A Highly Reliable Broadcast Scheme for IEEE 802.11 Multi-hop Ad Hoc Networks

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***Abstract*—In wired networks, the broadcast data packets can be easily and safely delivered to destinations. Nevertheless, it is a big challenge to transfer the broadcast frames over the IEEE 802.11 based multi-hop *ad hoc* wireless networks due to the high bit error rate, the high collision probability, and the lake of acknowledgement (ACK). Unfortunately, most of routing protocols need the broadcast function to exchange important information between nodes. From our observations, the efficiency of the routing protocol, such as DSR and AODV, finding the path from source to destination is strongly depending on the supported broadcast scheme in the underlying media access control (MAC) protocol. In this paper, we will first investigate the uncertain broadcast problem in the IEEE 802.11 MAC protocol while delivering the necessary broadcast frames. Since no acknowledgement will be sent by any recipient of the broadcast frame in IEEE 802.11 MAC protocol, we will propose a highly reliable broadcast scheme to solve such uncertain problem. The proposed scheme, which is still compatible with standard, can efficiently minimize bandwidth consumption as well as propagation delay.**

***Index Terms*— ad hoc, broadcast, multicast, MAC, RTS/CTS, WLANs, MANET.**

I. INTRODUCTION

Ad hoc wireless networks are constructed by several mobile handsets or laptops and characterized by multi-hop wireless connectivity, constantly changing network topology and the need for efficient dynamic routing protocols. There is no stationary infrastructure or base station to coordinate packets transmissions and advertise the information of network topology. According to these characteristics, each mobile node in the multi-hop ad hoc networks must act as routers, relaying data packets to their neighboring mobile nodes. Since network resource is limited, any transmission will interfere the neighbors which also have packets to transmit in the same radio channel. In order to route packets to all members in the network, one of the main actions of a mobile node is the dissemination of control messages to all other nodes that share the same physical channel. This procedure is known as *intra-team broadcasting* and is discussed in [8]. The existence of a reliable and resource-efficient broadcast protocol in a multi-hop ad hoc wireless network is indispensable due to the increased amount of circulating control information.

Wireless applications are becoming popular for high-speed communications in some areas, where wiring for conventional networking is difficult or not economic. The IEEE 802.11 standard provides detailed medium access control (MAC) and physical (PHY) layer specifications [5] for wireless local area networks (WLANs). A mobile ad hoc networks (MANET) working group [9] has been formed within the Internet Engineering Task Force (IETF) to develop a routing framework for IP-based protocol in ad hoc networks.

In conventional networks, there are many kinds of data needed to be transmitted by using broadcast method, e.g., address resolution protocol (ARP), routing information exchange, and advisement messages, etc. Any network node needs ARP to retrieve the MAC address information of other network node with a particular IP address or vice versa. The ARP packets are broadcasted to achieve this goal. Lack of this scheme, nodes may fail to reach the others due to insufficient network information. Besides, there are many routing protocols using broadcast approach to perform their routing procedure. For example, the dynamic source routing (DSR) protocol [6] and ad-hoc on-demand distance vector (AODV) protocol [10], [11] are two famous routing protocols for multi-hop ad hoc wireless networks. Both of them are on-demand routing protocols and are basing on the concept of source routing. To perform the route discovery, the source mobile node broadcasts a route request (RREQ) packet that is flooded through the network in a controlled manner and is answered by a unicast route reply (RREP) packet from either the destination mobile node or another mobile node that knows a route to the destination. Obviously, the correctness of the DSR and AODV protocols are relying on the efficiency of the broadcast scheme in the MAC protocol.

