to which a node should compete for and reserve the free slots in a different method. Moreover, there is a reservation acknowledgement process before data transmit in each reserved slot, so that the intruded terminal problem is solved. The throughput and average packets drop probability of this protocol are analyzed and simulated in a fully connected network, the results of which indicate that this protocol is efficient enough to support the real-time traffic, and it is more suitable to MANETs.

Keywords real-time traffic, multiple access control, packet reservation multiple access, mobile Ad hoc networks

1 Introduction

Many MAC protocols drawn on the basis of carrier sense multiple access/collision avoidance has been developed in recent years, such as multiple access collision avoidance [1], multiple access collision avoidance for wireless [2], Institute of Electrical and Electronics Engineers 802.11 MAC [3], floor acquisition multiple access [4], and so on. These protocols are operated in asynchronous mode, where small control packets (such as request to send/clear to send (RTS/CTS)) are used to compete for and obtain access to the channel. The throughput and delayed performance of these protocols in high load will be bad, thus the QoS requirements of real-time traffic cannot be ensured.

There are also some MAC protocols that are drawn on the basis of time division multiplex address (TDMA), such as distributed packet reservation multiple access (DPRMA) [5], multiple access control (MAC-RSV) [6], a Dynamically Adaptive Protocol for Transmission (ADAPT) [7], five-phase reservation protocol (FPRP) [8], collision avoidance time allocation (CATA) [9], and so on. These kinds of protocols are operated in synchronous mode, where each node reserves the idle-time slots through competing. Thus, the QoS requirements of real-time traffic are ensured. But these protocols also have their drawbacks, for example, MAC-RSV does not consider the mobility of nodes and DPRMA does not resolve the intruded and exposed terminal problems.

A distributed synchronous reservation MAC protocol—distributed synchronous reservation protocol (DSRP) protocol is proposed, which is drawn on the basis of TDMA. In this protocol, different priority is assigned to different traffic types, and different traffic types reserve the idle slots in different mechanisms. This protocol can guarantee the QoS requirements of real-time, and solve the hidden, exposed, and intruded terminal problems.

2 The principle of DSRP

2.1 Assumptions

The following assumptions are made in this study. Links are ideal and bidirectional. Nodes work on the same frequency and are synchronized with reference to a global clock. Nodes always receive packets when they are not sending. Nodes do not have capture capability, but they can distinguish not receiving signal (channel is idle), collision, and correct receiving.

2.2 Operating principle of DSRP

2.2.1 Frame structure

On the basis of TDMA, the DSRP protocol divides a frame into N time slots, which are shown in Fig. 1. Each slot has two possible states: idle or reserved. The idle slots are divided into

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m mini-slots, which can be used by nodes to compete for the channels. The time length of data filed in a revered slot is equal to $(m-1)$ mini-slots in an idle slot.

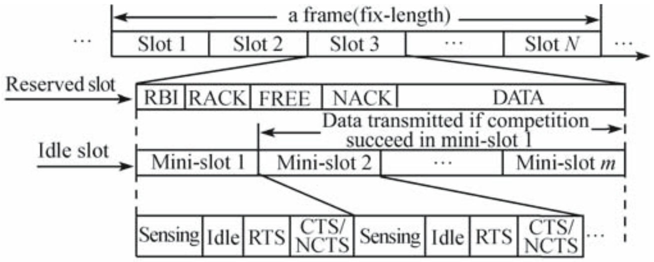

Fig. 1 Frame structure

2.2.2 Definition of nodes priority and guarantee mechanism of QoS requirements for real-time traffic

The priority of traffic is partitioned into two orders: 0 and 1. The priority of real-time is 0 and it can compete for the idle slots by probability P_a, whereas the non real-time is 1 and P_b, with the restriction $P_b < P_a$. If the waiting time of non real-time exceeds a boundary, its priority can be increased to 0. The traffic with priority 0 can compete in the mini-slot 1 of idle slots. If it succeeds, it can send data immediately and reserve this slot in subsequent frames also, or it can continue to compete in the other mini-slots. But if a node does not compete successfully in mini-slot 1, it can only reserve this slot in subsequent frames. The traffic with priority 1 can compete only in mini-slot 2 to *m*, and if it succeeds it can only send data in the slot in the next frame. Thus, the success probability of real-time traffic is improved and the QoS requirements are guaranteed.

