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Performance enhancement of IEEE 802.11 distributed coordination function for MANET

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Abstract: The medium access control (MAC) issue is discussed in mobile Ad Hoc networks (MANETs). Based on the IEEE 802.11 MAC protocol, this paper proposes two schemes, the forward-packet-first (FPF) scheme based on the adaptive backoff contention window and multihop forward chain transmission by invitation (MFCTI) scheme. In the FPF scheme, the contention window is adjusted adaptively according to the traffic priority. Route information and the broadcast characteristic of radio are utilized in MFCTI scheme. The performance of these schemes is studied in multihop environments by simulations. The results show that the proposed schemes can improve the network throughput, reduce the end-to-end average delay, and mitigate local congestion effectively. Another attractive feature is that the schemes can be implemented with minor modifications to the IEEE 802.11 MAC.

Key words: wireless LAN; mobile Ad Hoc network; medium access control; distributed coordination function

A mobile Ad Hoc network (MANET) is an autonomous system of mobile routers (and associated hosts) connected by wireless links. A challenging task in the design of such networks is the development of medium access control (MAC) protocols[1,2]. A great deal of effort has been made and many MAC protocols[3-5] have been proposed. However few of them were originally designed to be used in multihop wireless links, including the IEEE 802.11 protocol[6]. The IEEE 802.11 MAC distributed coordination function (DCF) is widely used in testbeds and simulations of MANETs and is supported by most portable wireless device manufacturers. Therefore it is worthwhile to improve the 802.11 MAC DCF performances in the MANET environment. Based on the 802.11 MAC DCF, this paper proposes two simple and effective schemes, the forward-packet-first (FPF) scheme and multihop forward chain transmission by invitation (MFCTI) scheme. The FPF scheme, based on an adaptive backoff contention window, can deal with the local congestion problem effectively. While the MFCTI scheme further improves the MAC performance by replacing the four-way handshaking technique with a three-way handshaking technique.

1 Basic 802.11 MAC DCF

As the point coordination function (PCF) in the 802.11 MAC protocol does not work in MANET, this section only summarizes the DCF as standardized by the 802.11 protocol briefly. Readers may refer to Ref. [6] for more details.

To cope with the hidden and the exposed node problem, a four-way handshaking technique, RTS-CTS-DATA-ACK, for the packet transmission, is adopted in the IEEE 802.11 MAC DCF. When a node has data to transmit, it picks a random waiting period. This waiting period is decremented when the channel is idle. When this period expires, the node tries to acquire the channel by sending an RTS packet. The destination node responds with a CTS packet indicating that it is ready to receive the data. The sender then transmits the data packet. If this packet is received without errors, the destination node responds with an ACK. If an ACK is not received within the specified time, the packet is assumed to be lost and retransmitted. If the RTS fails, the node attempts to resolve the collision by doubling the waiting period. To give preference to a node trying to send an ACK, different waiting intervals are specified. A node needs to sense the channel idle for a distributed inter-frame space (DIFS) before making an RTS attempt and a short inter-frame space (SIFS) interval before sending an ACK packet. Since the SIFS interval is shorter than the DIFS interval, the node attempting to send an ACK takes priority over a node attempting to send data. In addition to the physical channel sensing, virtual carrier sensing is achieved by using the network allocation vector field (NAV) in the packets, which indicates the duration of the current transmission to other nodes. All nodes that hear the RTS and CTS message back off NAV amount of time before sensing

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the channel again.

2 Proposed FPF and MFCTI Schemes

2.1 Forward packet first scheme based on adaptive backoff contention window

In MANET, several routes may meet at one node. In such cases, though the traffic of any route is not heavy, the crossing node may be overloaded. This may result in local congestion which can significantly deteriorate the network performance, such as the network capacity and the packet end-to-end delay.

The proposed FPF scheme classifies packets into two groups, those that are to be forwarded for other nodes and those that are generated by the node itself. All packets are placed in an FIFO queue. When transmitting a packet, the node first checks whether the packet is a forwarded one or not. If it is a forwarded packet, a small contention window C_{frd} is used to generate the random backoff number. Otherwise, the backoff rule in the 802.11 MAC protocol is used, that is, a large contention window and an exponential backoff scheme are used. Therefore, the node gives the forwarded packets higher priority than those that are generated by it.