In IEEE 802.11 MAC protocol, regardless of the length of the broadcast frame, no request-to-send (RTS) and clear-to-send (CTS) exchange shall be used. In addition, no acknowledgement (ACK) shall be transmitted by any recipients of the broadcast frame. Therefore, source node has no idea about the status of the transmitted broadcast frame. In DSR and AODV protocols, the request will be blocked if its source node has not received a valid route within *route discovery timeout*. Once the route discovery timeout is up, it is very hard to tell the timeout is caused by no path exists or resulted from losing RREQ broadcast frame. Consequently, the *reactive* nature of on-demand routing protocols can not obtain any benefit from saving bandwidth than traditional proactive protocols. Hence, it is desired to design an efficient and reliable broadcast transmission scheme for the IEEE 802.11 MAC protocol to realize the multi-hop ad hoc wireless networks. The problem of designing an *optimal* broadcasting protocol so that bandwidth consumption or time delay are minimized has been proved as NP-hard in [1], [2]. We therefore resort to heuristics, aiming at providing upper bounded performance with respect to these metrics.

The remaining of this paper is organized as follows. At first, in Section II, we describe the uncertain broadcast problem in

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Multi-hop MANET. In Section III, we present the proposed broadcast transmission scheme for IEEE 802.11 wireless networks. Some of simulation models and results are defined and given in Section IV. Finally, some conclusions and discussions are presented in Section V.

II. UNCERTAIN BROADCAST PROBLEM IN MULTI-HOP MANET

In the IEEE 802.11 Standard, the broadcast frame and the RTS frame are sent using same physical carrier sensing. They are transmitted only when the sensed channel idle time reaches the DIFS period as mentioned above. The key distinguishing feature of broadcast frames in wireless link is the lake of acknowledgements. Since the IEEE 802.11 WLAN adapter is designed as half-duplex mode, sender can not detect the collisions on its broadcast frame. This incurs a server problem for all protocols or applications which need broadcast control frames to retrieve useful information from networks. For example, the DSR and AODV protocols need broadcast RREQs to perform route discovery procedure. We can imagine that as the RREQ frame travels from a source to various destinations, the frame loss probability (without recovering) is proportional with the number of hops in its journey. Even though some RREQs are fortunately surviving after passing a number of consecutive contentions, the available paths by receiving the RREP frames from either destination or intermediate node which has the valid route to destination may not include the best route. This means that such routing protocols will work well in wireless network under the constrain that any node can successfully detect neighbors' broadcasts without loss as in the wired networks. Unfortunately, to apply such routing protocol for IEEE 802.11 based multi-hop ad hoc networks requires the IEEE 802.11 protocol providing reliable broadcasting. In the following section, we will propose a simple and efficient reliable broadcast scheme with limited bandwidth consumption to overcome the uncertain broadcast problem.

III. RELIABLE BROADCAST TRANSMISSION SCHEME

If the radio link between two neighboring nodes is symmetric, the broadcast sender will successfully receive the identical broadcast frame sent from its neighbor in the near future if the initial broadcast is success. Based on this concept, one way of a mobile node to recognize if its broadcast transmission is successfully received by all its neighbors can be accumulating the number of the same broadcast frames rebroadcasted from neighbors within a specified observing window. Nevertheless, how to give an appropriate observation window becomes an issue. A shorter observation window will cause excessively redundant rebroadcast overheads. On the other hand, a longer observation window will slow down the flooding speed. The CSMA/CA protocol assuming nodes contending channel in a distributed manner, it is very hard to measure a precise delay of each transmission to help determining the observation window size. Therefore, we propose an efficient duplicated broadcast scheme, which does not need the observation window, in the following subsection.

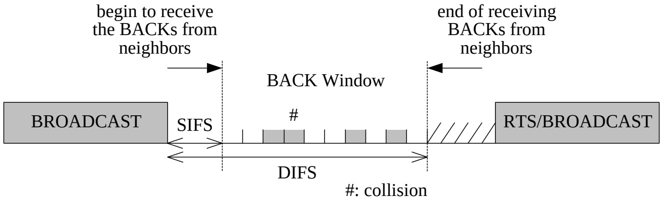

Fig. 1. An illustration of the BACK scheme.

