

A New Hybrid Channel Access Scheme for Ad Hoc Networks

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Abstract—Many contention-based channel access schemes have been proposed for multi-hop ad hoc networks in the recent past and they can be divided into two categories, sender-initiated and receiver-initiated, according to the collision avoidance handshake in use. Sender-initiated scheme is adopted in the IEEE 802.11 MAC protocol, which is by far the most popular and studied protocol. However, the IEEE 802.11 MAC protocol can experience serious fairness problems due to location-dependent contention and the binary exponential backoff it uses. On the other hand, receiver-initiated collision avoidance handshake is more effective at the receiver's side. Hence, we propose a hybrid channel access scheme that combines both sender-initiated and receiver-initiated collision avoidance. The new scheme involves only some additional queue management and book-keeping work while maintaining compatibility with the existing IEEE 802.11 protocol. Simulation experiments show that the new scheme is very effective as it can achieve much better fairness than the original sender-initiated scheme with almost no degradation in throughput. The hybrid scheme also eliminates the need for a good traffic estimator, which is usually mandatory in pure receiver-initiated schemes.

I. INTRODUCTION

Contention-based channel access schemes are very popular in wireless ad hoc networks. One reason is due to their simplicity. Unlike schedule-based schemes that generally require all the nodes in a network to be synchronized to a reference clock, contention-based schemes do not need global time synchronization. Another reason is due to their well-adaptability to bursty data traffic as channel is reserved on demand instead of a priori.

In contention-based channel access schemes, collision avoidance is very important to combat the adverse effects of hidden terminals [1]. In general, collision avoidance can be divided into two categories. One is sender-initiated and the other is receiver-initiated. In sender-initiated schemes, the sender of a data packet initiates collision avoidance handshake with a receiver. Usually short control packets such as request-to-send (RTS) and clear-to-send (CTS) are exchanged between a pair of sending and receiving nodes before actual data packet transmission begins. RTS and CTS packets carry information such as duration about the forthcoming data packet, so that other nodes that overhear these control packets can defer their access to the shared channel to avoid collisions. There are quite a

few variants of the basic sender-initiated scheme and they differ in whether packet sensing or carrier sensing is used, the length requirements of control packets or whether acknowledgement packet is sent. Among them, the most popular MAC protocol to date is the IEEE 802.11 distributed foundation wireless medium access control (DFWMAC) protocol [2] which is part of the IEEE recommended standard for wireless LANs. The IEEE 802.11 protocol has been used extensively as the underlying MAC layer in the investigation of routing protocols for ad hoc networks.

The other school of thought is based on the observation that usually collision avoidance is more important at the receiver's side to which relatively long data packet is destined. Besides, the receiver usually has better knowledge of the contention around itself. Talucci and Gerla [3] proposed MACA-BI (Multiple Access with Collision Avoidance - By Invitation) which was the first receiver-initiated MAC scheme. Garcia-Luna-Aceves and Tzamaloukas [4] proposed several RIMA (receiver-initiated multiple access) protocols. The basic receiver-initiated scheme works as follows. A node polls its neighbors to see whether they have packets for itself. If the polled neighbor has data packets for the polling node, it will send data packets to the polling node after some collision-avoidance procedures. Otherwise, the polling node will continue to poll other neighbors. To enhance throughput, RIMA-DP (dual polling) allows both the polled and polling nodes to send data packets. If the polled node has no packet for the polling node, it sends a short control packet back to the polling node to invite it to transmit a data packet to the polled node. The polling node sends a data packet to the polled node after receiving a control packet or a data packet from it. It is shown that, if the polled nodes always have packets for the polling node, RIMA protocols can outperform sender-initiated schemes due to reduced overhead of control packets [5]. Otherwise, the performance may degrade due to wasted transmissions of polling packets that poll inactive nodes with no packets for the polling node. The degradation in performance will be more conspicuous in light to medium traffic load, unless a good traffic predictor is available at the polling node.

