A New Cooperative MAC Protocol for Wireless LANs

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Abstract: This paper introduces a new cooperative MAC-protocol for wireless LANs. This scheme is totally compatible with the legacy systems and leverages the multi-rate capability of IEEE systems. The proposed protocol is evaluated via theoretical analysis and the result shows a throughput improvement using the same physical layer as in IEEE802.11b.

1. Introduction

Interference is an increasing challenge in all wireless local area networks (WLANs) environments. Any types of interference can have a harmful and destructive impact on WLAN performance, i.e. throughput and latency. By effectively transmitting multiple copies of the same signal over essentially independent channels, known as diversity, is an efficient technique that can be used to alleviate the negative effects of fading. Some well known forms of diversity to combat fading are spatial diversity, temporal diversity, and frequency diversity [12].

Independently of whether other forms of diversity are being used, special diversity depends on deployment of antenna array on small mobile unit. Unfortunately, this is infeasible due to the small size of the mobile node. In order to overcome this limitation, a new concept of diversity that has emerged called cooperative diversity is realized through utilizing cooperative communications [3, 4, 7, 8, 9]. Cooperative diversity has been proposed to take the advantage of the spatial diversity gains, by allowing different nodes in a wireless network to share their resources and cooperate through distributed transmission. This is achieved by relaying overheard information at stations surrounding a source and, thus, forming multiple transmission paths to the destination. The idea of cooperative communications has been meanly interpreted in the form of innovations at the physical layer (modulation, coding, etc.) to allow stations to cooperate in their transmissions in order to improve the overall performance of the wireless networks. However, research at the physical layer should be combined with higher layers, in particular the MAC layer to realize a fully cooperative networks. We adopt these ideas and design a new MAC protocol to increase the throughput of a wireless networks.

2. The IEEE 802.11 MAC Protocol

IEEE Project 802 recommends an international standard 802.11 [1] as the first standard for WLANs. It provides detailed specifications both for Medium Access Control (MAC) Layer and Physical (PHY) layer. IEEE 802.11b [2] was introduced later in 1999. It provides four physical layer rates 1, 2, 5.5, and 11 Mbps at the 2.4 GHz band. The basis of the IEEE 802.11b WLAN MAC protocol is Distributed Coordination Function (DCF), which is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) with binary exponential back-off scheme. There are two modes used for packet transmitting in DCF. The default one, known as basic access mode, is a two-way handshaking technique. Each station needs to sense the channel before data transmission and can send data packet if the channel is idle. A positive MAC acknowledgment (ACK) is transmitted by the destination station to confirm the successful packet transmission. The other one is a four-way handshaking technique, which uses a virtual carrier sensing to avoid collision, by the use of the Request-To-Send (RTS) and Clear- To-Send (CTS) frames. The two control frames RTS/CTS are used to set the Network Allocation Vector (NAV), where the reservation information of the channel is stored. This technique has been introduced to avoid the hidden terminal problem. After successfully exchanging the control packets, a data packet will be sent and the destination will send back positive acknowledgment (ACK) if the packet has been received correctly. Nevertheless, the drawback of using the RTS/CTS technique is increased overhead for the data frame. IEEE 802.11b "performance anomaly" [10] means that the low data rate stations significantly degrades the performance of a wireless network. Each station has an equal probability to access the channel but the low data rate stations will occupy more channel time than the high data rate stations, leading to higher delays and reducing the bandwidth utilization of high data rate stations, and as a result decreasing the overall throughput of the network. Therefore, a Medium Access Control (MAC) protocol based on cooperation should be implemented to provide an efficient way to share limited resources fairly to serve all the stations and still provide high throughput.

3. Related Work

Recently, several papers that address the cooperative MAC protocols in 802.11 are introduced. For instance, H.Zhu et al [15] proposed rDCF protocol to further exploit the physical layer militate capability and enabling two-hop in the DCF-Ad Hoc mode. In rDCF protocol, if a station can become a relay stain, it periodically advertises the relay information. Holland et al [6] have proposed a receiver-based auto rate (RBAR) protocol, with the rate feedback by the destination via the control frame Clear-to-Send (CTS). In [14], a relay enabled PCF protocol, so-called rPCF, which enables Multi-hopping in the PCF mode. However, the PCF mode is rarely used and has limited applications. A cooperative MAC protocol (CMAC) has been proposed in [13], reduces the number of retransmissions and leads to system performance improvement. A different cooperative MAC protocol has been proposed in [11]. This new protocol, so-called CoopMAC requires minimal changes to the existing DCF, and thus backward compatible with IEEE 802.11 standard. Our proposed protocol is modified CoopMAC, so-called CoopMAC$^+$, in which the total overhead to data packet is reduced and the probability of collision for RTS/CTS mode also reduced. Theoretical results show that our protocol can improve the system throughput.

