MAC LAYER BROADCAST SUPPORT IN 802.11 WIRELESS NETWORKS

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ABSTRACT

In this paper, we introduce a simple extension to IEEE 802.11 that supports broadcast in ad hoc networks. Ad hoc random access MAC protocols often treat unicast and broadcast packets differently. Unicast packets are preceded with MAC layer control frames, such as RTS, CTS and ACK, to ensure that the destination receives the unicast packets. Broadcast packets, on the other hand, are sent blindly without any control frames to assure the availability of the destinations. Therefore, the performance of the network degrades as contention increases. Our proposed extension to the broadcast mechanism of 802.11 helps alleviate such degradation when contention exists.

INTRODUCTION

Many random access protocols exist in ad hoc networks that facilitate wireless ad hoc communication. Some of these protocols include Carrier Sense Multiple Access (CSMA) [8], Multiple Access with Collision Avoidance (MACA) [9], MACAW [1], Floor Acquisition Multiple Access (FAMA) [4] and IEEE 802.11 [3]. However, none of these protocols are designed to support the reliable broadcasting of data. For example, 802.11 uses collision avoidance along with RTS/CTS/ACK control frames to transmit unicast packets in order to combat hidden and exposed terminals and high bit error rates. For broadcast packets, no control frames are used. Therefore, broadcast packets are sent blindly without consideration of hidden and exposed terminals and wireless channel noise. Broadcast packets are packets that are meant to be received by all neighbors of the source node.

BROADCAST SUPPORT

We propose a straightforward extension to the IEEE 802.11's protocol that facilitates the transmission of broadcast packets and can therefore be utilized to assist multicast protocols such as ODMRP [10][11] as ad hoc multicast protocols often heavily rely on broadcasting packets to achieve multicast operations.

The following outlines the step of our 802.11 extension to support broadcast packets:

1. Collision avoidance phase.
2. Source sends RTS to all neighbors and sets timer to WAIT_FOR_CTS.
3. Neighbors of source send CTS if not in YIELD state and set timer to WAIT_FOR_DATA.
4. If source receives CTS, send DATA. Else, if no CTS and WAIT_FOR_CTS timer expires, back off and go to step 1. Nodes that are not involved in the broadcast exchange, upon receiving CTS, sets their state to YIELD and set their timer long enough to allow for the broadcast exchange to take place.

Our proposed extension incorporates the collision avoidance and RTS/CTS control frames of 802.11's unicast features to also deliver broadcast packets. When a packet is broadcasted, the source node must first complete the collision avoidance phase [3]. Once the collision avoidance phase is accomplished, the source node broadcasts RTS to its neighbors and sets the WAIT_FOR_CTS timer. Upon receiving the RTS, each neighbor transmits CTS if it is not in YIELD state (due to the reception of remote frames) and sets the WAIT_FOR_DATA timer. If the source node receives CTS before the WAIT_FOR_CTS timer expires, the node transmits DATA. Otherwise, the source node backs off and retransmits at a later time. Any node hearing the CTS that are not neighbors of the source node sets its state to YIELD and yields long enough for the source node to transmit DATA.

The rationale behind the source sending RTS to all of its neighbors and then expecting CTS from any one of the neighbors is a follows: With the traditional CSMA approach, the source simply transmits the data packet and hopes that the packet is correctly received by its neighbors. However, when network contention grows, the probability of a packet being dropped at the neighbors dramatically increases. By sending RTS, the neighbors can respond with CTS and thus force the hidden nodes (nodes that are not neighbors of the sender) to yield long enough for the data exchange to take place between the sender and its

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neighbors. Since hidden nodes will yield even if they themselves have packets to send, the channel contention level decreases and thereby packet drops occur less frequent.

The previous extension assumes the radio has DS (direct sequence) capture ability. That is, if more than one signal overlaps at the radio, the radio will acquire the most powerful of the signals. Our proposed improvement to 802.11's broadcast method also works if the underlying radio does not possess the DS capture feature. It can however detect a busy channel if more than one neighbor is transmitting at the same time. It can also determine when the channel becomes idle again. In this case, the following steps are used:

1. Collision avoidance phase.
2. Source sends RTS to all neighbors and sets timer to WAIT_FOR_CTS.
3. Neighbors of source send CTS if not in YIELD state and set timer to WAIT_FOR_DATA.
4. If source senses the channel busy, send DATA when channel becomes idle again. Else, if channel is idle and WAIT_FOR_CTS timer expires, back off and go to step 1. Nodes that are not involved in the broadcast exchange, upon receiving CTS, sets their state to YIELD and set their timer long enough to allow for the broadcast exchange.