2.2.3 The process of competition and reservation

An example of traffic with the priority 0 is given here. If node *A* wants to send data to node *B*, it will sense the channel first. Once it finds an idle slot, it will send the RTS packet in a probability of P_a. If node *B* receives the RTS packet and detects that the receive acknowledgement (RACK) field is idle (which shows there are no intruded terminals), it will send the CTS packet to *A* to indicate that the reservation is successful. If *B* can receive the RTS packet but detect that the RACK field is not idle, it will send a NCTS packet to inform *A* to stop competing for this slot.

If node *A* competes successfully in mini-slot 1, the neighbor nodes of *A* will detect that *A* is sending data, thus they will not compete for this slot again. The neighbor nodes of *B* will detect the CTS packet sent by *B*, so they will not send any signal.

If node *A* competes successfully in another mini-slot, then in the remainder mini-slots the neighbor nodes of *B* can answer to the RTS packets of other nodes. The neighbor nodes of *A* can send RTS packets, but cannot answer to any other RTS packet.

The success of node *A* shows that it had reserved the same slots in subsequent frames to send data to node *B*. Therefore node *B* should send receive busy indicator (RBI) packet in the RBI field in those slots to indicate the state of those slots. As a result, the hidden terminal problem is resolved.

2.2.4 The resolution of mobility and the problem of intruded terminals

In mobile Ad hoc networks, nodes move randomly, which results in the intruded terminal problem. Figure 2 shows that if *C* moves to the position of C', the data sent by *C* and *A* will collide at *B*. If *E* moves to the position of E', the data sent by *A* and *F* will collide at *E*.

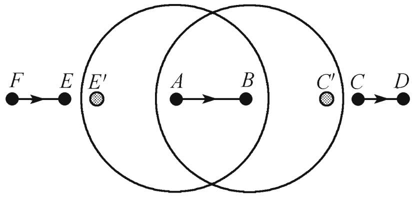

Fig. 2 Intruded terminal problem

To resolve this problem, it is requested in this protocol that the senders and receivers should confirm the reservation before sending and receiving data. The senders send RACK packets, and if intruded terminals appear, the receiver (such as *B* and *E*) will detect collision in RACK field. When this happens the receiver should send negative acknowledgement (NACK) packet to notify that the reservation for this slot is terminated. The senders will stop the reservation as long as they detect that the NACK field is busy.

2.2.5 The resolution of hidden and exposed terminal problem

Figure 3 shows that node *A* has reserved a slot to send data to *B*. At the beginning of the slot node *B* sends an RBI packet, therefore, node *E* and *F* will detect that the slot is not idle. As the frame structure shows, if the hidden terminal *F* receives the RTS packet in mini-slot 1, it can send a CTS packet without any impact on *B* receiving it, thus the hidden terminal problem is solved. But in the other mini-slots node *F* cannot send any signals.

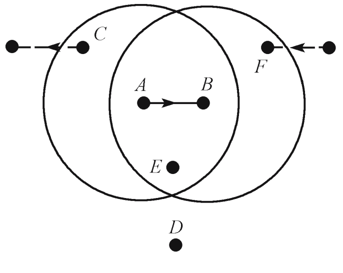

Fig. 3 Hidden and exposed terminal problem

The exposed terminal *C* can send an RTS packet to compete for this slot. In the mini-slot 1, the CTS packet to be received by node *C* would not collide with the RACK packet sent by node *A*, thus the sending problem of the exposed terminal is resolved. In the other mini-slots, node *A* begins to send data, therefore node *C* can detect that the channel is busy and would not send the RTS packet.

3 Analysis of DSRP protocol

3.1 System model and assumptions

Consider a fully connected network with M nodes. Each node has voice traffic, which can be described by slow speech activity detector (SAD) model. The average burst interval t_1 is 1 s and the average silent interval t_2 is 1.35 s, and they both obey the uniform distribution. The traffic has two states: burst and silence, and the state only transfers on the time of frame boundary. The nodes in burst will send one data packet in each frame, and use one slot. The packet that is not sent successfully in a frame should be dropped, thus the maximum delay of a packet is the time length of a frame. Failure of competing for an idle slot or success in competing in mini-slot 2-m will cause the drop of a packet. Each node transferred from silence to burst should compete for the idle slot in probability P_a named allowable probability. Throughput is defined as the average number of successfully transmitted packets in a frame divided by the number of slots in a frame. The average drop probability of packets is defined as the average number of packets dropped in a frame divided by the average number of packets produced in a frame.