The rest of this paper is organized as follows. In section 4, we describe the CoopMAC in detail. In section 5, we specify the proposed protocol. The theoretical results for the proposed protocol are given in section 6. Some concluding remarks and possible future research are given in Section 7.

4. The Cooperative MAC protocol (CoopMAC)

The CoopMAC protocol is described in details in [11]. In this paragraph we provide the basic functionality of this protocol. As in figure 1, the source station S_s instead of sending its data directly to the destination S_d low date rate transmission, transmits the data in two-hop manner using the potential helper S_h. The benefit of the two hop transmission is that the transmission time between the source and the destination is reduced, because the two links that are used are fast. The source transmits the data frame to the helper, therefore the helper retransmits it to the destination after a SIFS period, and thus there is no need to contend the channel. When the destination receives the frame from the helper, it sends a direct positive acknowledge to the source, confirming the reception.

In this protocol, to achieve the right selection of the helper, each station contains a table, so-called a CoopTable, of all possible helpers around it. Each time a station receives a frame from any other station, it check if the transmitting station is already in the table. If not, new information is added to the table. Each raw of this table corresponds to a potential helper. Then it updates the corresponding row with the information from the receiving packet. The CoopMAC protocol also defines a new handshake technique involving RTS/CTS with a new message called HTS (Helper ready-To-Send). Details of this handshake mechanism and the required information in a CoopTable can be found in [11].

5. The proposed cooperative MAC protocol (MAC^+)

The proposed cooperative MAC protocol is based on the CoopMAC protocol, therefore it is based on the distributed Coordination function (DCF) of IEEE 802.11 It assumed that the transmission power are fixed for all stations. Transmitting stations choose the best modulation scheme based on the received signal to noise ratio (SNR). It assumes also the channel between each station and its destination is symmetric, because the uplink and downlink traffic use the same frequency.

5.1 $CoopMAC^+$ OUTLINE

1. When a station Ss has data packet with length L bytes to transmit to a destination S_d, it first checks the CoopTable and calculate the required transmission time via each potential helper. The transmission occurs in two steps, first from the source to the potential helper with rate R_{sh} and then from the potential helper to the destination with rate R_{hd}, so the transmission time is $8L/R_{sh} + 8L/R_{hd}$, ignoring the overhead time. After checking all the potential helpers, the one with minimum transmission time is chosen. If the rate R_d between S_s and S_d, $8L/R_d$ is the direct transmission time. If $8L/Rsh + 8L/Rhd < 8L/Rd$, two hope transmission is more efficient.

2. S_s sense the channel first. If the channel is idle for a DIFS time and Ss completed the required backoff mechanism, a MRT frame will be sent, reserving the channel for a NAV duration for the data transmission. Format of the MRT and the CoopMAC RTS is shown in figure 2(a). In the MRTS frame, will reserve the channel for time needed to receive the helper reply, in contrast with CoopMAC protocol which reserve the channel for duration of direct transmission. The MRTS frame includes the helper ID and the XORing ID of the source and the destination, so MRTS length is equal to RTS frame in IEEE 802.11 and less by ten bytes than CoopMAC protocol. This procedure has two advantages. First, it reduces the overhead time, second, it reduces also the probability of the collision with any other stations RTS. As a result, it will help to improve the network performance.

3. If the helper station which has the same MAC address as indicated in HelperID field in the MRT frame can decode the RTS frame, it will reply with BusyTone signal after a SIFS period to confirm helper ready to send. The BusyTone signal length is from one to tow time slots (20-40 us, in IEEE 802.11b). We replaced HTS with busy tone to reduce the overhead as well as the BusyTone is more reliable than HTS. This packet will be heard both by S_s and S_d.

