A LEADER BASED PRIORITY RING RELIABLE MULTICAST IN WLANs

Ping Ding, JoAnne Holliday, Aslihan Celik
Santa Clara University
Santa Clara, CA 95053, USA
{pding,jholliday,acelik}@scu.edu

Abstract:

Reliable multicast is difficult to achieve in CSMA/CA networks when multiple multicast and unicast senders compete for the medium. We propose a leader based priority ring multicast protocol (LPRMP) to increase reliability in wireless LANs. The algorithm is specifically tailored to accommodate a large number of legacy stations in multiple overlapping cells since the LPRMP solution only requires extensions in the Access Point (AP). An AP implementing LPRMP will be scheduled to send multicast packets after waiting a unique multicast collision detection interval (MCDI), and sending a RTS to reserve the channel. We reduce the occurrence of collisions among multicast packets and unicast packets. A simulation verifies that our protocol improves the performance of multicast communication in WLANs.

Keywords: *Reliable Multicast, 802.11, WLANs*

1. Introduction

Reliable multicast is difficult to achieve in CSMA/CA networks when multicast and unicast senders compete for the medium. Mechanisms are already in place to ensure reliability in unicasting: when a unicast packet is successfully transmitted, it is acknowledged by the receiver. In this way, unicast packet loss can be detected and the packet is retransmitted. On the other hand, the 802.11 standard [1] does not define any method for detecting the loss of multicast packets and they are never retransmitted. This is a major problem that hinders the application of reliable multicasting in wireless networks. Adding reliability through acknowledgements is problematic and leads to the ACK implosion problem.

Multicast packet loss is due to a number of reasons. First, any multicast packet must be transmitted by each access point (AP) in an Extended Service Set (ESS, which is a set of one or more interconnected BSSs) leading to a high risk of collisions. Secondly, in a Basic Service Set (*BSS*) (i.e., and Access Point and wireless stations associated with it), stations are explicitly forbidden to eavesdrop on APs with which they are not associated thus making it less efficient to use channel reservation techniques. Thus, when a unicast sender sends a unicast packet, there is a chance that the packet will collide with a multicast packet sent by an AP, leading to the irrecoverable loss of the multicast packet.

In this paper, we propose the Leader Based Priority Ring Multicast (LPRMP) protocol to address the multicast packet collision problem. In LPRMP, every AP waits in a unique multicast collision detection interval (MCDI). The AP performs clear channel assessment (CCA) before the MCDI is over. LPRMP conserves the bandwidth by using channel reservation rather than acknowledgements. If the channel is sensed busy, then the AP waits in a back-off window and tries to retransmit next time. If the channel is sensed idle, then the AP sends an RTS to reserve the channel. Finally, the AP sends the multicast packet. In this way, collisions among multicast packets and unicast packets will be avoided. Our protocol works for dynamic overlapping cells, large number of stations, and does not require changes in end-user equipment. In addition, no changes are made to management or control frames. LPRMP avoids collisions within the same BSS and reduces the multicast packet loss due to hidden stations.

To evaluate our protocol, we compare the throughput and the average delay time of 802.11 with LPRMP using ns-2 simulator. From the results, we verify that LPRMP improves the performance of WLANs that use multicasting. This paper is organized as follows: we review the literature in Section 2, and describe the problem in more detail in Section 3. We then propose LPRMP in section 4. In Section 5, we evaluate LPRMP, and conclude in Section 6.

2. Related Work

Several solutions have been proposed to either prevent multicast packet loss or detect loss and perform a repair action, such as retransmission. Related works fall into two basic categories: acknowledgement-based detection with retransmission, and channel reservation. Sobrinho et al [2] proposed a blackburst algorithm to avoid collisions in multicast. The length of the blackburst is determined by the station's waiting time. The station with the longest blackburst will gain access to the channel. Bharghavan [3] proposed a token-based solution for multicast in multi-access WLANs, where the AP distributes the tokens to potential senders in the WLAN and collects the tokens when it needs to transmit a multicast packet. These solutions belong to the channel reservation category. Tourrihes [4] proposed a robust broadcast using a collision detector to inform the AP whether the broadcast packet is successful or not. Kuri [5] proposed a leader based reliable multicast solution, where the leader takes the responsibility of informing the AP. These solutions belong to acknowledgement-based plus retransmission. They expect CTS from the multicast receivers to answer the RTS from the multicast sender. All of these previous protocols are intended for use in a BSS and will have problems in an ESS (Extended Service Set). Nilsson [6] proposed an early multicast collision detection solution, which sends an early multicast collision detection packet and works in an ideal ESS with no hidden stations. However, it may fail when two APs get the same length detection packets and it will cause overhead and additional traffic in the network.