One important point about our extension is that the sender sends the data packet as long is it receives any CTS. The reasoning is that as long as a node is able to receive the data packet, it may not be a bad idea to send it anyway instead of waiting for all the neighbors to be ready. This may be an optimistic assumption. It may turn out that it is more efficient to wait for all neighbors to be able to receive before the sender transmits the data packet. We are currently investigating this alternative.

It is important to emphasize at this point the fact that our proposed scheme "enhances" delivery but does not "guarantee" reliable broadcast/multicast service. Work is in progress on reliable multicast. In the interim, however, the improved 802.11 delivery will already have significant impact on several applications. One example is the delivery of CBR traffic, say voice, videoconferencing, etc. Voice will be transmitted with a high degree of redundancy in a wireless network, especially if it is multicast. Data interleaving and voice packet replication can render voice robust to substantial loss (even above 50%). In this scenario, a scheme such as the one proposed here, which can improve delivery ratio from 20% to 40%, can be of great practical interest in that it reduces the overhead and improve voice quality.

SIMULATION CONFIGURATIONS

We have simulated our broadcast extension of 802.11 using GloMoSim [16]. GloMoSim is a discrete event, parallel simulation environment implemented in PARSEC, PARallel Simulation Environment for Complex Systems [1]. We use the On-Demand Multicast Routing Protocol (ODMRP) [10][11] to multicast packets from different sources to numerous destinations and with varying traffic rates. ODMRP was selected due to the fact that the protocol by nature heavily relies on the broadcast mechanism of the MAC layer to achieve multicast.

The On-Demand Multicast Routing Protocol (ODMRP) creates and maintains a mesh of nodes known as the forwarding group. The forwarding group is responsible for forwarding the multicast packets to the multicast members in the mesh via flooding. ODMRP uses a soft state approach to maintain multicast groups. Thus, members are refreshed periodically instead of sending explicit leave messages to leave the group. Since ODMRP is an on-demand protocol, group membership and multicast routes are established and updated by the source on a need-only basis (on-demand). The protocol consists of two phases: request and reply. During the request phase, the source floods the network with a JOIN DATA packet when the source has data to send. When a node receives the JOIN DATA, it records the upstream node ID and rebroadcasts the packet to its neighbors unless JOIN DATA packet circulation is prevented by source ID check and duplicate detection/discard. Once the JOIN DATA packet reaches a multicast group receiver, the receiver creates a JOIN TABLE packet and broadcasts the packet to its neighbors. This is the reply phase. Upon receiving the JOIN TABLE, a node determines whether or not it is the next node of one of the entries in the JOIN TABLE. If so, the node knows it is on the path to the source and thus assigns itself as a member of the forwarding group. It then builds its own JOIN TABLE and broadcasts to its neighbors. The JOIN TABLE is propagated until it reaches the source. The process of sending the JOIN DATA packet to multicast members and the JOIN TABLE packet to the source forms a mesh of nodes called the forwarding group. The sender refreshes the membership by sending the JOIN DATA packet periodically.

For our simulation experiments, we consider several topologies varying from a 3 x 3 grid to 20 and 25 nodes randomly or uniformly placed in a 1000m by 1000m area. Constant bit rate with various packet transmission rate running on top of UDP is used for the application. We utilize ODMRP to route multicast packets. Radios with capture ability are modeled with a channel bandwidth of

2Mbps. That is, a radio with capture ability has the capability to lock onto a sufficient strong signal in the presence of other interfering, less powerful signals. If the ratio of the arriving packet's signal strength over the sum of all colliding packets is larger than the predefined threshold value, the packet is successfully received while the other colliding packets are dropped. Else, nothing is received. Furthermore, the channel uses free-space with a threshold cutoff and the power of a signal attenuates as $1/d^2$ where d is the distance between two nodes. The simulation results are obtained from multiple simulation runs (each lasting 600 seconds) with varying seed numbers and are averaged out over the multiple runs. Each data packets are 1460B.

The metric we use to determine the effectiveness of our extension is the packet delivery ratio of ODMRP. The packet delivery ratio is the ratio of the number of data packets actually delivered to the destinations over the number of data packets that are supposed to be received. The packet delivery ratio is a common measure of the effectiveness of a multicast protocol [12].