4. S_d receives MRT first, each station will calculate the result of XORing its ID with the received one to get the source ID and compares it with sources look-up table. If the ID is found in the table, S_d will confirm that it is the intended receiver. So destination station S_d will be expecting the BusyTone after receiving the MRT frame. If the BusyTone is received, the Modified-Clear-To-Send (MCTS) frame will sent and reserve the channel for the time needed for two hope transmissions. An illustration of the exchange of the control packet for the cooperative MAC protocol is shown in figure 2(b).

5. Once the source receives the MCT frame from the S_d, The data packet starts transmission. If BusyTone signal ha been received, Ss the data packet to S_h using rate R_{sh}. S_h checks the CRC field of the data packet and forwards the packet to Sd, if it is not corrupted, using rate R_{hd} after a SIFS time.

6. After S_d receives the data packet, an ACK packet is sent. Otherwise S_d stays idle. In the later case the source will notice the failure transmission after a time out period and start the binary exponential backoff procedure similar to the IEEE 802.11 standard.

6. Theoretical Results

To validate the proposed cooperative MAC protocol we used analysis similar to CoopMAC in [11] which is based on Bianchi [5]. The transmitting range is shown in Table I. other basic parameters used in the simulation are shown in Table II. The mobile stations are uniformly distributed in a circle with a radius 100 meters and the access point is located in the centre of the circle. The minimum congestion window size (W_min) is 31 and the maximum number of backoff stages is 6 after which the packet is dropped.

Figure 4 shows the saturated throughput for CoopMAC and our proposed CoopMAC protocol. As we can see, the proposed protocol has a higher throughput than the CoopMAC when increasing the number of stations. Figure 5 compares the throughput improvement under different MSDU packet length. The saturated throughput of our proposed MAC scheme achieves higher throughput than CoopMAC scheme.