A. *Duplicated Broadcast Scheme*

Upon a node successfully transmitting a broadcast frame, all the recipients of this frame will forward it as fast as they can. Unfortunately, it is quite often the neighbors of a node can hear each others in wireless LANs. Hereafter, the expected severe contentions will make the following broadcastings fail. In the IEEE 8021.11 MAC protocol, each broadcast frame will be transmitted once in a mobile node, the flooding may not cover all members in the ad hoc wireless networks. The simple way of enlarging the flooding area (flooding fraction) is to increase the number of transmissions of a broadcast frame in every mobile node. If each node transmits a broadcast frame twice, the flooding fraction will become higher than that with single transmission. In general, given a larger number of duplicative transmissions, a wider flooding area and a higher flooding fraction will be obtained. From the network's point of view, it is not wise to transmit too many identical broadcast frames in a node since too much overhead will significantly degrade the network throughput. Obviously, it is a tradeoff between the flooding fraction and the control overhead. Thus, it is worthy to designing an efficient scheme with minimal broadcast transmissions to enhance the flooding capability in the complicated multi-hop ad hoc wireless networks.

An efficient broadcast scheme should prevent a node from transmitting redundant broadcast frames. In fact, rebroadcasting is necessary only when there is any neighbor does not receive the broadcast frame. To achieve this goal, there are two important information must be obtained by the broadcast sender: the number of active neighbors and the number of neighbors which have successfully received the broadcast frame. The former information can be determined by maintaining a local connectivity table (LCT) in each node. Each time a node receives a frame, it will update its LCT according to the source address. Without losing generality, entries in LCT should be aged by timeout due to mobility. (For simplicity, we let $\#(\mathrm{LCT})$ denote the number of active neighbors of a node.) In the next subsection, we will introduce the broadcast acknowledgement scheme to provide sender the information of the number of its neighbors already received the broadcast frame.

B. *Broadcast Acknowledgment Scheme*

Recall the uncertain broadcast problem is mainly caused by the lake of acknowledgment of broadcast frame. To ensure the sender be aware of the status of broadcast frame, we slightly modify the IEEE 802.11 MAC protocol to provide broadcast acknowledgement. To avoid producing extra overhead, we enforce all the receivers to response right away in the following

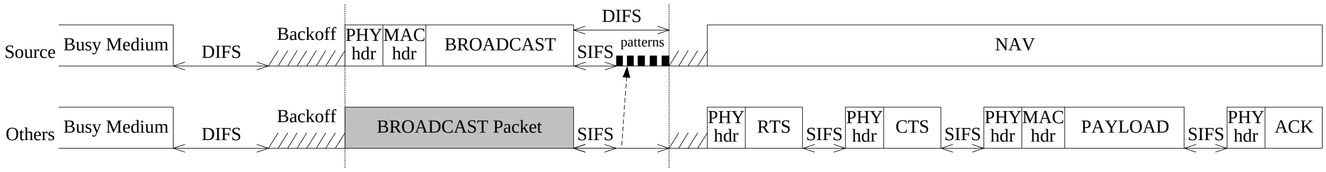

Fig. 2. An illustration of broadcast, RTS/CTS and backoff scheme of DCF.

DIFS. By applying the same collision avoidance procedure in CSMA/CA, the 50 μs DIFS time period (named as the Backoff Acknowledgement window (BACK_W) in this scheme) is divided into several minislots and each receiver will select one of them to transmit acknowledgement as shown in Fig. 1. Since the transmission time of a formal ACK frame is longer than DIFS, the broadcast acknowledgement (BACK) message must be short enough to accommodate the minislot in the BACK_W. To help nodes to recognize the BACK message, we use m-bit pattern, say x, to identify the BACK message. Basically, the link quality in wireless network will determine the pattern length (in bits). If the channel quality is poor, a longer pattern length should be used and less minislots will be allocated in limited BACK_W. There are two *patterns* $p(x)$ are used in the proposed scheme:

$$p(x) = \begin{cases} 0, & \text{new ACK for received broadcast packet} \\ 1, & \text{duplicted ACK for received broadcast packet} \end{cases} \tag{1}$$