To gauge the effectiveness of our proposed extension to 802.11, we compare the performance of ODMRP when ODMRP is running on top of our extension with that of the typical CSMA broadcast approach.

SIMULATION RESULTS

In this section, we compare our 802.11 extension for broadcast support against CSMA.

Our first set of experiments focuses on a grid topology as shown in Figure 1.

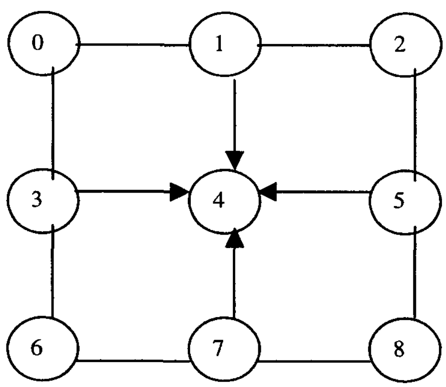

Figure 1. Grid topology with nine nodes, with nodes 1, 3, 5 and 7 transmitting to node 4.

In the grid experiment, nine stationary nodes are placed in a grid topology as shown in Figure 1. Nodes 1, 3, 5 and 7 are transmitting data to node 4 at the same time. Each node can only reach its immediate neighbors. This is a rather unusual multicast pattern, in that the multicast group consists of four senders and just one receiver. However, the grid experiment was orchestrated to evaluate the performance of the two MAC protocols in situations where hidden terminals exist. The simulation results of the experiment are given in Figure 2.

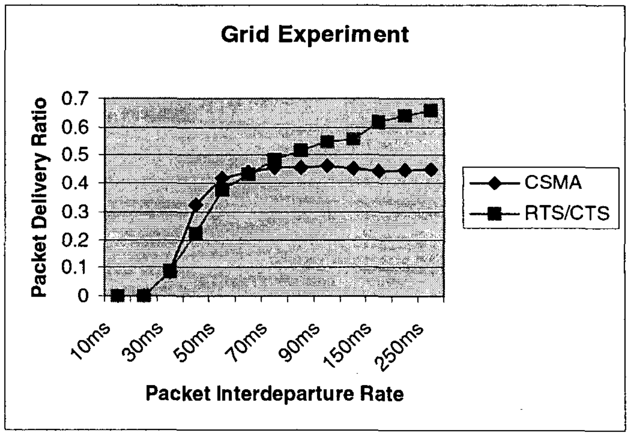

Figure 2. Grid experiment.

Here, we observe that at high rates, both protocols collapse. With a packet size of 1460B and channel bandwidth of 2Mbps, the transmission delay of each data packet is 5.84ms. At a packet interdeparture rate of 10ms and with four nodes transmitting to node 4 all at once, the channel contention becomes so high that hardly any packets get through to node 4. Keep in mind that ODMRP requires a request and a reply procedure to be completed before the forwarding group is set up. Due to the extremely high contention, the success rate of forming the mesh is low and as a result the packet delivery ratio suffers significantly. However, as the packet interdeparture time increases, our extension to 802.11 using RTS/CTS control frames for broadcasting packets outperforms the CSMA broadcast approach. In fact, the packet delivery ratio of our extension asymptotically converges to 70 percent while CSMA tops at 45 percent. At lower traffic rates, the RTS/CTS mechanism of our extension is given time to combat loss. Nodes that transmit RTS control frames but did not receive a CTS back are given ample time to back off and retransmit at a later time where contention is less and before the next scheduled data packet is to be transmitted. With the traditional CSMA broadcast approach, recovery is not possible once a packet is dropped. Therefore, the performance degrades.

Since traffic rate has a major impact in the grid experiment where hidden terminals exist, we further investigate the effect of traffic rate under a more random topology. To this end, we generate 20 nodes that are uniformly placed in a 1000m x 1000m area, each with a radio power range of 250m. There are five senders and five receivers in the multicast group. Again, the packet transmission interval varies from 10ms to 250ms. Figure 3 depicts the result.

