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Efficient Medium Access Control with IEEE 802.11 for Mobile Ad Hoc Networks

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Abstract—The IEEE 802.11 Medium Access Control (MAC) protocol has inherent weakness of channel wastage while operating a Mobile Ad hoc Network (MANET). In this paper, we therefore propose several new mechanisms we collectively name as Exhaustive MAC, to alleviate this problem and thus improve performance of IEEE 802.11 in MANETs. The basic principle of our proposals is to ensure utilization of channel capacity that is otherwise wasted. In addition to the concept of extra frame transmission during the wasted reservation period, our main contributions in this paper include (i) idea of RTS Release (RTSR), (ii) channel rescue and reuse, (iii) moving the state of the channel forward through ahead-of-time decrement of back-off timer. In addition, our proposed mechanisms are free from compatibility problems with standard IEEE 802.11.

keywords: *QoS, Wireless Networks, Mobile Computing, IEEE 802.11, Medium Access Control, MANET*

I. INTRODUCTION

In recent years, issues related to Mobile Ad hoc Networks (MANET) have been considered as important as well as challenging in the networking world. Wireless technology lies at the core of these concerns. However, despite rapid expansion, wireless technology is still faced with the inherent problems of lower bandwidth, high delay and link errors. The ultimate consequence is a lower yield in network performance. MANETs are even more vulnerable to these issues. An appropriately designed MAC protocol can play a significant role in this case. In this

paper, we therefore present efficient Medium Access Control (MAC) mechanisms for enhanced operations of Mobile Ad hoc Networks (MANET) deployed on IEEE 802.11.

Many research [1],[2],[3] have focused on developing the wireless medium access control (MAC) that efficiently share limited resources between all stations. Among these, the IEEE 802.11 MAC is clearly the most accepted and widely used one at present.

The major application of IEEE 802.11 is for Wireless LANs (WLAN) with fixed access points. In addition, IEEE 802.11 can support an ad hoc mode. Since the protocol bids fair for long deployment in the future WLANs, it is likely that the same will also be used widely for ad hoc networks. Deployment of IEEE 802.11 in mobile ad hoc networks however, does not always yield good performance [2]. As such, research on performance improvement of mobile ad hoc networks using IEEE 802.11 deserve special attention.

The IEEE 802.11 is a distributed foundation wireless medium access control (DFMAC) protocol based on CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). It provides positive acknowledgment frame (ACK) to confirm the completion of reception as basic mechanism. Request-to-send/clear-to-send (RTS/CTS) handshaking mechanism, incorporating virtual carrier sensing, is described as an optional mechanism to better avoid the collisions due to hidden terminal problem. A station reserves the channel by sending an RTS frame and waits for its reply from intended destination prior to the

transmission.

The performance of the IEEE 802.11 in Mobile Ad Hoc Networks (MANET), in which multihop topology and mobility are main characteristics, has been investigated in [2], [4]. It is observed [2] that hidden and exposed terminal problems become worse in MANET while using IEEE 802.11. The ultimate result is heavy degradation in throughput and instability of networks. In [4], it is shown that this problem is more severe in large and dense ad hoc networks. In [5], the authors show that the performance of upper layer protocols suffer severely for multihop ad hoc networks that are based on IEEE 802.11 protocol.

Several works have proposed some modifications to the standard aiming to improve its performance. For instance, [6] used dynamic backoff algorithm based on number of stations and current traffic, [7] suggested sending data in backward direction after basic transmission to improve performance of reliable transport protocol. In [8], the authors propose a hop-by-hop approach to overcome failure in multihop ad hoc network.

In the following sections, we show that collision resolution algorithm in the IEEE 802.11, sometimes, keeps the channel unnecessarily inaccessible leading to inefficient channel utilization. These scenarios are often found in multihop mobile ad hoc networks. The result is drastic degradation of network performance.

In this paper, we therefore propose schemes we collectively name as Exhaustive MAC (E-MAC) that manipulate the RTS/CTS handshaking while operating in ad hoc mode. The basic idea is to make use of this otherwise wasted idle channel period. The proposed scheme allows sender, which cannot accomplish RTS/CTS exchanging sequence, an extra transmission. In addition to the concept of extra frame transmission during the wasted reservation period, our main contributions in this paper include (i) idea of RTS Release (RTSR), (ii) channel rescue and reuse (CRR), (iii) moving the state of the channel forward through ahead-of-time decrement of back-off timer. In addition, our proposed mechanism is free from compatibility problems with standard IEEE 802.11.