3. Background

We focus on multicasting in DCF (Distributed Coordination Function) in this paper. Basic DCF uses CSMA/CA. In this section, we review the DCF protocol as specified by the 802.11 standard, and discuss why the protocol may lead to multicast packet loss.

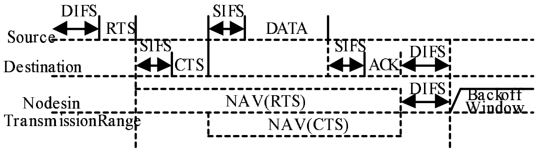

Figure 1: DCF Protocol

3.1. MAC layer DCF protocol

The DCF protocol in 802.11 is illustrated in Figure 1. When a sender wants to access the medium, it needs to sense the channel for a given DIFS time. If the channel is busy in DIFS time, then it has to wait another time interval given by the back-off window and try to sense the channel again. If the channel is idle in the DIFS time, then the sender sends an RTS control frame. After the sender receives the CTS from the receiver, it waits SIFS time, and then sends the data packet. If the sender receives an ACK from the receiver after sending the data packet, the transmission is considered successful.

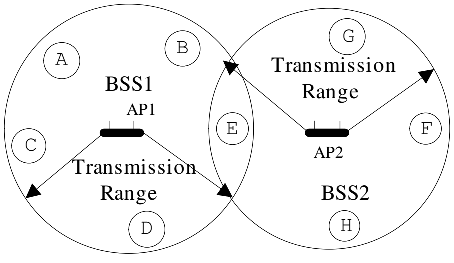

Figure 2: Transmission Range

Each station in IEEE 802.11 maintains a NAV (Network Allocation Vector) that indicates the remaining time of the on-going transmission sessions. Using the duration information in RTS and CTS, stations update their NAVs whenever they receive an RTS or a CTS. Figure 1 shows stations using RTS and CTS information to adjust their NAVs.

3. 2 Multicast packet loss and hidden stations

When a station wants to send a multicast packet, it sends the packet to the AP that it is associated with. Since this transmission is done via unicasting, the packet will not be lost at this step (RTS/CTS and ACK guarantees reliable transmission here). Multicast packet loss may occur at the next step, when the AP sends the packet to the stations associated with it, and to the other APs for distribution to their associated stations. Due to overlapping cells, when more then one AP or station sends packets simultaneously, there are two cases for multicast packet loss: 1) collisions between a multicast sender and a unicast sender, and 2) collisions between two multicast senders.

Colliding packets may originate from stations that are “hidden” from the multicast sender. We use the term *transmission range* [7], which covers the area that a station can receive and correctly decode packets from a given AP. Figure 2 shows an ESS that is composed of two BSSs. BSS1 includes AP1 and stations A, B, C, and D. BSS2 includes AP2 and stations E, F, G, and H. The stations in each BSS are associated with their corresponding APs, and even if they detect other APs’ signals, they are forbidden to decode the information.

In Figure 2, all these stations (including AP1 and AP2) share the same channel. In BSS2, even if station E is inside the transmission range of AP1, it may or may not sense any transmissions from the stations associated with AP1. Since it is inside the transmission range of AP1, it can detect the transmission from AP1 itself. Stations F, G, and H can not sense any transmission from any stations associated with AP1, including AP1. Therefore, E, F, G, and H are *hidden stations* to the stations associated with AP1. F, G, and H are *hidden stations* to AP1, but not including E. Similarly, A, B, C, and D are hidden stations to the stations associated with AP2, including AP2. The hidden station problem can occur as follows: AP1 begins to send a multicast packet to stations A, B, C, and D at the same time that station E unicasts a packet to AP2. The two packets collide and the multicast packet is lost.

When a multicast packet collides with a unicast packet, the collision occurs between the RTS of the unicast packet and the multicast packet. Since there is no RTS or CTS preceding the multicast packet. The loss of the multicast packet is not detected and the AP assumes it was received, so the packet is lost. When two multicast packets collide, the losses are not detected, so both multicast packets are lost. The unrecoverable loss of multicast packets is the motivation for this paper. A more detailed analysis of the conditions is available in [8]. To simplify, we assume that a collision is the only reason for packet loss.