Despite the potential benefits of receiver-initiated schemes, they have not received widespread acceptance. One reason for this is their deviation from the general store-and-forward paradigm. Another reason is the absence of an appropriate

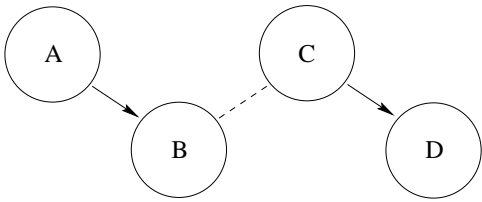


Fig. 1. Illustration of Fairness Problem

polling discipline that is well adapted to the dynamic environments of ad hoc networks. In addition, the widespread adoption of the IEEE 802.11 MAC protocol in the research community of ad hoc networks also leads to performance enhancements that are confined to the sender-initiated framework stipulated by the IEEE 802.11 MAC protocol.

However, the IEEE 802.11 MAC protocol is not failproof. As is already pointed out in the research literature (e.g., [6–9]), serious fairness problem may occur due to location dependent contention which is a salient characteristic of multi-hop ad hoc networks. In such networks, some nodes are at a disadvantage in contending with other nodes due to their locations and may suffer severe degradation in throughput. In addition, despite its robustness against repetitive collisions, the binary exponential backoff (BEB) used in the IEEE 802.11 MAC protocol can aggravate the fairness problem, because the node that succeeds in the last transmission period will gain access to the shared channel again with much higher probability while other nodes suffer starvation. This can be illustrated in Fig. 1. Suppose there are two flows, one from node *A* to node *B* and the other from node *C* to node *D*. It is clear that flow *CD* has the advantage in contending with flow *AB*. This is because, whenever node *C* transmits an RTS, node *D* can always receive it successfully and the handshake can go on unobstructed unless in very rare situations. Node *B*, as a receiver, has better knowledge of the contention around itself but has no way to notify node *A* in the basic sender-initiated scheme. Repetitive failures to solicit a response from node *B* also makes *A* back off for a very long time. However, if the basic sender-initiated scheme is augmented with additional control packets as is done in Reference [10], it will complicate the protocol and may degrade the overall network throughput unnecessarily when the basic scheme suffices.

Hence this motivates us to design an adaptive channel access scheme that makes use of both sender-initiated and receiver-initiated handshakes, because receiver-initiated handshake is more desirable when a receiver has better knowledge of the contention around itself than the sender. The new hybrid scheme should have the following desired properties. The scheme should fit within the IEEE 802.11 framework, in that nodes implementing the new scheme should not break the existing network. The new scheme should still be simple and not introduce new types of control packets, as they complicate implementation of the finite state machine of the protocol.

The rest of the paper is organized as follows. In Section II, the new hybrid scheme is specified. In Section III, simulation experiments with the original IEEE 802.11 MAC protocol and the new hybrid scheme are presented. It is shown that various degrees of fairness problems exist in the original IEEE 802.11

MAC protocol in some network configurations with two competing flows and how the new hybrid scheme can alleviate these problems. Section IV discusses some related work and concludes this paper.

II. THE HYBRID SCHEME SPECIFICATION

The hybrid scheme is built around the framework of the IEEE 802.11 MAC protocol. It operates alternately in two modes, sender-initiated (SI) and receive-initiated (RI). The SI mode is the default mode, which is in effect the same as the original IEEE 802.11. The RI mode is triggered only when the SI mode does not perform well. Because the new scheme is a hybrid of both sender-initiated and receiver-initiated schemes, it calls for some more cooperation between a pair of sending and receiving nodes. To facilitate our exposition, the states of both sending and receiving nodes are shown in Fig. 2 and are explained separately.