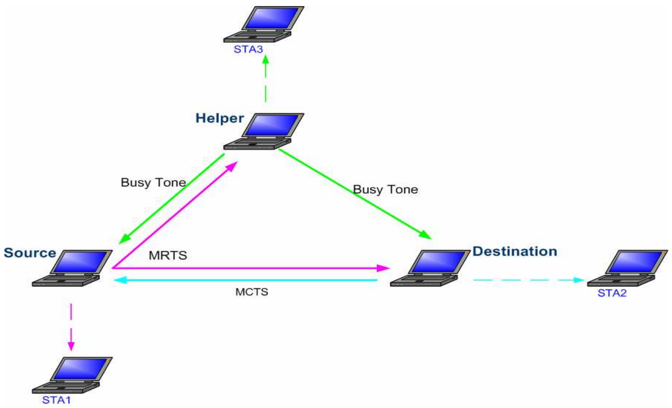

fig. 1 Exchange of control packets for CoopMAC

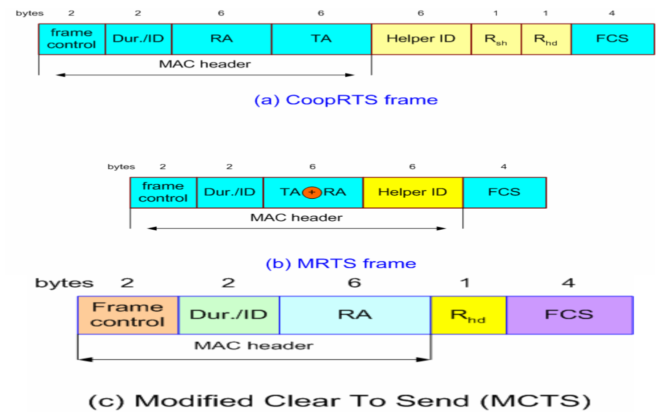

fig.2 Frame control format

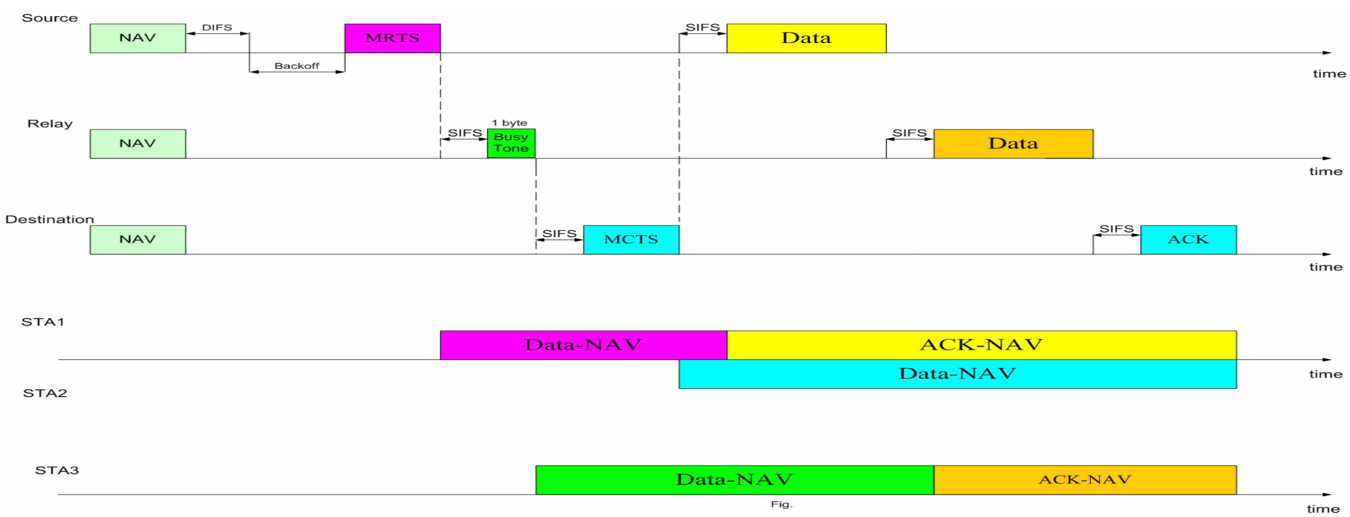

fig. 3 Proposed cooperative MAC protocol

Data rate (Mbps)	11	5.5	2	1
Range(m) ($BER>10^{-5}$)	48.2	67.1	74.7	100

Table I
Physical model table

MAC header	272 bits
PHY header	192 bits
RTS	352 bits
CTS	304 bits
ACK	304 bits
Data rate for PHY header	1 Mbps
Slot time	20 µs
SIFS	10µs

Table II
Parameters used in Simulation

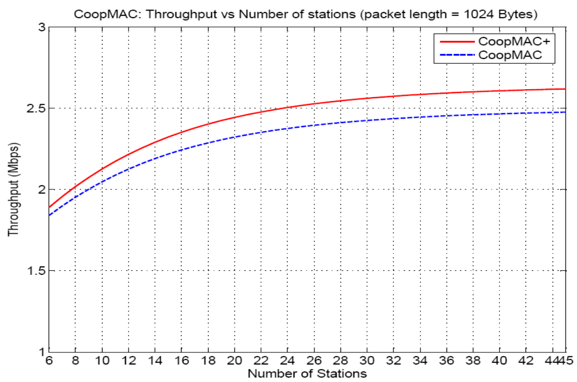

fig. 4 Throughput for CoopMAC and CoopMAC+ vs number of Stations

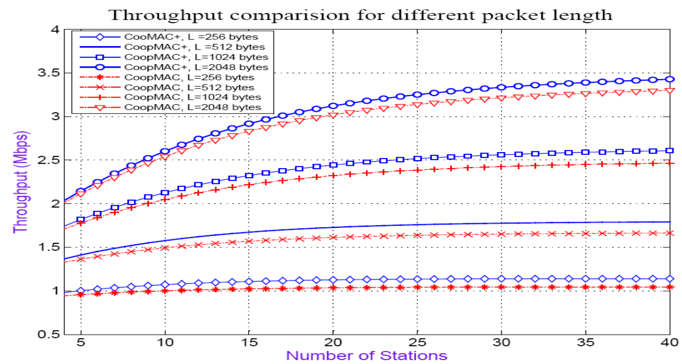

Fig. 5 Throughput vs number of Stations under different packet lengths

7. Conclusions

In this paper, we have proposed a new MAC protocol for IEEE 802.11b wireless LAN. This scheme is totally compatible with the legacy systems and can extend to higher physical rate systems. The proposed protocol is evaluated via theoretical analysis and the result shows that a throughput improvement using the same physical layer as in IEEE802.11b. for future work, we will need to build a simulator to evaluate the proposed algorithm and apply for the IEEE802.11 a/g. We will also extend the proposed algorithm to Ad-Hoc networks

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