The rest of this paper is organized as follows. In Section II, we briefly summarize basic operations of

the IEEE 802.11 MAC. In Section III, we describe its operation in MANET under missing CTS. We then propose our enhancements to IEEE 802.11 in Section IV. In Section V, we present the primary performance metrics based on which we are evaluating our mechanism. Finally we conclude in Section VI.

II. MEDIUM ACCESS CONTROL IN IEEE 802.11

The IEEE 802.11 describes two medium access functions called Point Coordination Function (PCF) and Distributed Coordination Function (DCF) [9]. DCF provides a distributed access mechanism scheme which supports both the operation in WLAN and ad hoc networks. Our consideration on this paper is on the DCF based on CSMA/CA access mechanism.

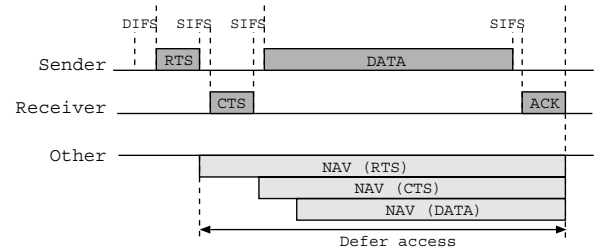


Fig. 1. The RTS/CTS access mechanism

A. Virtual Carrier Sensing

The RTS/CTS access method is provided as an option in IEEE 802.11 to reduce the collisions caused by hidden terminal problem. A station that needs to transmit large data frame (longer than predefined RTSThreshold value), at first, sends a special short control frame called request-to-send (RTS). This frame includes information about the source, destination, and duration required by the following transaction (CTS, DATA and ACK transmission). Upon receiving RTS, the destination responds with another control frame called clear-to-send (CTS), which also contains the same information. The transmitting station is allowed to transmit data only if the CTS frame is received correctly.

All other nodes overhearing either RTS and/or CTS frame adjust their Network Allocation Vector (NAV)

to the duration specified in RTS/CTS frames. The NAV contains period of time in which the channel will be unavailable and is used as virtual carrier sensing. Stations defer transmissions if either physical or virtual sensing results as channel being busy. Nevertheless, If receiver's NAV is set while data frame is received, DCF allows the receiver to send the ACK frame.

The RTS/CTS mechanism was shown to be very effective [10] as it can early detect the collisions by the lack of CTS. However, the protocol cannot free or reallocate the channel that was already reserved by the previous RTS frame. Stations receiving only the RTS frame but not CTS, cannot assume that transmission does not take place. Therefore, they defer for an interval declared in last RTS. This results in wastage of channel capacity around and sender.

III. THE MISSING CTS

In this Section, we analyze the situation in which CTS is not received at the sender and see how the channel utilization may be improved in each situation.

- *Situation 1*, backoff timers at two or more stations reach zero at the same time and they send RTS simultaneously. This happens more frequently as the traffic of network increases.

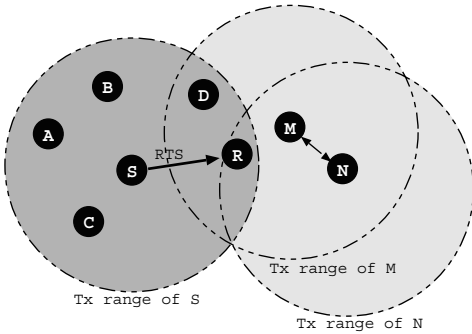


Fig. 2. S is not aware of transmission between M and N while transmitting RTS to R .

- *Situation 2* is illustrated in Fig. 2. Station S starts the RTS/CTS sequence while another transmission, which interferes the reception but is out of the S 's sensing range, is carrying on. Even if the RTS correctly reaches the receiver, the virtual

carrier sensing at station R will forbid the CTS response.

- *Situation 3* occurs when intended receiver, R , (Fig. 2) moves to a new position out of communication range of S . Hence, it cannot receive RTS from S .

The above situations are regularly found in MANET where stations route packets through each other in multihop fashion, and stations are free to move arbitrarily. In situation 1, the channel can be considered as unusable and backoff algorithm should play its role. But in situation 2 and 3, channel around the sender is allocated but unused because of unavailability at the receiver. Thus, the sender who had contended for medium and won should be given another opportunity.