A sender enters *RI setup* mode when it sends the same RTS packet for more than one half of the times allowed in IEEE 802.11 without response from the intended receiver. Failure to solicit response from the intended receiver usually implies that contention around the receiver is so severe that the receiver is prevented from responding and it is more appropriate to let the receiver start the collision-avoidance handshake. When the sender is in *RI setup* mode, it sets the RI flag in all the subsequent RTS packets and other packets that it sends out and requests the intended receiver to enter the RI mode as well. During this stage, the node keeps sending RTS packets following the usual collision-avoidance procedures. There are two possible outcomes. One is that it never gets any CTS packet from the intended receiver. In this case, the sender can declare the receiver down after dropping a few packets. The other is that it receives CTS packet from the intended receiver. In this case, the sender enters *RI associated* mode and will not send RTS to the receiver thereafter. Instead, it sets the RI flag in all the data packets that it sends out, which keeps the receiver in RI mode. The RI flag is cleared only when the sender's queue becomes empty.

At the receiver's side, the receiver enters and stays in the RI mode when it receives RTS packets or data packets destined to it with the RI flag set. The receiver then generates RI-response packets (which are in fact self-initiated CTSs) and multiplexes them with other data packets in its MAC queue. However, the receiver should not generate RI-response packets indiscriminately when it receives a packet with the RI flag on, lest serious fairness problem may occur. This can be reasoned as follows. When an RI-response packet becomes the head-of-line (HOL) packet of a receiver's queue, the node will send a self-initiated CTS to the sender, which in fact serves as the ready-to-receive (RTR) packet to poll the sender in the RIMA protocols [4]. If the sender replies with a data packet with the RI flag still on, the receiver will add another RI-response packet to the end of its queue. If there is no packet for other nodes intervened in the MAC queue, the receiver will be *locked into* the sender and keeps sending CTS packets to it. In this way, they may monopolize the shared channel for a long time which obviously defeats the purpose of the hybrid scheme. Hence, when a node receives a packet with the RI flag on, it checks its HOL packet

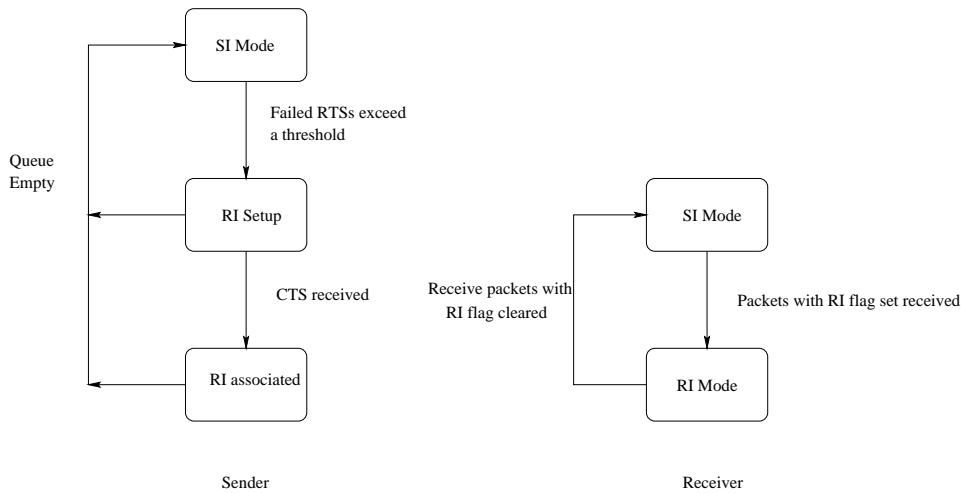


Fig. 2. States of sending and receiving nodes

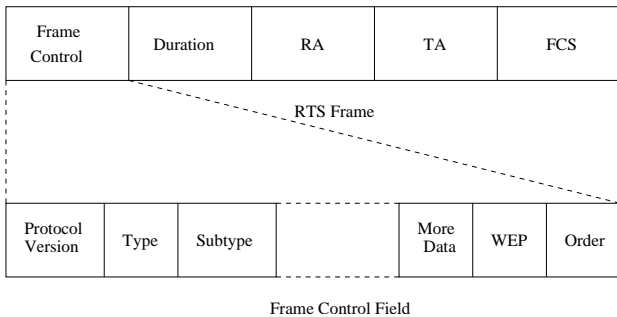


Fig. 3. Illustration of the IEEE 802.11 frame structure

to see whether it is an RI-response packet for the node that just sent this packet. If so, the RI request is ignored; otherwise, it is added to the end of its MAC queue.