4. Leader Based Priority Ring Multicast Protocol

In this section, we propose the *Leader Based Priority Ring Multicast Protocol* (LPRMP) that increases multicast reliability of 802.11. In LPRMP, an AP is chosen to be the leader. To send a multicast packet, a sender first detects an idle channel using the Sense Channel Operation (SCO). The sender must then send an RTS to reserve the channel. Then, it waits a time interval MCDI (*Multicast Collision Detection Interval*) in addition to DIFS before transmitting. The function of the leader AP is to assign each station its MCDI. Multicast transmitters on the same channel avoid collisions by waiting a unique MCDI.

4.1 Protocol Elements: MCDI and Leader

Multicast Collision Detection Interval (MCDI) is a number ranging from N1 to N2, where N1 is 20µs and N2 is 310µs. The interval between two consecutive numbers is 10µs, which is long enough to signal the MAC layer the state of the channel (busy detect time, which is less than or equal to 4µs) [1]. N2 is chosen to allow for 30 APs sharing a channel. If more APs might share a single channel, N2 could be made larger, however, this will increase the overhead slightly. The sense channel operation (SCO) is used to perform a clear channel assessment (CCA), which lasts 15µs.

When an AP joins an ESS, it needs to randomly generate a number ranging from 20µs to 310µs to be its temporary MCDI. The AP announces its temporary MCDI and looks for the leader with a broadcast packet using LPRMP. The broadcast packet needs to be sent twice by the AP to increase the probability of a successful transmission. The maximum probability that two APs generate the same MCDI and send them twice simultaneously is $(1-\prod_{k=1}^{n}(\frac{n-k}{n}))(1-\frac{32\times 31}{32^2})$, where k is the number of APs and n is the number of MCDI from N1 to N2. This probability is very small, and can be ignored. If there is no response after two transmissions, the new AP considers itself to be the leader of the ESS and assigns the highest priority MCDI to itself. Otherwise, it will receive a response from the leader.

When the current leader hears the looking-for-leader message, it responds to the new AP by assigning it a new MCDI, which will be used for sending multicast packets. The leader assigns unique MCDIs to APs based on the order that they join the ESS. The newly arriving AP always gets the next largest MCDI in the ESS for its MCDI. An AP has high priority if it has a small MCDI; An AP has low priority if it has a large MCDI. A ring is formed from the smallest MCDI to the largest MCDI in the ESS. The leader records all the MCDI information for APs in its MCDI table. The leader will re-distribute the MCDIs after a pre-set adjustment interval, which is used to keep the ring fair. If the leader knows it will be leaving the ESS, it assigns the job of leader to the highest priority AP (except itself) and sends its MCDI table to the new leader.

A leader needs to be selected from among the APs in an ESS. This can be done using one of the well-known leader election algorithms, such as the Bully algorithm, or using the following method. The first AP to join the ESS will send a looking-for-leader message and find none, so it declares itself the leader. If two APs join at the same time, whoever announces it first, becomes the leader. For example, when two new APs (for example, AP1 and AP2) join the ESS, they might generate the same MCDI. If AP2 receives a broadcast packet from AP1 looking for the leader before AP2 gets a chance to broadcast, then AP2 regenerates a larger MCDI than the one it currently has and looks for the leader again. Either AP1 will be answered by the leader or, if there is no leader, AP1 will become the leader. Once an AP is chosen to be leader, its job is to assign MCDI's to APs in the ESS and ensure fairness.

4.2 How the LPRMP works

To transmit multicast packets, the AP sends an RTS following the DIFS interval instead of sending the data packet. The stations and other APs that hear the RTS will identify it as a multicast channel reservation via the multicast address and packet length included in it. Then, the AP waits for its MCDI. The SCO starts in the last 15µs of the MCDI since the duration of SCO is 15µs. If the channel is idle during the SCO, then the AP sends the multicast packet after sending another RTS to reserve the channel. Otherwise, if the channel is busy in the SCO, the AP waits and tries to transmit next time. When the APs waiting in their MCDI, hear RTS from stations or other APs, they wait in a back-off window and try next time.

The leader is responsible for distributing the MCDI intervals to ensure fairness since a short MCDI gives an AP a high priority. An AP will not change its MCDI until it receives a new MCDI. Every 10 minutes, which is called the adjustment time, the leader will re-distribute the MCDI intervals. The leader sends unicast packets to every AP to assign their new MCDI. If some AP has left in the last 10 minutes, the leader will re-arrange the MCDI ring during the adjustment time. The AP with MCDI right behind the missing one will take its place. In this way, the leader guarantees that the smaller MCDIs are used before a larger one is assigned.