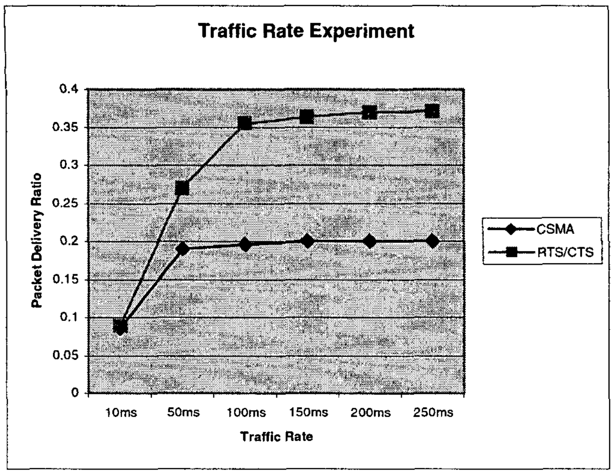

Figure 3. Traffic rate experiment.

In Figure 3, the behavior of CSMA and our RTS/CTS extension is somewhat similar to that of the grid experiment. With CSMA, the packet delivery ratio levels out to at about 20 percent while our proposed scheme reaches 37 percent. The difference between the results obtained from the grid experiment and that of this experiment is due to the fact that in the grid experiment, the sender is only one hop away from the receiver. In the traffic rate experiment, the senders are randomly placed in a 1000m x 1000m area and thus are more likely to be 2 to 4 hops away from the receivers. In this scenario, flow and congestion control is critical. UDP does not carry out flow control. Our extension is able to almost double the packet delivery ratio of CSMA in part because the RTS/CTS mechanism acts as a rudimentary flow control scheme; if no CTS is received after transmitting RTS, the sender backs offs and retransmits at a later time.

We also investigate the effect of the number of multicast senders on performance. In this experiment, 25 nodes are randomly placed in a 1000m by 1000m area, each with a radio power range of 250m. There are five multicast receivers and the number of multicast senders ranges from 1 to 20. The interdeparture time of the packets is 200ms (5 packets per second). All nodes are stationary throughout the experiment. Figure 4 shows the result as we vary the number of multicast senders in ODMRP.

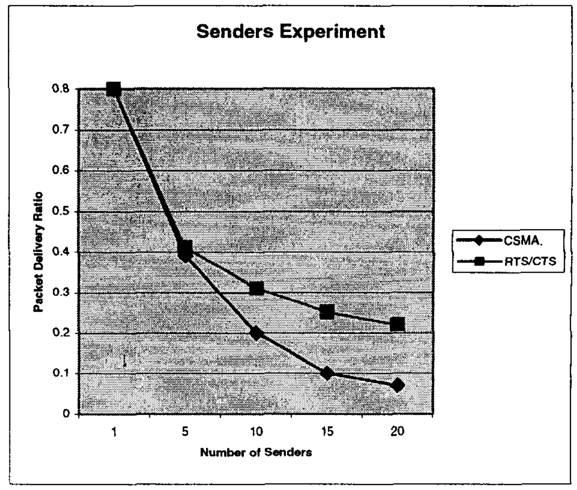

Figure 4. Senders experiment.

We note from Figure 4 that with a single sender, the packet delivery ratio is high (80 percent). With a single sender, channel contention is rare and therefore we would expect a high packet delivery ratio no matter what MAC protocol we use to broadcast packets. As the number of senders increases, we observe dramatic performance degradation as expected. Still, the RTS/CTS extension improves upon the CSMA broadcast. Our approach has an asymptotic packet delivery ratio of 20 percent as the number of sender increases compared to that of the typical CSMA broadcasting practice, which is only 5 percent.

CONCLUSION

In this paper, we presented a straightforward extension to IEEE 802.11's broadcast mechanism and showed that our extension improves the network performance compared to that of the conventional CSMA broadcast approach. Our approach is favorable to the CSMA method as the number of multicast senders increase. Also, our extension functions best when packet transmission rate is low to medium. When the transmission rate is high, the RTS/CTS control frames merely contribute to network congestion. We must stress the point that the proposed scheme "improves" multicast delivery, but does not "guarantee" delivery. More research is required in the direction of reliable multicast, i.e., the assurance that all multicast neighbors have received the packet. In a unicast environment, this is accomplished through ACKs sent back by the destination. In multicast, this will lead to ACK implosion. Moreover, in wired networks (e.g. the Internet) the reliable multicast problem is typically solved at the transport and/or application level. That approach is justified by the fact that link loss is negligible in wired networks, and the major cause of loss in congestion (which is prevented with separate mechanisms). In the wireless case, link loss due to interference is the major problem. Thus, it is necessary to act at the MAC and link layer first in order to achieve measurable efficiency. The transport and application layer recovery mechanisms will also be invoked, after the lower layer has been made reasonably reliable.

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