The RI-response packets are treated like normal data packets. That is, when they are served via a successful receiver-initiated CTS-data-ACK handshake or when they are transmitted more than the times allowed for RTS packets in IEEE 802.11, they will be dropped from the MAC queue. Such precautions are necessary. One reason is to avoid excessive delay or deadlock when the sending node is down or moves out of range. Another reason is to ensure fairness so that neighboring nodes may initiate handshake with the receiver or other nodes.

A note on implementation is in order. Fig. 3 illustrates the frame structure of the IEEE 802.11 RTS frame (ref. Fig. 13 in Page 35 and Fig. 16 in Page 41 of the IEEE 802.11 standard [2]). As the *More data* bit is not used in ad hoc mode according to the standard, it may be reused as the RI flag to indicate if the RI mode is on or not. Nodes that do not implement the hybrid channel access scheme can safely ignore this bit.

The above specification clearly shows that with some additional queue management and book-keeping work, the existing IEEE 802.11 can be easily extended to support receiver-initiated scheme while maintaining compatibility.

III. SIMULATION RESULTS

In our simulation experiments, we focus on how two competing flows share the available channel resource in simple net-

TABLE I
IEEE 802.11 PROTOCOL CONFIGURATION PARAMETERS

RTS	CTS	data	ACK	DIFS	SIFS
20-byte	14-byte	1460-byte	14-byte	50 μ sec	10 μ sec
contention window		slot time	sync. time	prop. delay	
31–1023		20 μ sec	192 μ sec	1 μ sec	

work configurations. These configurations are shown in Figs. 4 and 5, in which a dashed line means that two nodes can hear each other's transmissions and arrows indicate flows. Nodes without any lines in-between are hidden from each other.

We use GloMoSim 2.0 [11] as the network simulator and implement the new hybrid scheme based on its implementation of IEEE 802.11 MAC protocol for fair comparison. Direct sequence spread spectrum (DSSS) parameters are used throughout the simulations, which are shown in Table I. The raw channel bit rate is 2Mbps. For each flow, one node keeps sending data packets to the other at a constant bit rate, such that the sending queue is always non-empty. UDP is the underlying transport layer, thus no acknowledgement packet is sent back to the initiating node. Simulation results are shown in Tables II and III. In Table II, the performance of the original IEEE 802.11 MAC protocol is shown. It is clear that, for configurations 4-1 and 4-8, some nodes are almost denied access to the shared channel and suffer severe degradation in throughput. For other configurations, it is unnecessary to use the new hybrid scheme. In Table III, the performance of both IEEE 802.11 and the hybrid scheme is shown.¹ It is clear that the fairness problems in configurations 4-1 and 4-8 are alleviated significantly without sacrifice in throughput. The RI mode is triggered unnecessarily only in three other configurations and has almost no negative effect on throughput.

¹When the RI mode is not triggered in some network configurations, the hybrid scheme is the same as the original IEEE 802.11. For simplicity, performance of both schemes in these configurations is not shown here.