We have previously proposed a non-leader based priority ring protocol [8] to achieve reliability. However, there are benefits to having a leader, such as: the leader can ensure that the smallest MCDIs are used; no problem of two APs picking the same MCDI; the leader can also keep records of AP activity in the ESS.

4.3 Avoiding collisions

In this section, we identify two cases where a multicast packet collides with other packets, and explain how LPRMP avoids collision altogether or reduces its occurrence.

1)Collision between a unicast and a multicast packet

In this case, the multicast packet is sent by an AP, and the unicast packet is sent by either a station or an AP. The unicast sender may or may not be a hidden station to the multicast sender. We evaluate each case individually.

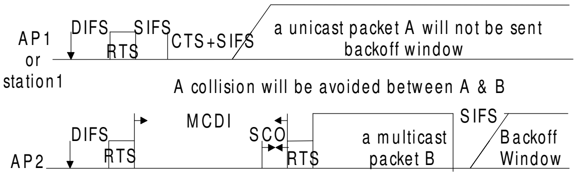

Figure 3 Collision avoidance (1)

●Unicast sender is not a hidden station

Figure 3 illustrates how the collision between a unicast packet and multicast packet is avoided using LPRMP. AP2 wants to send a multicast packet. It sends an RTS and then waits for MCDI. The RTS is used by other stations to infer the duration of the multicast packet, which is *2* RTS+MCDI+length of the multicast packet*. It is also necessary because: 1) the MCDI duration of the AP causes a delay, and the RTS is used to give priority to the multicast sender over the unicast sender; and 2) AP1 or station1 could be a hidden station to AP2, thus SCO of AP2 may not detect the transmission of the hidden station. If either condition happens, because of the collision of RTS between the two senders, the unicast sender (hidden station or not) does not receive CTS from its receiver, so it waits in its back-off window. However, AP2 waits for MCDI, senses the channel in its SCO, and sends the multicast packet after sending a second RTS.

The SCO lasts 15μs. This is because the duration of the SIFS is 10μs. It is possible that the SCO starts at the same time the SIFS starts. So, the time of SCO should be longer to avoid matching the duration of the SIFS. Plus, CCA is defined to be 15μs in [1]. If the SCO detects an idle channel, then the only possible simultaneous transmission is a unicast packet. This is because each multicast sender has unique MCDI. Since the MCDI is longer than or equal to the DIFS, only a unicast packet could be sent simultaneously.

The second RTS is also used by other stations to infer the duration of the multicast packet, which is *RTS+length of the multicast packet*. It is also used by AP2 to prevent any additional unicast senders, hidden or not, from starting an RTS after DIFS interval exactly at the same time AP2 starts to send the second RTS. The only possible collision will be between the RTS from the unicast sender and the RTS from the multicast sender. If a collision does occur, the multicast packet will still be transmitted, but no other packet will be transmitted to collide with it. If collision does not occur, either the multicast RTS was sent first and the unicast sender hears the RTS from the multicast sender; or the unicast RTS was sent first and the channel is sensed busy by the multicast sender, so the multicast sender waits in a back-off window. An example is given in [8].

In Figure 3, during the MCDI interval of AP2, no new unicasts are transmitted. After AP2 senses the channel in SCO, it sends the second RTS. Finally, it transmits the multicast packet. The unicast sender, AP1 or station1, waits in a back-off window after it does not receive a CTS from the receiver. This is because the RTS from AP1 collides with the RTS from AP2. Therefore, the intended receiver of AP1 will not receive the RTS and will not respond with a CTS.

●Unicast sender is a hidden station

In this case, the unicast sender is a hidden station to the multicast sender. Even if the hidden station to the multicast sender transmits a unicast packet simultaneously with the multicast sender, the RTS from the hidden station will collide with the first RTS of the multicast sender. LPRMP still works in this case. The multicast sender does not need to detect the collision between its RTS and any other packets. The hidden unicast sender will infer the collision by the loss of the CTS, and will not transmit. This is the advantage of LPRMP over other reliable multicast protocols. However, if another hidden station starts transmission during the MCDI interval, since the SCO of the multicast sender can not detect it, a collision will occur between the multicast packet and the unicast packet.

