BEAM: Broadcast Engagement ACK Mechanism to Support Reliable Broadcast Transmission in IEEE 802.11 Wireless Ad Hoc Networks

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Abstract— **To safely transfer a broadcast packet to all nodes in computer networks is an important issue. However, it is a big challenge to transfer broadcast packets over wireless networks reliably due to the unsettled wireless links and lack of the acknowledgment (ACK) scheme. Therefore, in this paper, we proposed a reliable broadcast scheme named broadcast engagement ACK mechanism (BEAM), which is completely compatible with the IEEE 802.11 protocol, in the data link layer rather than the network layer. This is because that the overhead of raising the reliability of broadcast transmission in network layer would be significantly reduced in data link layer. Simulation results show that the proposed BEAM can reach approximate 100% reliability even in heavy traffic load. Besides, by using the proposed mechanism, the IEEE 802.11 protocol could provide the reliability of unicast transmissions as well as broadcast transmissions and avoid redundant control overhead.**

I. Introduction

A mobile ad hoc network (MANET) is constructed by several mobile handsets or laptops, which is used on-demand, and needs dynamic routing protocols when there is a packet needed to be transferred more than one hop. In point-to-point communication networks a large number of broadcast-routing protocols have been proposed [4], [7]. The mobile node usually broadcasts a *route request* (RREQ) packet that is flooded through the network in a controlled manner to perform route discovery and is replied by unicasting a *route reply* (RREP) packet from either the destination node or intermediate nodes that have a route to the destination. However, unlike wired networks to which broadcast packets can be easily and safely delivered, it is a big challenge to transfer broadcast packets over MANETs due to the uncertain of the reception of broadcast transmissions and the unsettled wireless links.

Flooding packets to all nodes in networks could be achieved by using multiple unicast transmissions in network layer or using broadcast transmissions in data link layer. The former solution, however, would cause many control overheads and degrade the performance of MANETs since too many duplicated packet transmissions are performed in one broadcast transmission [12]. These solutions have been investigated and discussed in many literatures [1], [3], [5], [12].

In [1], Algar and Venkatesan proposed a reliable broadcast protocol, named as AVR, based on replying acknowledgment (ACK) packets back to the sender. The basic idea of AVR is the provision for each mobile node to retain a so called *history* of messages broadcast to and received from its neighbor(s). A node which receives a broadcast packet replies an ACK to the sender via unicasting and updates its local history. If a sending node does not receive an ACK from a neighbor within a certain time, it timeouts and resends the packet. If a sender does not receive an ACK after several retries, it assumes the link disconnection is not transient and stops sending the message. Obviously the exchange of local information and redundant broadcast retransmission would lead to the *broadcast storm problem* [12] and degrade the performance of networks. Besides, the requirement of sending ACKs in response to the receipt of a packet for all receivers may cause channel congestion and packet collisions, which is called ACK implosion [3]. The ACK implosion problem may worsen the broadcast storm problem [12].

In order to alleviate the broadcast storm problem, Lou and Wu proposed a *broadcast with selected acknowledgements* (BSA) [5] protocol for reliable broadcast transmission in MANETs. When a node broadcasts a packet, it selects a subset of one-hop neighbors as its forwarding nodes to forward the broadcast based on a greedy manner. The selection scheme of forwarding nodes is based on neighbor-designating algorithm [6], [8]. Although the BSA can reduce the ACK implosion phenomenon, finding the forwarding nodes in a given graph is the NP-complete problem [6]. This drawback would consume the limited battery power of mobile nodes rapidly.

The wastage of redundant transmissions of a broadcast packet could be solved in data link layer since the broadcast frame is transmitted once by using broadcast identification. However, many medium access control (MAC) protocols such as IEEE 802.11 [2] adopt *blind broadcasting* mechanism to transmit broadcast frames and leads to unreliable broadcast problem due to the lack of ACK[1] scheme. The uncertain broadcast problem might not satisfy the requirement of reliable broadcast transmissions of higher layers.