We propose modifications to IEEE 802.11 in next section to reuse this wasted channel capacity.

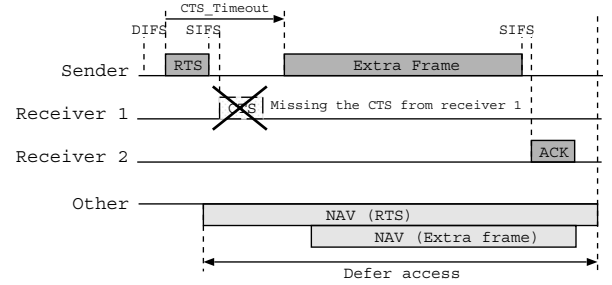


Fig. 3. Extra frame transmission

IV. EXHAUSTIVE MEDIUM ACCESS CONTROL (E-MAC): OUR PROPOSAL

In this section, we present our approaches we collectively name as Exhaustive MAC protocol for optimizing the use of otherwise wasted channel capacity in MANET. E-MAC is a superset of several mechanisms. Implementations can choose one or a combination of them based upon the suitability. An important component of E-MAC is CTS timeout, which is, basically, a time threshold [11]. Beyond this threshold, it is practical to consider that CTS to the RTS under consideration will never come if it already has not. Therefore channel capacity that is otherwise

wasted during the time between CTS timeout and that the channel has been reserved for by the RTS can be better utilized. With this context, in following subsections we present the mechanisms, namely, Extra Frame Transmission (EFT), RTS Release (RTSR), Channel Rescue and Reuse (CRR) and two categories of Move Ahead State of the channel (MAS). We begin with an outline of CTS timeout mechanism.

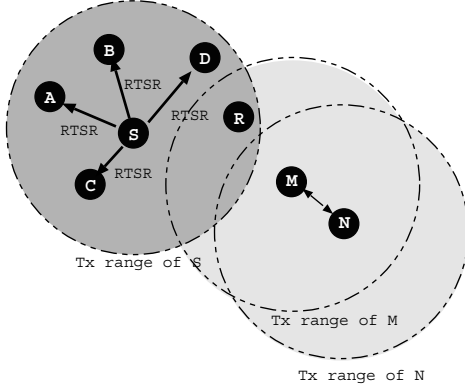


Fig. 4. S sends RTSR to release the channel for nodes A, B, C, D

A. CTS Timeout

IEEE 802.11 RTS/CTS sequence uses strict timing. So we introduce a new parameter $CTS_Timeout$ which accounts for the maximum time that may be required to receive a CTS, if any. We assume $CTS_Timeout$ expires after $RTS_Tx_time + propagation_delay + SIFS + CTS_Tx_time + propagation_delay$. Having waited for this $CTS_Timeout$, sender is assured that the CTS response from receiver will not come at all.

B. Extra Frame Transmission (EFT)

1) *EFT Mechanism*: Our proposed modification works as shown in Fig. 3. After sender transmitted RTS for receiver 1 and have waited until it is conceivable that the CTS does not come, it picks a frame from sending queue and immediately transmit to alternate receiver 2, if an appropriate one exists. We explain 'appropriate frame' in the following sections. The extra frame is removed from queue if the transmission

completed (confirmed by link layer acknowledgement from receiver 2) [9] or the transmitted extra frame is broadcast. Then, whether the extra frame transmission has succeeded or not, the sender goes back to normal operation by scheduling the retransmission of the original frame with doubled CW.

2) *Conditions for Extra Frame Transmission*: A frame to be transmitted as extra frame should maintain the following properties. These are in line with our previous work [11].

- 1) An extra *appropriate* frame should be destined to a different station from the currently attempted one.
- 2) An extra frame should not require RTS/CTS handshake. These are broadcast frames or frames smaller than $RTSThreshold$ (so no need for RTS/CTS exchange).
- 3) The chosen extra frame should be the first in sequence frame destined for this receiver in the queue. For example, suppose there are two frames for a destination at the sender. First frame (arrived at the sender first) is larger than $RTSThreshold$ but the second frame is not. The second frame must not be chosen as extra frame although it satisfies the first and second conditions. This constraint is suggested to avoid any out-of-order transmission.