3.2 Math model of the protocol

It is supposed that the system state is defined as the number of reserved slots k ($0 \leqslant k \leqslant N$) at the beginning of a frame. There is the probability that when a node transfers from silence to burst at the system transfer time is $P_{\text{burst}} = 1 - \exp(-T/t_2)$, and when it transfers from burst to silence it is $P_{\text{silence}} = 1 - \exp(-T/t_2)$, and here T is the time length of a frame. Therefore, any node will compete for an idle slot in a probability of $p = P_a \times P_{\text{burst}}$, and the reserved node will be set free in a probability of $q = P_{\text{silence}}$.

It is assumed that there are i nodes competing for the same slot at the probability of p at the same time, and that the probability of a success node is $P_{\text{succ}}(i, p) = P_1(i, p) + P_2(i, p)$, and here $P_1(i, p)$ is the probability that this node is a success in mini-slot 1, and $P_2(i, p)$ is the probability that this node succeeds in the other mini−slots

$$\begin{cases} P_1(i,p) = C_i^1 p(1-p)^{i-1} \\ P_2(i,p) = \sum\limits_{j=2}^{m} [1 - P_1(i,p)]^{j-1} P_1(i,p) \end{cases} \tag{1}$$

Suppose there are y nodes that have not reserved any slot, and will compete for x slots in the probability of p, thus the probability of z nodes success is

$$\begin{aligned} \phi(x,y,z,p) = {} & [1 - P_{\text{succ}}(y,p)] \cdot \phi(x-1,y,z,p) \\ & + P_{\text{succ}}(y,p) \cdot \phi(x-1,y-1,z-1,p) \end{aligned} \tag{2}$$

The restriction of Eq. (2) is

$$\phi(x,y,z,p) = \begin{cases} 1, & x=0, y=0, z=0; \\ & \text{or } x=0, y \neq 0, z=0; \\ & \text{or } x \neq 0, y=0, z=0 \\ 0, & x=0, y=0, z \neq 0; \\ & \text{or } x=0, y \neq 0, z \neq 0; \\ & \text{or } x \neq 0, y \neq 0, x<z; \\ & \text{or } x \neq 0, y \neq 0, y<z; \\ [1-P_{\text{succ}}(y,p)]^x, & x \neq 0, y \neq 0, z=0 \end{cases} \tag{3}$$

If the system state is k, it means there are k slots that have been reserved. In next frame the probability that j slots will be set free is

$$F_k^j(q) = C_k^j q^j (1-q)^{k-j} \quad 0 \leqslant j \leqslant k \tag{4}$$

From above description, the transfer probability of the system is Eq. (5), where d indicates the number of slots to be set free

$$P_{kh} = \begin{cases} \sum\limits_{d=0}^{k} F_k^d(q)\phi(N-k, M-k, h-k+d, p), & k \leqslant h \\ \sum\limits_{d=k-h}^{k} F_k^d(q)\phi(N-k, M-k, h-k+d, p), & k > h \end{cases} \tag{5}$$

If the probability that system state k is P_k, then the following formulas will be true

$$\sum_{k=0}^{N} P_k = 1, \qquad P_k = \sum_{h=0}^{N} P_h P_{hk} \tag{6}$$

From above analysis, the system throughput can be derived as

$$S = \frac{1}{N} \sum_{k=0}^{N} P_k \cdot (\, k + \text{Num}_k) \tag{7}$$

where Num_k is the average number of slots successfully reserved in mini-slot 1 when the system is in state k, which can be described by Eq. (8)

$$\text{Num}_k = \begin{cases} \sum\limits_{n=1}^{M-k} \{ C_{M-k}^n (P_{\text{burst}})^n (1-P_{\text{burst}})^{M-k-n} \\ \quad \cdot \{ \sum\limits_{i=0}^{N-k} [\phi(N-k, n, i, P_a) \cdot \sum\limits_{j=n-(i-1)}^{n} P_1(j, P_a)]]\}\}, \\ & M-k \geqslant 1 \\ 0, & M-k < 1 \end{cases} \tag{8}$$

where n is the number of nodes transferred from silence to burst, i is the number of idle slots which are reserved successfully, and j is the number of nodes that had joined the competition when these idle slots are reserved successfully.