In order to solve this problem, a reliable MAC broadcast scheme named broadcast medium window (BMW) protocol is introduced in [9], [10]. The basic idea of the BMW

[1]We notice that the ACK control frame is an MAC control frame, which is provided in data link layer.

protocol is that it treats each broadcast request as multiple unicast requests. Each node maintains three lists: its neighbors, sending buffer, and receiving buffer. In BMW, when a node has a broadcast data to send, the sender places the packet into its sending buffer and sends out an request-to-send (RTS) control frame containing the sequence number of the upcoming data frame and the MAC address of the first node in its neighbor list. When a node receives a RTS containing its MAC address, it will check the list of its receiving buffer to see whether it has received all the data frames with sequence number smaller than or equal to the upcoming one. If all the data frames (including the upcoming one) have been received, the receiver sends a clear-to-send (CTS) with appropriate information to suppress the sender's data frame transmission. Otherwise, the receiver sends a CTS frame with all the missing data frame sequence numbers. This process would be terminated when all nodes in the neighbor list have been served.

Unfortunately, the BMW is inefficient since it requires at least n contention phases for each broadcast data frame where n is the number of neighbors. Not only is each contention phase lengthy time, but also the sender has to contend for the right of access to the medium with other nodes. It is possible that some other nodes win the contention and thereby interrupts and prolongs the ongoing broadcast process. Besides, the BMW also has a lot of overhead and does not guarantee the reliability of the transmission immediately, and needs to cost a maintenance of three lists. According to these drawbacks, we proposed an efficient reliable broadcast scheme named broadcast engagement ACK mechanism (BEAM), which is operated in data link layer and is compatible with the IEEE 802.11 MAC protocol.

The remainder of this paper is organized as follows. Section II introduces the operations of proposed BEAM and illustrates the frame format of the BEAM in detail. The simulation models and results are given in Section III. Finally, we will give some conclusions in Section IV.

II. The Broadcast Engagement ACK Mechanism

The reliability of broadcast transmission could be improved by adopting the acknowledgment scheme [11] (the ACK frame used in data transmission). We use the subfields Type (=10) and Subtype (=1000), which is a reserved number in the IEEE 802.11 protocol [2], of the frame control field of MAC header to indicate a specific broadcast frame that would receive *broadcast ACK* (denoted as BACK for short) frames from its neighbors. The frame format is shown in Fig. 1. However, requiring all nodes which have successfully received the broadcast frames to reply a BACK would be a problem since these nodes will reply their BACKs at the same time and collide with each other. In order to solve the troublesome problem, we use an additional field named BACK Order, which is an MAC header extension, to request all receiving nodes to reply their BACKs in specified order. The length of BACK Order field is determined by its neighbors, which can be easily obtained by persistently monitoring the transmission activities around its transmission range, e.g., using a neighbor

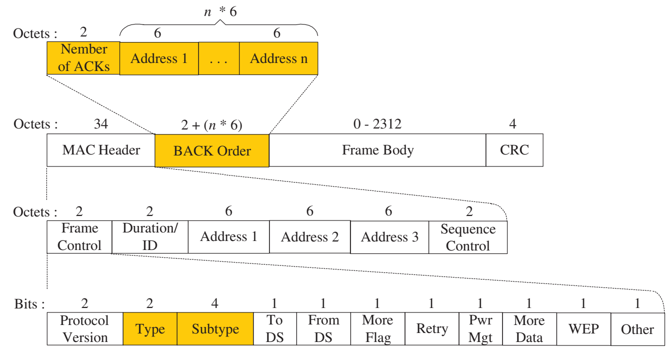

Fig. 1. The frame format of broadcast data where subfields of the Frame Control Type=10 and Subtype=1000, and an additional ACK Order field is designed for proposed BEAM.

table to record the transmitter address (TA) of each data frame and maintain for a period. The record would be removed from the table when there are no transmissions of the node after a specific time period. Since the number of neighbors varies by time, we use a subfield Number of BACKs shown in Fig. 1 to indicate how many nodes n should respond to the broadcast frame. This subfield's length is 2 octets long (for supporting maximum $2^{16} = 65{,}536$ neighbors).

After receiving the broadcast frame, nodes which are specified in the BACK Order would reply BACKs one by one according to the order of the list indicated in the frame body. Thus the sender node could uses the conditions of acknowledgment to confirm the reception of each node. The broadcast frame will be retransmitted immediately after doing not receive a BACK frame within an idle slot time (e.g., 20μs in direct sequence spread spectrum (DSSS) system). This process would be terminated after receiving all BACKs of its recorded neighbors. However, the sender may not receive all its neighbors' BACKs due to the mobility or the communication interference. This problem could be solved by adopting the limitation of maximum time of broadcast retransmission.