Each node records the number of active routes used to forward packets for other nodes. In addition, every node records the number of neighboring nodes which is forwarding packets for others. To accomplish this, each transmitted packet is tagged with a forwarding tag, which indicates whether it is a forwarding packet or not. Suppose a node supports M_{acrt} active routes and it has K_{fn} neighboring nodes which forward packets for others. It determines its contention window size as follows:

$$C_{\mathrm{frd}} = \frac{C_{\min}}{2^{M_{\mathrm{acrt}}}} \tag{1}$$

$$\text{If } C_{\mathrm{frd}} < 4, \text{ then } C_{\mathrm{frd}} = 4 \tag{2}$$

$$\text{If } C_{\mathrm{frd}} < \rho K_{\mathrm{fn}}, \text{ then } C_{\mathrm{frd}} = \lfloor \rho K_{\mathrm{fn}} \rfloor + 1 \tag{3}$$

$$\text{If } C_{\mathrm{frd}} > C_{\min}, \text{ then } C_{\mathrm{frd}} = C_{\min} \tag{4}$$

where $\rho > 1$ is a relaxation factor; we take $\rho = 1.5$ in our simulations, $C_{\min}$ denotes the minimum contention window.

2.2 Multihop forward chain transmission by invitation scheme

A multihop forward chain is a directed chain that consists of all nodes in a route, including the source node and the destination node, and the actions of forwarding packets. The direction is from the source to the destination. By means of the broadcast characteristic of radio propagation and the handshaking technique, a node in the forwarding chain can learn that a packet has reached the previous node successfully. So it can invite the previous node to transmit the packet. Thus the handshake of RTS and CTS is not needed. This process may be performed by other forwarding nodes in the chain till the packet reaches the destination node.

To implement the proposed MFCTI scheme, the formats of ACK frame and the DATA frame should be changed. Also a new INVITE frame is needed. All of them are given in Fig. 1. The modified ACK frame introduces an NRA field. Usually NRA is an address indicating the MAC address of the next node in the current multihop forward chain. The modified DATA frame introduces an Addr5 field which is the MAC address of the next two-hop node.

Ctrl	Dur	RA	NRA	FCS

(a)

Ctrl	Dur	RA	TA	FCS

(b)

Ctrl	Dur/ID	Addr 1	Addr 2	Addr 3	Seq Ctrl	Addr 4	Addr 5	Frame body	FCS

(c)

Fig.1 Frame formats. (a) Modified ACK frame; (b) INVITE frame; (c) Modified DATA frame

Suppose that the multihop forward chain is shown in Fig. 2. Node A has a packet to transmit to node E and the packet has to be relayed by node B, node C, and node D. Our proposed MFCTI scheme can be described as follows.

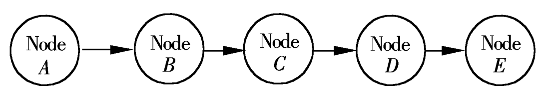

Fig.2 A multihop forward chain

1) The handshake of RTS and CTS between node A (the source node) and node B is executed according to the rules defined in the 802.11 MAC protocol.

2) Node A transmits the DATA frame. The Addr 5 field is set to the MAC address of node C.

3) If the destination node receives the DATA frame successfully, it submits the received data to the upper layer (No fragmentation/defragmentation is considered here). Then it responds the DATA frame with an ACK after a period of time SIFS and updates the NAV. The fields of Dur and NRA should be set correctly according to the field in the received DATA frame.

4) If the destination node of the ACK frame receives the ACK frame successfully, the following operation will be performed. If the NRA field in the ACK frame contains a valid MAC address, the node updates its NAV. Otherwise it discards the ACK frame.

If the node whose address is NRA receives the ACK frame successfully and its internal NAV denotes that the channel is busy, it discards the ACK frame. Otherwise, it updates its NAV and transmits the INVITE frame after a period of time DIFS. The fields of Dur, RA and TA should be set correctly. All other nodes receiving the ACK frame should update their internal NAVs.

5) If the invited node receives the INVITE frame successfully and its NAV shows the channel is idle, it updates the NAV and transmits the DATA frame after SIFS time. All other nodes receiving the INVITE frame update their NAV according to the value in the INVITE frame.

6) Steps 3) to 5) are repeated until the DATA frame reaches its final destination node.