These two patterns are designed to inform sender the new or the duplicative receive of the broadcast frame from a neighboring node. As soon as a node receives a broadcast packet, it will randomly choose a BACK minislot to fill the corresponding pattern. Since the WLAN adapter uses half-duplex mode to access channel, a switching delay for sender and receiver to change the transceiver state is required. According to the PHY specification, we need allocate a time period, which is set as equal as SIFS ($= 10$ μs), for the PHY layer transferring between receiving and transmitting states at the end of broadcasting. Consequently, for the x-bit patterns used in the m-Mb/s WLAN, a number of $\frac{(DIFS-SIFS)}{x/m} = \frac{(50-10)}{x/m}$ minislots will be allocated in the BACK_W. For example, if we use 4-bit patterns in 2 Mb/s WLAN, we have 20 minislots (BACK_W = 20).

Since the BACK messages are only used for notification, they can be treated as particular control signallings between broadcast sender and receivers. Hence, in this scheme, all mobile nodes can ignore the channel busy caused by these BACK signallings within the time period DIFS following the broadcasting and will content the channel immediately after passing DIFS as the standard does. As a result, the proposed scheme will not waste any channel resource to easily acknowledge broadcast frames as shown in Fig. 2.

According to the broadcast acknowledgement scheme, any forwarding node has sufficient information to help deciding the necessity of rebroadcasting. In the case of the number of received BACKs is less than the number of its neighbors minus one ($= \#(\text{LCT}) - 1$)[1], the forwarding node needs rebroadcast it again. Recall the connectivity between nodes is time varying, sender may fail to collect sufficient BACKs no matter how many rebroadcasts it attempts. Thus, we still need a maximal broadcast retry threshold (MBRT) to minimize the bandwidth wastage. Accordingly, a node will rebroadcast broadcast frame until either the number of BACKs is sufficient or the retry count reaches the MBRT.

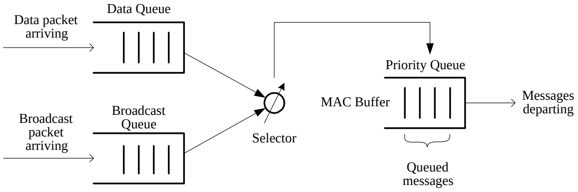

Fig. 3. Model of data queue and broadcast queue in network layer and a priority queue in MAC layer.

C. Priority Queue

In the original IEEE 802.11 MAC broadcast scheme, there is no priority between broadcast frames and ordinary data frames. Propagated broadcast frames probably spend a long propagation delay at intermediate nodes even if the traffic load is low. This is because that each time a broadcast frame relayed by a node needs wait in the FIFO queue. This is a fatal drawback in multi-hop communication network, especially when these priority frames have a delay bound. Therefore, the normal data and broadcast packets come from the higher layer (network layer) should be separated as two priority queues as shown in Fig. 3. Broadcast packets will get a higher priority than normal data to be serviced. Besides, to avoid circulating broadcast frames in network, each broadcast frame should contain the following fields:

- Source Address (SA)
- Destination Address (DA)
- Broadcast ID (BID)
- Hop_count
- Retry_flag
- Data Payload

Every mobile node maintains a BID counter and increases the value by one each time it has a new data to broadcast. The pair <SA, BID> uniquely identifies a broadcast packet. Each time the broadcast frame is forwarded by a node, the associated Hop_count will be increased by one. According to the Hop_count indication, we let the broadcast frame with the largest Hop_count to have the highest priority to shorten the propagation delay. Field Retry_flag is used to identify the broadcast frame is a new one or just a retransmission.