The duration of broadcast transmission includes the broadcast data frame transmitting time plus $n \times$ (SIFS + ACK) in normal condition. The duration will be extended if a corrupted data frame or missing a BACK frame occurs. We use the *network allocation vector* (NAV), named broadcast NAV (BNAV), recorded in the duration field of the MAC header in each broadcast data frame and BACK frame to indicate the duration of the broadcast transmission. The duration will be recalculated if a broadcast retransmission is performed. We note that the duration of new recalculated BNAV denoted as extended BNAV equals the length of original duration except the portion of having been replied BACKs. We also note that the duration field of BACKs records the remaining BNAV in its duration field to restrain the hidden nodes' transmissions.

Fig. 2 illustrates an example of the proposed BEAM. The network topology shown in left side consists of a sender, four receivers, and four hidden terminals. The duration of original broadcast data frame equals the data frame length plus four SIFSs and BACKs. Assume node 1 receives the

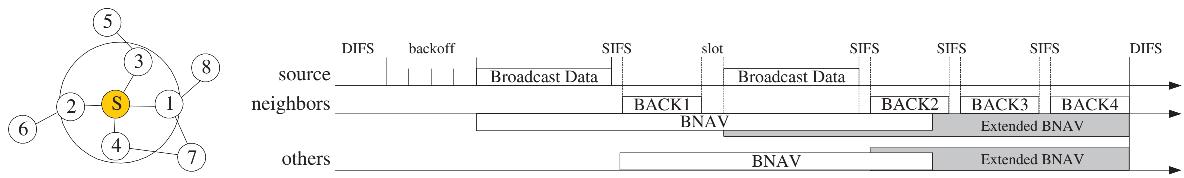

Fig. 2. An example of broadcast transmission process (a) the network topology (b) the time line of the proposed BEAM in ad hoc networks.

```
Procedure TRANSMIT_BROADCAST()
BEGIN
    nBACK := number of neighbors;
    RetryCount := 0;
    Sends the broadcast data and waits the BACKs;
    WHILE nBACK > 0 and Retry_count < MaxRetry DO
    BEGIN
        waiting the BACKs;
        IF missing a BACK THEN
            rebroadcast the data frame;
            RetryCount := RetryCount + 1;
        ELSE receiving a BACK THEN
            nBACK := nBACK − 1;
        END
    END
END
```

Fig. 3. The algorithm of broadcast transmission procedure.

```
Procedure RECEIVE_BROADCAST()
BEGIN
    IF a new broadcast frame THEN
        according to BACK Order to reply BACK;
        calculate the BNAV;
    ELSE a rebroadcast frame THEN
        according to BACK Order to reply BACK;
        recalculate the BNAV;
    END
END
```

Fig. 4. The algorithm of broadcast reception procedure.

broadcast frame and reply its BACK (denoted as BACK1) to sender s successfully but node 2 does not receive the broadcast frame (interrupted by node 6) and does not reply a BACK. After one idle slot, node s rebroadcasts the data frame and recalculates the new duration of retransmission as extended BNAV. The length of extended BNAV is the data frame length plus the remaining three BACKs. Finally all remaining nodes receive the broadcast data and reply their BACKs accordingly. The broadcast transmission algorithm is shown in Fig. 3 where nBACK represents the number of BACKs. Besides, the algorithms of transmission and reception are given in Fig. 3 and Fig. 4, respectively.

III. Simulation Models and Results

In order to evaluate the performance of our proposed BEAM, two kinds of simulation models are designed to observe the broadcast fraction and broadcast delivery ratio. Simulation parameters follow the IEEE 802.11b Standard and are listed in Table I. In our simulation models, direct sequence spread spectrum (DSSS) system, the long physical layer convergence protocol (PLCP), and PLCP protocol data unit (PPDU) format are used. The background data packets arrival rate of each mobile node follows the Poisson distribution. The broadcast request arrival rate of each mobile node also follows the Poisson distribution, and the broadcast frame length is a fixed length of 25 octets. Each simulation run lasts 60 seconds and each simulation result is obtained by averaging the results from twenty independent simulation runs.