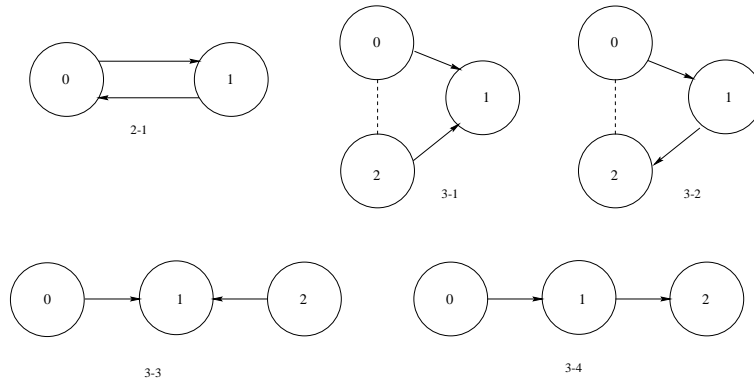


Fig. 4. Networks with 2 or 3 nodes

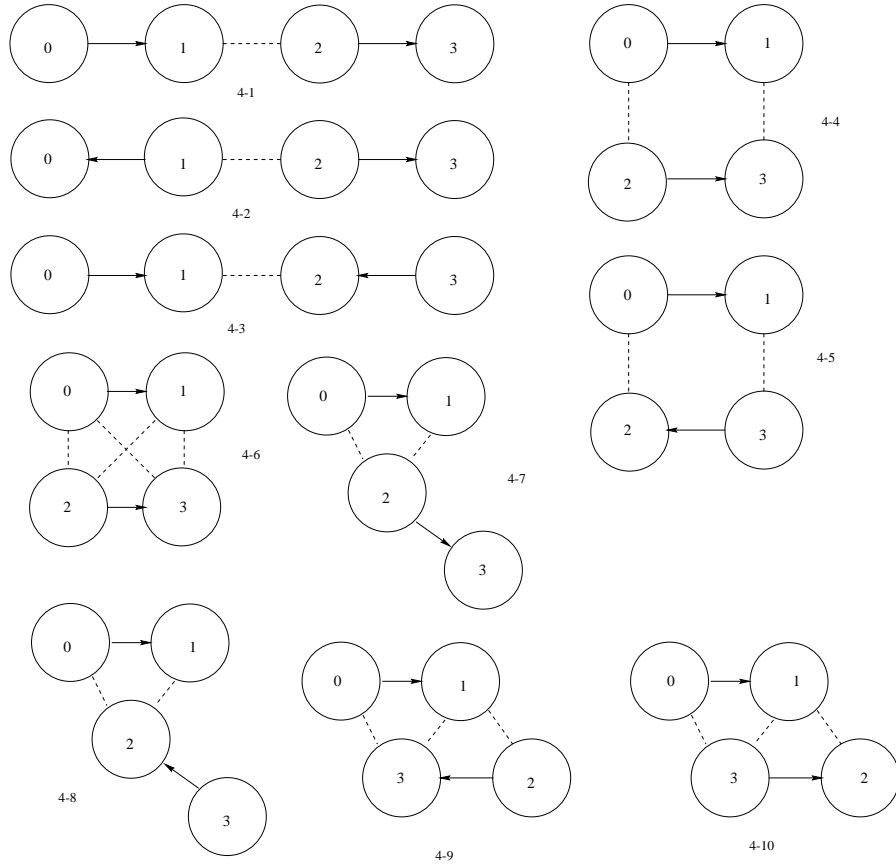


Fig. 5. Networks with 4 nodes

IV. RELATED WORK AND CONCLUSION

The fairness problem in contention-based MAC protocols with binary exponential backoff for multi-hop wireless networks is well known and has been investigated vigorously in recent years. The schemes proposed so far can be roughly divided into two categories. In the first category, the goal is to achieve max-min fairness [6, 12–14]. To be specific, these schemes try to reduce the ratio between maximal throughput and minimal throughput of flows, should it be at either node’s level or link’s level. In the second category, the approach used in fair queueing for wireline networks is adapted to multi-hop ad hoc networks, taking into account the salient characteristics of such networks such as location-dependent contention, distributed coordination

and possible spatial reuse [7–9, 15, 16]. These schemes generally involve some form of tradeoff between throughput and fairness. Nodes that are *leading* in channel access (in terms of throughput) will increase their backoff interval while nodes that are *lagging* will decrease their backoff interval. In this way, nodes are encouraged to compete fairly but at the cost of increased contention which may degrade the overall throughput. In this paper, we have proposed a new hybrid channel-access scheme that includes both sender-initiated and receiver-initiated collision avoidance. This is based on the observation that sometimes receiver-initiated scheme is more appropriate as receivers are more knowledgeable of the contention around them and can compete for the channel more effectively. Our scheme is