2) Collision between two multicast packets

Now we consider two APs, each sending a multicast packet. The APs could be hidden stations to each other or not. We will discuss both cases as follows:

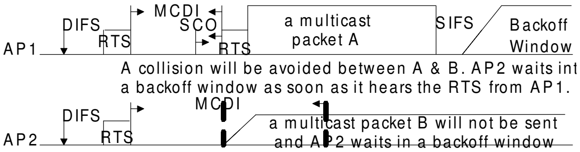

Figure 4 Collision avoidance (2)

●Multicast senders are not hidden to each other

As shown in Figure 4, the collision between multicast packets A and B will be avoided using LPRMP. Before AP1 and AP2 send their multicast packets, both of them wait in their MCDI after sending the first RTS. Because of the smaller MCDI, AP1 transmits packet A after sensing the channel in SCO and sending the second RTS. As for AP2, it waits in a back-off window after sensing busy channel in its SCO. AP2 will not send the second RTS unless it detects an idle channel. Even if the MCDI of AP1 is longer than DIFS, and a new AP senses the channel idle for DIFS, then transmits RTS during MCDI of AP1, a collision still will not occur. The final transmitter is determined by whose SCO starts first.

●Both stations are hidden to each other

If the two senders are hidden stations to each other, a collision between the two multicast packets occurs. This is because their SCO will not work correctly. However, since the senders have different MCDI, they will transmit the multicast packets at different time, so, the possibility of a collision is reduced.

4.4 Summary

In this section, we proposed LPRMP to solve collisions caused by simultaneously sending in an ESS with or without hidden stations. We do not use the RTS/CTS handshake for multicast because it is difficult to choose a station to answer with a CTS from the large number of multicast receivers in different BSSs with variable reception conditions. However, we use RTS to inform others of the transmission of multicast packets since the RTS contains the multicast address and the length of the multicast packet. Also, we schedule the multicast sender's transmission time to avoid collisions, so, no multicast packets have to be retransmitted. LPRMP is robust in that, and it works in some situations even when hidden stations exist. The overhead caused by MCDI and RTS is very small compared with a collision packet and a retransmitted packet length. Furthermore, we do not need to add additional control frames to implement LPRMP on APs.

5. Evaluation of LPRMP

To evaluate our protocol, we simulate LPRMP and 802.11 using ns-2 with the CMU wireless extensions [9]. We compare the performance of an ESS using the proposed LPRMP and 802.11 with two metrics: 1) Throughput (the number of packets that can successfully pass through in a fixed time); 2) Average delay time (the interval from the time a user requests a service to the time the service is granted).

Each simulation is run for 100 seconds in an ESS with 5 APs. The first simulation is run for 3 stations in each AP. We increased that number to 5, 7, 9, and 11 stations for subsequent runs. Therefore, a total of 20, 30, 40, 50, and 60 stations (including APs) contend for the same channel. There are no hidden stations. We use CBR applications as traffic generators. All the simulations set the data packet rate to be 2Mbps and the packet size is fixed to be 512 bytes. All the stations in the ESS belong to the multicast group.

In Figure 5, 30% network load is broadcast traffic. The x-axis is the number of stations that contend in the same channel and the y-axis is the throughput. The throughput of 802.11 reduces with more stations contending in the channel (thus causing more collisions). However, the throughput of LPRMP increases with more stations contending. This is because broadcast traffic is being correctly received.

To demonstrate that LPRMP will not increase the average delay, we measured the average delay time of both protocols. As shown in Figure 6, the delay of 802.11 increases whereas that of LPRMP decreases with more stations contending for the channel. Therefore, the additional delay caused by MCDI of each AP is much less than the additional delay caused by retransmission of the unicast packets.

In Figure 7, 50% of the network load is broadcast traffic. The throughput of 802.11 decreases slowly when more stations contend for the channel because of increased collisions. However, the throughput of LPRMP increases when more stations contend for the channel as the increased traffic is being handled successfully. In Figure 8, the average delay time of 802.11 increases with more stations contending for the channel. However, the average delay time of LPRMP reduces with the contention. Therefore, the additional delay caused by MCDI of the stations has little effect on the average delay time, compared to the delay due to the retransmission of the unicast packets.