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[1] The expected number of BACKs in the original sender is equal to the exact number of active neighbors.

```
Procedure TRANSMIT_BROADCAST()
input: BPkt
begin
  set BACK_count(BPkt) := $\#(\mathrm{LCT})-1$; // or $\#(\mathrm{LCT})$ in the original sender
  set Retry_count(BPkt) := 0;
  set BPkt→Retry_flag := False;
  While (BACK_count(BPkt) $> 0$ and Retry_count(BPkt) $<$ MBRT )
  begin
    broadcast the BPkt and then wait the replied BACKs;
    receive all replying BACKs in BACK window;
    BACK_count(BPkt) := BACK_count(BPkt) $-$ new $\#$BACKs;
    BPkt→Retry_flag := True;
  end
  drop this BPkt;
end
```

Fig. 4. The algorithm of transmitting broadcast packet procedure.

This will help the receiver to reply a correct BACK back to sender. In addition, a node needs maintain two counters, named as *BACK_count* and *Retry_count*, for each broadcast frame buffered in queue to make the decision of rebroadcast. The *BACK_count* stands for a number of *BACK_count* BACKs are expected to be received from neighbors before discarding the broadcast frame. A node will continue rebroadcasting it until the *BACK_count* is decreased to zero. Initially, the *BACK_count* is set as $\#(\mathrm{LCT})-1$ or $\#(\mathrm{LCT})$. Another counter *Retry_count* is used to indicate that how many retries of a broadcast frame has been done. If the *Retry_count* is equal to MBRT, the broadcast frame will be discarded immediately. We note that since a node may receive the identical broadcast frame from any of its neighbors, the bandwidth consumption can be further minimize by detecting the Retry_flag, SA and BID of the frame. That is, each time it receives the identical broadcast frame with Retry_flag = False, it decreases the associated *BACK_count* of the broadcast frame buffered in the priority queue if any. As a result, some waiting broadcast frames could be quickly removed from queue. This is another advantage of the proposed broadcast acknowledgement scheme. The broadcast transmission and receive procedures are listed in Fig. 4 and Fig. 5, respectively.

IV. MODEL SIMULATION AND RESULTS

In order to evaluate the proposed broadcast scheme in a more precious way, we consider a detailed simulation model which is based on the distributed coordination function (DCF) of IEEE 802.11 [5] WLAN. In simulations, we considered the realistic system parameters (listed in the direct sequence spread spectrum (DSSS) physical specification) in IEEE 802.11 MAC protocol, which are shown in Table I. The 802.11 DCF uses RTS/CTS exchange precedes data packet transmission and implements a form of virtual carrier sensing and channel reservation to reduce the impact of the well-known hidden terminal problem [12]. Data frame transmission is followed by an ACK and the RTS/CTS frames are sent using physical carrier sensing. “Broadcast” frame transmission follows by a number of BACKs and can be treated as control frame in proposed scheme. All broadcast, RTS/CTS, and ACK are sent using physical carrier sensing. The radio model uses characteristics similar to a commercial radio interface, Lucent’s WaveLAN [3]. WaveLAN is modeled as a shared-media radio with a nominal bit rate of 2 Mb/s and a nominal radio range of 100 m.

```
Procedure RECEIVE_BROADCAST()
input: BPkt
begin
  if BPkt→BID $>$ BIDTable[BPkt→SA] then // New broadcast frame
    if BPkt→DA $=$ self address then // Arrive the destination
      receive the BPkt and response via unicasting;
    else
      if $\#(\mathrm{LCT})>1$ then //excluding the sender
        BPkt→Hop_count := BPkt→Hop_count + 1;
        insert BPkt into priority queue and perform
        InsertionSort(Hop_count);
      endif
    endif
    select a random(BACK_W) to reply a new BACK;
    update BIDTable[BPkt→SA] := BPkt→BID;
  else // Duplicate broadcast frame
    if BPkt→BID = BTable[BPkt→SA] then
      if BPkt→Retry_flag = False then
        find the buffered BPkt, say Pkt, from local priority queue if any;
        if found Pkt then
          BACK_count(Pkt):= BACK_count(Pkt)-1;
          if BACK_count(Pkt) $= 0$ then
            remove Pkt from priority queue;
          endif
        endif
        select a random(BACK_W) to reply a duplicate BACK;
      else
        drop this BPkt;
      endif
    endif
  endif
end
```

Fig. 5. The algorithm of receiving broadcast packet procedure.