The average packets drop probability is

$$P_{\text{Drop}} = \sum_{k=0}^{N} P_k \text{Drop}_k \tag{9}$$

where Drop_k is the average probability of packets drop of each frame when the system state is k, and the meanings of n, i, j are the same as Eq. (9)

$$\text{Drop}_k = \begin{cases} \displaystyle\sum_{n=1}^{M-k} \Big\{ C_{M-k}^{n} (P_{\text{burst}})^n (1-P_{\text{burst}})^{M-k-n} \\ \quad \cdot \left\{ \displaystyle\sum_{i=0}^{N-k} \left[\phi(N-k,n,i,P_a) \cdot \dfrac{n-i+\displaystyle\sum_{j=n-(i-1)}^{n} P_2(j,P_a)}{k+n} \right] \right\} \Big\}, & M-k \geqslant 1 \\ 0, & M-k<1 \end{cases} \tag{10}$$

4 Simulation of DSRP protocol

The performance of DSRP is simulated in a fully connected network, and the parameter is as follows: the time length of a frame is 16 ms and a frame is divided into 10 slots. Each slot is 1.6 ms in length and has 5 mini-slots. When the number of nodes is different and the allowable probability is different, then the simulation results are as shown in Figs. 4 and 5.

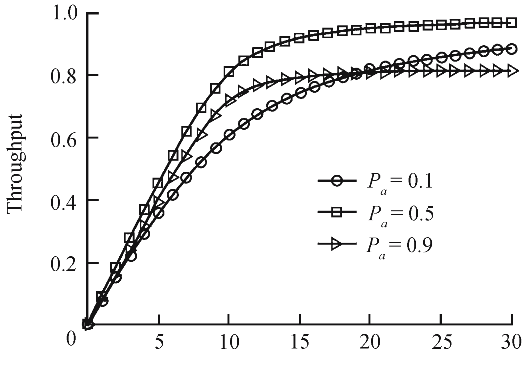

Fig. 4 Throughput

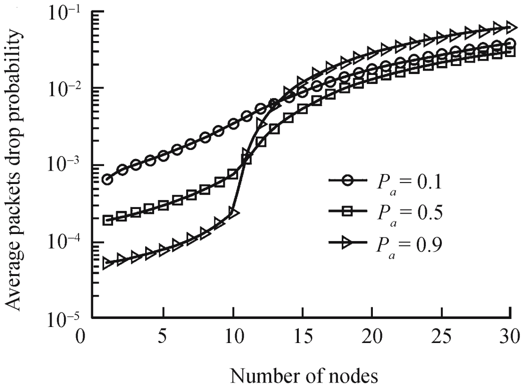

Fig. 5 Packets average drop ratio

The Figure shows that when the number of nodes increases, the throughput and packets drop ratio are increased also, and the maximum of throughput is near to 1, that is, the capability of the channel. According to the requirements for packets drop probability, the number of nodes allowed to communicate at the same time is determined, and the QoS requirements are guaranteed. Proper selection of allowable probability helps to get the best performance of throughput and packets drop probability. For muti-hop networks, because this protocol can resolve the hidden and exposed terminal problems, the channel can be reused most spatially and the utilization and throughput of channel are improved greatly.

5 Conclusions

This paper proposes a distributed synchronous reservation multiple access control protocol, which resolves the hidden and exposed terminal problems and combines competition with reservation. As a result, the QoS requirements of real-time traffic are guaranteed. Furthermore, the intruded terminal problem is resolved by confirming the reservation before sending data. The performance of the DSRP protocol is simulated in a fully connected network, and the results of throughput and packets drop probability prove that the protocol is effective. The results indicate that the protocol can satisfy the requirements of real-time on throughput and packets drop probability.

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