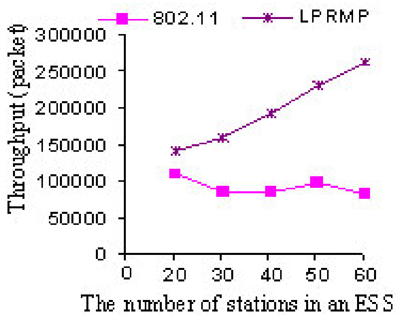

Figure 5 Throughput (30% broadcast)

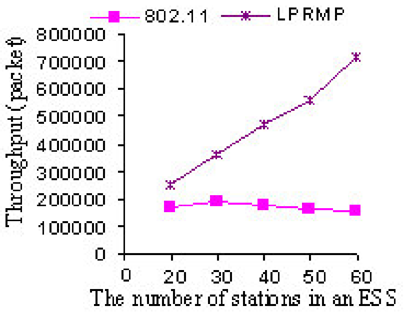

Figure 7 Throughput (50% broadcast)

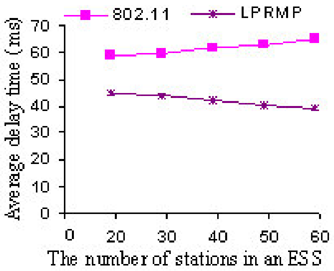

Figure 6 Average Delay Time (30% broadcast)

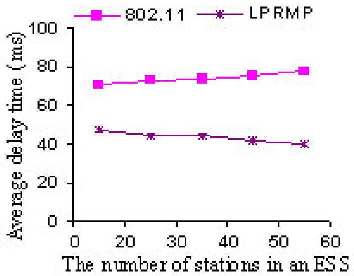

Figure 8 Average Delay Time (50% broadcast)

Comparing all figures, the gap between the throughput of LPRMP and 802.11 increases and the difference between the average delay time of LPRMP and 802.11 becomes bigger. Thus, the advantages of LPRMP become more apparent when the network has more multicast traffic. When there is no multicast traffic, LPRMP has no effect as the MCDI is only used when the AP multicasts. When there is multicast traffic, the unicast traffic actually benefits from the packet collision avoidance.

In this section, we showed that LPRMP improves the throughput and reduces the average delay time of a WLAN. We also showed the effect of MCDI of stations to the average delay time is much less than the effect of unicast packet retransmission to the average delay time.

6. Conclusion

This paper addresses the collision of multicast and unicast packets, thus the disruption of multicasts in a WLAN. This problem exists because the 802.11 standard does not require a channel reservation or an acknowledgement for sending a multicast packet. Furthermore, the packet collision problem is aggravated when there are hidden stations.

To avoid collisions and increase the reliability of the multicast, we (1) proposed a leader based priority ring multicast protocol (LPRMP), and (2) compared the throughput and the average delay time of the WLAN using 802.11 and LPRMP when both unicast and multicast exist.

LPRMP is designed for a large number of stations in multiple overlapping cells in an ESS. Changes are not required to the stations to implement LPRMP; only the Access Points are affected and only for multicast traffic. In addition, no new control frames are introduced. LPRMP protocols improves the reliability of multicast in a WLAN. In the future, we will test our protocol with a prototype.

References:

[1] IEEE standard for Wireless LAN Medium Access Control(MAC) and Physical Layer (PHY) specification, ISO/IEC 8802-11:1999(E), Aug, 1999.

[2] JL Sobrinho, AS Krishnakumar. "Real-time traffic over the IEEE 802.11 medium access control layer", *Bell Labs Technical Journal* 1996,172-87.

[3] V.Bharghavan, "A new Protocol for Medium Access in Wireless Networks," *Internal Technical Report*, University of Illinois, Urbana Champain, 1998.

[4] J.Tourrilhes "Robust broadcast: improving the reliability of broadcast transmission on CSMA/CA", in *Proceedings of the Ninth IEEE International Symposium on. Personal, Indoor and Mobile Radio Communications*, 1998.

[5] J Kuri, SK Kasera. "Reliable multicast in multi-access wireless LANs", in *Proceedings of INFOCOM '99*

[6] T.Nilsson, G.Wikstrand, J.Eriksson, "Early Multicast Collision detection in CSMA/CA Networks" *The Fourth IEEE Conference on Mobile and Wireless Communications Networks* (MWCN 2002)

[7] Eun-Sun Jung, Nitin H.Vaidya, "A Power Control MAC Protocol for Ad Hoc Networks", The Ninth Annual International Conference on Mobile Computing and Networking (MobiCom 2002).

[8] P.Ding, J.Holliday, "Reliable Multicast In Wireless LANs", *Technical Report*, Computer Engineering Dept., Santa Clara University, http://www.cse.scu.edu/send.cgi?research/techreports/index.htm

[9] The CMU Monarch Project, "The CMU monarch project's wireless and mobility extensions to NS," http://www.monarch.cs.cmu.edu/cmu-ns.html