TABLE II
FAIRNESS PROBLEMS IN THE ORIGINAL IEEE 802.11 – TWO CBR FLOWS

Config #	Flow #	Throughput (bps)	Flow #	Throughput (bps)	Aggregate (bps)
2-1	0 → 1	8.06e+05	1 → 0	7.99e+05	1.60e+06
3-1	0 → 1	8.06e+05	2 → 1	7.97e+05	1.60e+06
3-2	0 → 1	7.97e+05	1 → 2	8.07e+05	1.60e+06
3-3	0 → 1	7.61e+05	2 → 1	7.83e+05	1.54e+06
3-4	0 → 1	7.69e+05	1 → 2	8.39e+05	1.61e+06
4-1	0 → 1	8.34e+04	2 → 3	1.50e+06	1.58e+06
4-2	1 → 0	8.20e+05	2 → 3	8.14e+05	1.63e+06
4-3	0 → 1	6.88e+05	3 → 2	7.09e+05	1.40e+06
4-4	0 → 1	8.24e+05	2 → 3	8.08e+05	1.63e+06
4-5	0 → 1	8.08e+05	3 → 2	7.95e+05	1.60e+06
4-6	0 → 1	8.07e+05	2 → 3	7.95e+05	1.60e+06
4-7	0 → 1	7.83e+05	2 → 3	8.24e+05	1.61e+06
4-8	0 → 1	1.55e+06	3 → 2	2.81e+04	1.58e+06
4-9	0 → 1	7.34e+05	2 → 3	8.09e+05	1.54e+06
4-10	0 → 1	7.81e+05	3 → 2	8.26e+05	1.61e+06

TABLE III
THROUGHPUT COMPARISON FOR THE IEEE 802.11 AND THE HYBRID SCHEME (WITH RI MODE) – TWO CBR FLOWS

Config #	Scheme	Flow #	Throughput (bps)	Flow #	Throughput (bps)	Aggregate (bps)
3-3	802.11	0 → 1	7.61e+05	2 → 1	7.83e+05	1.54e+06
	+RImode	0 → 1	7.94e+05	2 → 1	7.74e+05	1.61e+06
4-1	802.11	0 → 1	8.34e+04	2 → 3	1.50e+06	1.58e+06
	+RImode	0 → 1	3.69e+05	2 → 3	1.23e+06	1.60e+06
4-3	802.11	0 → 1	6.88e+05	3 → 2	7.09e+05	1.40e+06
	+RImode	0 → 1	6.65e+05	3 → 2	6.43e+05	1.31e+06
4-8	802.11	0 → 1	1.55e+06	3 → 2	2.81e+04	1.58e+06
	+RImode	0 → 1	1.28e+06	3 → 2	3.19e+05	1.60e+06
4-9	802.11	0 → 1	7.34e+05	2 → 3	8.09e+05	1.54e+06
	+RImode	0 → 1	8.15e+05	2 → 3	7.42e+05	1.56e+06

a simple extension to the existing IEEE 802.11 MAC protocol and maintains compatibility with the standard. Through simulation experiments, it is clear that although the proposed hybrid scheme does not solve the fairness problem conclusively, it does alleviate the fairness problem without sacrificing throughput or simplicity. The new scheme may be used together with the aforementioned mechanisms [9, 15, 16] to approximate fair queuing for ad hoc networks, which will be investigated in future work.

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