C. RTS Release (RTSR)

In many cases, an appropriate extra frame as per conditions in IV-B2 is not available. This reduces the EFT enabled E-MAC to be equivalent to standard IEEE 802.11. Therefore, we propose a more proactive approach of releasing channel in case an extra frame cannot be transmitted. An extra control frame we name RTS Release (RTSR) is deployed for the purpose (Fig. 4).

RTSR is provisioned within an ordinary RTS frame with a zero duration of transmission length field. If the sender finds no frame satisfying conditions in section IV-B2, it initiates an RTSR signal and relinquishes own control of the channel. We term the duration between receipt of RTSR and NAV becoming free as *Conservative Wait*.

Two new variables are deployed in the process. For neighboring nodes to keep track of which node, NAV_{set} caused them set their NAV to its current value. If the RTSR source matches this node, each corresponding node sets another variable, a status, NAV_{state} to an *unoccupied* state. However, the NAV value is still maintained the same as if no RTSR has been sent.

D. Channel Rescue and Reuse (CRR)

In channel rescue and reuse mechanism, upon changing NAV_{state} to *unoccupied*, an E-MAC supporting node (node D in Fig. 4) waits for DIFS time to sense whether the node itself is within the range of some ongoing transmission. If it is discovered that D is not in the range of any other transmission during this, D sets its NAV to zero and resumes operation like a node that has not heard the RTS from S at all.

The reason is, since the node received an RTSR that corresponds to NAV_{set} , the node does not need to wait until the longest duration, i.e., value of NAV. However, it is possible some communication that had set node D's NAV to a lower value was still on. Therefore node D should wait this DIFS time. If there is no transmission within this time, then probably there was no other transmissions affecting D. Total waiting time for node D is then expressed as,

$$T = RTS_Tx_time + 2 \times propagation_delay + 2 \times SIFS + CTS_Tx_Time + RTSR_Tx_Time + DIFS \quad (1)$$

When deployed over a mixed environment that supports both E-MAC extension and IEEE 802.11, CRR capable nodes may occupy a larger share of bandwidth than nodes capable with standard IEEE 802.11 only.

E. Moving the Channel State Ahead

Upon receiving an RTSR, resuming the nodes' operation to normal state can be a source of discrimination among E-MAC capable and non-capable nodes (section IV-D). Also this can increase collision level among the nodes in the released channel. Alternatively, we propose for moving the state of the network ahead in the otherwise wasted time as follows.

- 1) Upon receiving an RTSR, all the nodes wait for a duration of DIFS. NAV_{state} of the nodes remains unaltered.
- 2) All can reply a CTS to an incoming RTS from some other node.
- 3) Nodes that want to move their state ahead, can start decreasing their back-off timers. This timer, however stops if the corresponding node hears some occurrence of a transmission (or collision).

In case the Conservative Wait period is shorter than the MAS node's back-off timer length, even when the NAV becomes free and NAV_{state} becomes *unoccupied*, the decrement continues. To the contrary, if back-off timer length is shorter, then it should stop decreasing the timer one slot before it becomes zero. The decrement resumes again after NAV becomes free. Decrementing the back-off timer leads a node to do ahead what it was supposed to after NAV expiration. Thus as the state of some node(s) moves ahead, the state of the entire network moves ahead. There can be two types of moving the network state ahead described as follows.

1) *Single Node State Move Ahead*: In this case, the original sender, in its RTSR frame, includes a destination x , chosen randomly from one of its neighbors. Therefore only node x gets the exclusive right to decrement its back-off timer and move its state ahead. Other nodes however, can reply to an incoming RTS if appropriate. We name this scheme as Single Move Ahead State (SMAS).

Decrementing x only, serves good enough particularly where the node density is high.

2) *Multiple Node State Move Ahead*: In this case, the RTSR frame from the original sender allows all the neighboring nodes to decrement their back-off timer as well as reply to an incoming RTS signal. However, if all the nodes decrement at the same time (as they do in standard IEEE 802.11) and the Conservative Wait time is larger than back-off timer for more than one node, there will be higher probability of collision after NAV becomes free. Therefore, allowing a fraction of the nodes to go ahead with Multiple Move Ahead State (MMAS) can be a good choice. MMAS works good in cases where the node density is not high.

F. Compatibility Concerns

All frame formats used in our modifications remain unchanged. The newly introduced RTSR frame is also incorporated within a normal RTS frame. Thus, our proposed modifications are fully compatible with the IEEE 802.11 standard. If there are some stations which do not support our modifications in the network, they still can exchange frame using basic DCF. This makes our proposals suitable for incremental deployment - an important practical concern.