Transmission failures may happen in the above process. In such case, some frames have to be retransmitted. If the transmission failure happens on the first hop in a multihop forward chain, the retransmission follows the rules defined in the 802.11 MAC protocol. There are some differences in dealing with the transmission failures on other wireless hops. The INVITE frame is not allowed to be retransmitted in any case. If a forwarding node that has transmitted a DATA frame by invitation does not receive the ACK frame within a specified time, it should retransmit the DATA frame by means of the four-way handshaking technique and the backoff interval is picked randomly in the range of $[0, C_{\text{frd}}]$. A duplicated DATA frame should be discarded and the node should respond with an ACK frame whose NRA field is set to null.

The basic MFCTI access mechanism can be illustrated in Fig.3.

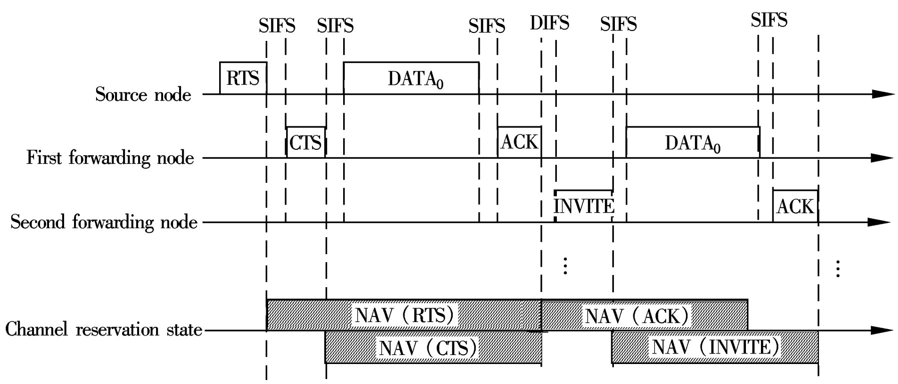

Fig.3 Basic MFCTI access mechanism

3 Simulation and Performance Evaluation

3.1 Simulation environment

At the physical layer, the two-ray radio propagation model and omni-directional antennas are applied. The network interface approximates the 802.11 DSSS implementation. The transmission range is about 300 m. At the MAC layer, the IEEE 802.11 MAC DCF and the proposed schemes are implemented for comparison. The simplified DSR protocol[7] is used to route packets. The packet generator generates packets according to the given arrival process and the frame length distribution. Typical default values of the parameters used in simulations are summarized in Tab.1. To see the effect of our proposed schemes clearly, a fixed network topology in Fig. 4 is considered. The distance between two neighboring nodes is about 200 m. When the buffer in a forwarding node is full, all packets received later will be discarded.

Tab.1 Simulation parameters and their values

Parameters	Values
Channel rate/(Mbit · s^{-1})	1
DSSS preamble/bit	144
DSSS header/bit	48
Slot time/μs	20
Short IFS/μs	10
DCF IFS/μs	50
Short retry limit	4
Long retry limit	7
Station buffer/kbit	256
Minimum contention window	32
Maximum contention window	1 024

3.2 Simulation results

Fig.5 shows the average packet end-to-end delay. In this set of experiments, node 0 and node 5 generate packets at a given constant rate and transmit them to node 4 and node 8, respectively. The packet load is 1 kbit. Each simulation run lasts 10 min. We can see

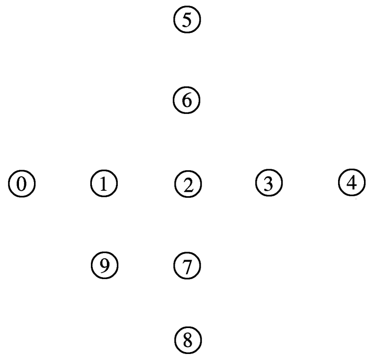

Fig.4 Network topology

that with the increase of network traffic, the average end-to-end delay becomes greater. At some point an abrupt increase appears. When the network load is light, the average end-to-end delays for both schemes are very low and our proposed schemes are slightly superior. However with the increase of network traffic, our proposed schemes outperform the IEEE 802.11 MAC DCF significantly. This can be explained as follows. When the traffic is light, the end-to-end delay is mainly due to the MAC access delay. While the network traffic becomes heavier, the queuing delay becomes the main part. Our proposed schemes ensure the process of transferring a packet from the source to the final destination will seldom be interrupted. This can be verified in Fig. 6 which shows the average packet numbers in the node buffers at an arrival rate 150 packet/s.