A. Simulation Models

In our simulations, we simulated a scenario of N mobile nodes active in a square area of 300 m × 300 m. The initial location of each node is assigned randomly within the area. Excepting the first mobile node, the other mobile nodes will be reallocated until it has at least one neighbor. This ensures the simulated network topology is a connected graph. For the sake of comparisons, nodes are assumed to stay at its original spot during the simulation duration. Each mobile node has one transceiver and its transmission range is 100 m (in 2 Mb/s). The background data packets arrival rate of each mobile node follows the Poisson distribution with a mean λ_d, and the packet length is an exponential distribution with a mean of L slots time. The packet mean length is according to the analyzed average network packets on ordinary LAN [7], which is about 50∼150 Bytes (i.e., about 10∼30 time slots in 2 Mb/s transmission rate). These popular TCP/UDP packets occupy overall traffic loading over 74%. Thus, we assume the data packet length $L = 30$ time slots, and including PHY and MAC headers ($\approx$ 17 time slots) will be approximate 47 time slots, in our simulations. The broadcast request arrival rate of each mobile node also follows the Poisson distribution with a mean λ_b, and the broadcast frame length is a fixed length of 25 Octets. The broadcast request arrival rate per node λ_b is considered from

TABLE I

SYSTEM PARAMETERS IN SIMULATIONS

Parameter	Normal Value
Channel bit rate	2 Mb/s
Transmission Range (2 Mb/s)	100 m
RTS frame length	160 bits
CTS frame length	112 bits
ACK frame length	112 bits
Broadcast frame length	25 Octets
Preamble and PLCP header	192 μs
MAC header	34 octets
A slot time	20 μs
SIFS	10 μs
DIFS	50 μs
aBACK_Wmin	5 minislots
aBACK_Wmax	20 minislots
aCWmin	31 slots
aCWmax	1023 slots
Air propagation delay	1 μs
Density 1	30 nodes in 300m $\times$ 300m
Density 2	60 nodes in 300m $\times$ 300m
Density 3	100 nodes in 300m $\times$ 300m

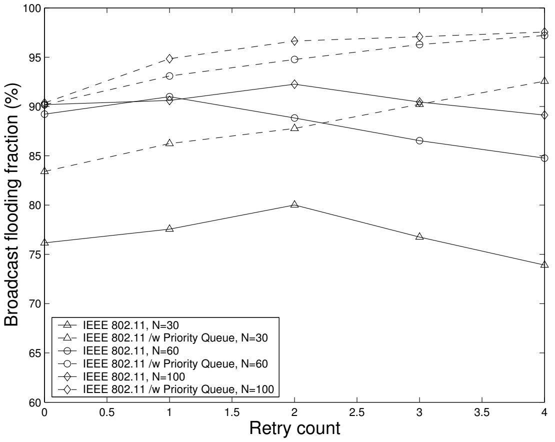

Fig. 6. Comparisons of derived broadcast flooding fractions by the traditional IEEE 802.11 and the proposed broadcast method priority queue method under different retry counts.

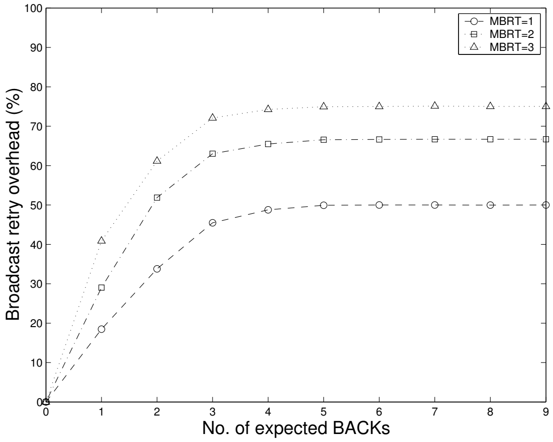

Fig. 7. The derived retry overheads by proposed broadcast scheme under different number of BACKs.