V. EVALUATION CRITERION

We are conducting experiments with the most widely deployed network simulator, *ns-2*, [12] to evaluate the effectiveness of our mechanism. Performance comparisons between standard IEEE 802.11 [9] and IEEE 802.11 with our proposed enhancements are made for the purpose.

Network model is general multihop wireless topology [13] using AODV (Ad hoc On demand Distance Vector) as routing protocol [14]. The link layer is shared media radio with nominal channel bit rate of 1 Mbps. The antenna is omni-directional with radio range of 250 meters. We ignore the effect of *capture* and *interference* and assume perfect channel sensing in our model, i.e. any two stations are either in-range of one another or out-of-range. Some important parameters are listed here; slot time = 20 μ s, SIFS = 10 μ sec, DIFS = 50 μ sec, propagation delay = 2 μ sec, RTSThreshold = 1024 or 2000 bytes if not otherwise stated. A high value of RTSThreshold is deployed owing to practical considerations.

Traffic source and destination pairs are randomly spread over the network. Type of traffic is constant bit rate (CBR) with packet size randomly chosen between 512-2048. Simulation time is 200 seconds per run. Each point in all graphs is an average from at least 8 simulation runs.

A. Simulation Scenario

We are conducting experiments with the following scenarios.

1) *Varying RTS Threshold*: In this case, the RTS Threshold value is varied from 0 to 2000 Bytes. The nodes move with a maximum speed of 10m/s with a pause time of 50sec.

2) *Varying Mobility*: In our experiments, we use random waypoint mobility model [16] to simulate nodes' movement. In the random waypoint model, a mobile station begins by staying at one location for a period of time (we call this *pause time*). Once this time expires, station chooses a random location in the simulation field and a random speed uniformly distributed between [*minspeed*, *maxspeed*]. We use *minspeed* = 0 and *maxspeed* = 10 in our simulation. The number of stations is 50 and simulation field is of size 1500 m x 300 m. We conduct experiments by varying pause time and speed.

- 1) In case of varying pause time, we set *maxspeed* at 10 m/s and change pause time between 0-200 seconds. Traffic in this experiment is 30 CBR sources at 500Kbps combined sending rate.
- 2) We also explore the impact of varying node speed. For this, simulation is conducted by setting the *pause time* at 50 seconds and change maximum node speed. We offer 40 CBR at 500Kbps as traffic source.

B. Performance Metrics

We consider the following as our performance metrics [15].

- 1) Throughput
- 2) Fairness
- 3) Amount of dropped data

Throughput is computed as the total amount data successfully sent per unit time. Suppose u_i is the amount of data in bytes successfully transmitted by node i . If the total transmission time is t , then the total throughput T in bits per second (bps) will be:

$$T = \frac{\sum_{i=1}^{i=N} u_i \times 8}{t} \quad (2)$$

Fairness is computed as follows. Suppose, x_i is the throughput for node i , e_i indicates the expected or desired throughput for the same node. Then for N number of nodes, fairness index is calculated as:

$$F = \frac{\left(\sum_{i=1}^{i=N} x_i/e_i\right)^2}{N \times \sum_{i=1}^{i=N} (x_i/e_i)^2} \quad (3)$$

In our experiments, we consider the other way to represent fairness in terms of unfairness index as:

$$U = 1 - F \quad (4)$$

Hence a lower unfairness will be desirable.

Results from initial simulations reveal that our mechanisms yield a gain of upto 15% in throughput. Also, a relatively good fairness is maintained between different connections. The figures are however, subject to further experiments.

VI. CONCLUSION

In this paper, we have shown the inherent inefficiency of the RTS/CTS handshaking mechanism in mobile ad hoc networks, when allocated channel is not utilized. Therefore, we proposed several enhancements, we name collectively as Exhaustive MAC, to the IEEE 802.11 to reuse this otherwise wasted channel. We have evaluated E-MAC mechanisms through simulations. The results examined from initial simulations under various scenarios show that our scheme performs considerably better than standard IEEE 802.11 by more than 15%. Also, our E-MAC proposals basically maintain fairness among different nodes and in some cases, yield considerably better fairness than standard IEEE 802.11. In addition, our E-MAC proposal is fully compatible with IEEE 802. Hence can be deployed on an incremental basis.

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