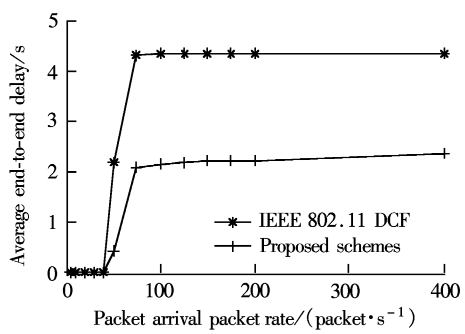

Fig.5 Average end-to-end delay vs.offered load

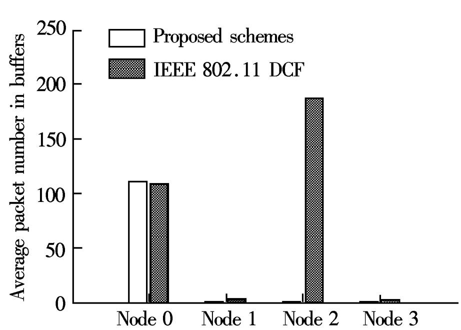

Fig.6 Average packet number in buffers

Fig. 7 shows the network throughput under different packet sizes. In this set of experiments, node 0 and node 5 are the source nodes and node 4 and node 8 are the final destinations, respectively. The packets are generated according to the Poisson process.

The throughput of different flows under the proposed schemes is shown in Fig.8. Three data flows are set up. The source of flow one is node 0 and the final destination is node 4. The other two are single-hop data flows. The source and the destination of flow two are node 1 and node 9, respectively. While the source and the destination of flow three are node 6 and node 5. The packet arrival process is the Poisson process with the mean arrival rate 200 packet/s. The packet length is 2 kbit. The obtained results show that the proposed FPF scheme does not result in unfairness.

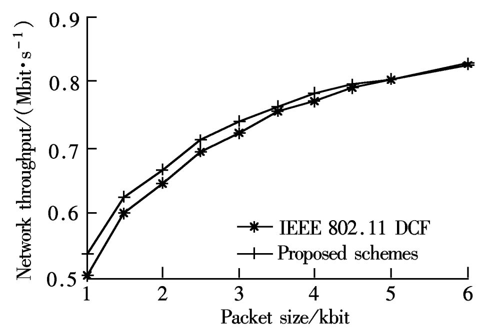

Fig.7 Network throughput vs. packet size

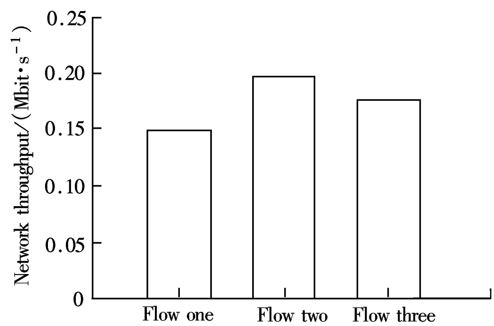

Fig.8 Throughputs of three flows under proposed schemes

4 Conclusion

Two simple and effective schemes based on the 802.11 MAC DCF are proposed for MANET. The FPF scheme, whose basic idea is the classification of packets, prioritizes the packets to be forwarded by means of reducing the contention window. The MFCTI scheme replaces the four-way handshaking process with a three-way handshaking process by utilizing the broadcast characteristic of radio propagation. Simulation results demonstrate that the proposed schemes can effectively improve the network performance, mitigate the local congestion to a great extent, improve the network throughput and reduce the average end-to-end delay in MANET.

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IEEE 802.11 分布式协调功能在 MANET 网络中的性能改善

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摘要: 研究了移动 Ad Hoc 网络中的媒体接入控制问题. 首先, 基于 IEEE 802.11 媒体接入控制协议, 提出了应用于 MANET 网络媒体接入控制的 2 个机制: 自适应回退窗转发优先机制(FPF)和多跳链邀请发送机制(MFCTI). FPF 机制根据业务优先级自适应调整竞争窗大小, 而 MFCTI 机制则充分利用了网络层路由信息和无线传播的广播特性. 在此基础上对所提出的机制进行了仿真研究并与原 IEEE 802.11 媒体接入控制进行了比较. 结果表明, 所提机制可以有效地提高网络吞吐率, 降低端对端迟延, 缓解网络局部拥塞, 从而提高了 MANET 网络的性能. 其另一优点是只需对IEEE 802.11媒体接入控制作少量的补充和改动.

关键词: 无线局域网; 移动 Ad Hoc 网络; 媒体接入控制; 分布式协调功能

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