10^{-5} to 10^{-4} in a step of 10^{-5}. Each node maintains an infinite *waiting buffer* (priority queue) in MAC layer. It contains all data and broadcast frames waiting for transmission, in which, broadcast frames have a higher priority than data frames. Each simulation run lasts 60 seconds ($\approx 3 \times 10^6$ time slots) and each simulation result is obtained by averaging the results from one hundred independent simulation runs.

B. Results

Two important performance metrics are investigated:

- *Broadcast flooding fraction* – The average ratio of the number of nodes successfully received the broadcast frame and the total number of mobile nodes in the network.
- *Broadcast retry overhead* – The average fraction of the number of broadcast retries to the total broadcast times during entire simulation duration.

In the first simulation, we consider three different network densities which are generated by allocating 30, 60 and 100 mobile nodes into a fixed square area 300m $\times$ 300m. We first investigate the efficiency of broadcast flooding by using traditional broadcast scheme in IEEE 802.11 MAC protocol and vary the retry count to observe the broadcast flooding results. From the results shown in Fig. 6, we can see that with a lower network density (i.e., with fewer nodes in network), a lower flooding fraction will be obtained. For example, the best flooding fractions in cases $N = 30$, $N = 60$, and $N = 100$ when retry count is zero (i.e., the traditional broadcast scheme) are about 76%, 89% and 90%. This is because that the link degrees of nodes in the network with lower density is smaller than that of a network with higher density. In other words, in the network with higher density, once a broadcasting fails in reaching some nodes, they have a higher probability to receive/recover it from their neighbors. We can see that the flooding capability is linear proportional (contra-proportional) with the number of retries when the network load including the extra control overhead is under (beyond) the saturated load. On the other hand, combining the priority queue approach with the IEEE 802.11 MAC protocol can easily achieve a higher flooding fraction in all cases. The reason is that the priority queue approach speeds up the propagation speed for an ongoing flooding. We also emphasize the broadcast flooding fraction increases as the increasing of the retry count. The highest flooding fraction can be up to 97% in the high network density where $N = 100$, $\lambda_b = 10^{-6}$ and the retry count is equal to 4. From Fig. 6, we concluded two results that the broadcast retry may raise or degrade the flooding fraction depending on the generated control overhead and the proposed priority queue scheme can significantly enhance the flooding fraction especially when the network density is high.

In the following simulations, we only consider the network size of 30 nodes since the worse performance occurs in this case as shown in Fig. 6. Fig. 7 shows the generated retry overheads under different expected numbers of BACKs and different MBRTs in the scheme with broadcast acknowledgement when BACK_W = 5. We find that a larger expected number of BACKs will result in a higher broadcast retry overhead. The retry overhead will finally saturate at $\frac{MBRT}{MBRT+1}$ by the MBRT.

Fig. 8 shows the derived flooding fractions by the pure IEEE 802.11 broadcast scheme, the IEEE 802.11 with priority queue and the proposed broadcast scheme with broadcast acknowledgement and priority queue under different broadcast request loads. We can see that the flooding fraction is contra-

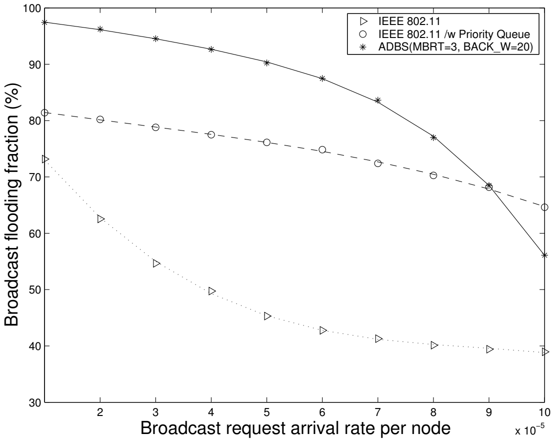

Fig. 8. Comparisons of the derived broadcast flooding fraction by three different schemes under different network loads.

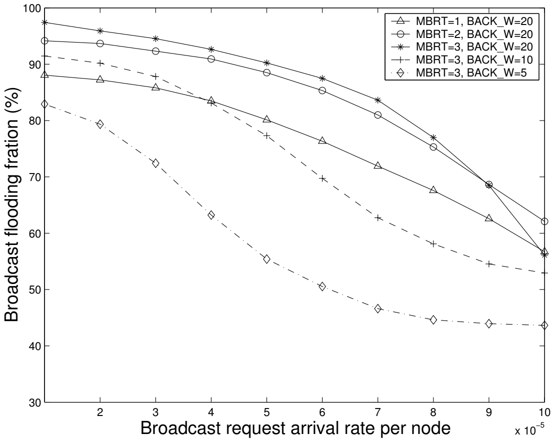

Fig. 9. Comparisons of the derived broadcast flooding fraction by proposed broadcast schemes under different MBRTs, BACK_Ws, and network loads.

proportional with the broadcast request load and the flooding fraction may be down to only 39% when $\lambda_b = 10^{-4}$. This implies that over 60% mobile nodes can not be notified by the broadcast frame. As a result, routing protocols like DSR and AODV become useless in the IEEE 802.11 based multi-hop ad hoc wireless networks. Contrarily, the proposed broadcast scheme with broadcast acknowledgement and priority queue can reach about 97% when the broadcast request arrival rate is 10^{-5} when MBRT = 3 and BACK_W = 20. Even though with broadcast acknowledgment and priority queue schemes when $\lambda_b = 10^{-4}$, we still have 60% flooding fraction. The performance degradation is mainly caused by the generated extra broadcast retry overhead and the broadcast request load. We also note that the IEEE 802.11 broadcast scheme with priority queue will outperform the proposed scheme when $\lambda_b = 10^{-4}$. This is because that no retry overhead will be generated in the pure priority queue approach which will sustain an acceptable flooding fraction even when the network load is heavy.

In order to investigate how the MBRT and the BACK_W affect the efficiency of proposed scheme, we consider different combinations of MBRT and BACK_W in simulations. Fig. 9 illustrates that by assigning a larger MBRT or BACK_W will result in a higher flooding fraction. Moreover, the flooding fraction improvement by enlarging the BACK_W is more obvious than enlarging the MBRT. With a small BACK_W, lots of BACKs will collide with each other and the sender will rebroadcast as many times as possible. However, too many rebroadcastings in a node will consume network bandwidth, increase queue length and slow down the propagation speed to reach all members. The advantage of the priority queue is being repressed by large amount of broadcast retry overhead. From Fig. 9, we also find that if the number of minislots in BACK window is sufficient (e.g., BACK_W = 20), a larger MBRT should be used to derive a higher flooding fraction.

V. SUMMARY AND CONCLUSIONS

This paper pointed out the uncertain broadcast problem in the IEEE 802.11 multi-hop ad hoc wireless networks. Without the robust broadcast scheme, some well-known multi-hop routing protocols will become inefficient in such wireless networks. In this paper, we had proposed the broadcast acknowledgement scheme and the priority queue scheme to enhance the reliability and efficiency of conventional IEEE 802.11 broadcast scheme. These two waste-free schemes can respectively minimize the unnecessary broadcast retries and the propagation delay of broadcast frames in wireless networks. Simulation results show that, with moderate network load, the proposed broadcast scheme can provide an acceptable flooding fraction. This encourage us to realize the IEEE 802.11 multi-hop ad hoc wireless networks.

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