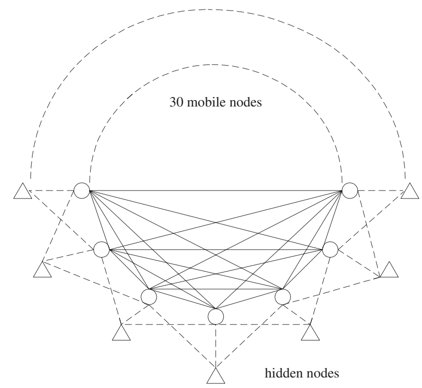

Fig. 5. The environment of full connected with some hidden nodes.

TABLE I

System Parameters in Simulations

Parameter	Normal Value
Channel bit rate	2 Mb/s
Transmission Range (2 Mb/s)	120 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
aCWmin	31 slots
aCWmax	1023 slots
MaxRetry	3 times
Air propagation delay	1 μs

The first simulation model, shown in Fig. 5, simulates the network of 30 nodes acting within a 300 m $\times$ 300 m space. All nodes are full connected with each other and each node has several hidden terminals around it. These hidden terminals are used to play the potential disturbing source of ongoing

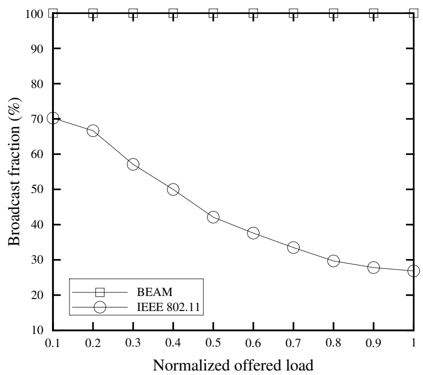

Fig. 6. The comparison of broadcast fractions by the BEAM and traditional IEEE 802.11.

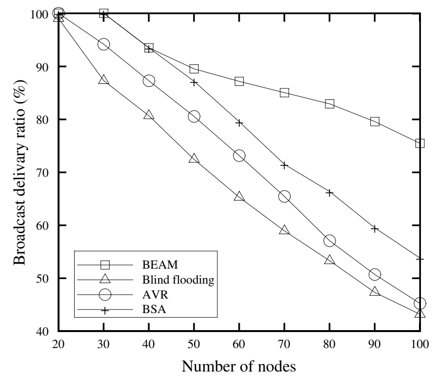

Fig. 7. Broadcast delivery ratio of BEAM, Blind flooding, AVR, and BSA where retry count set to 1.

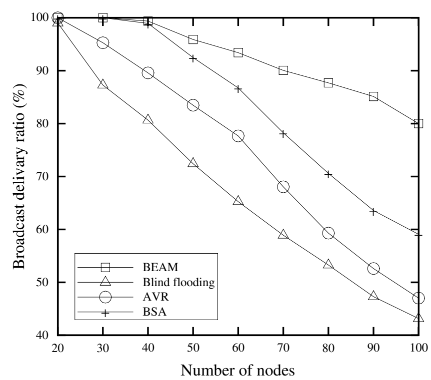

Fig. 8. Broadcast delivery ratio of BEAM, Blind flooding, AVR, and BSA where retry count set to 2.

broadcast transmissions and the data arrival rate of each hidden terminal is 10 packets/second. The unicast data arrival rate of each node (consider as background traffic) is 2 packets/second, and the broadcast arrival rate of each node is considered from 0.5 packets/second to 2.5 packets/second.

Fig. 6 shows the broadcast fractions by the pure IEEE 802.11 broadcast scheme and BEAM under different offered load. This offered load is calculated by data packet arrival rate of hidden terminals and background traffic and broadcast requests of full connected nodes. We can see that the broadcast fraction of the IEEE 802.11 lowers from 70% to 27% gradually due to the interference of hidden terminals. However, the proposed BEAM uses the BACKs scheme to prevent hidden node phenomenon and reaches approximate 100% reliability even in heavy traffic load.

Afterward we run the simulation in the multihop ad hoc environment. The working space is enlarged to 600 m $\times$ 600 m with a transmission radius of 120 m. Different numbers of nodes (range from 20 to 100) are randomly placed in this 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. The unicast data arrival rate of each mobile node is 1 packets/second, and the data arrival rate of broadcast request in each mobile node is considered as 2 packets/second.

We compare the performance of our proposed BEAM with the following schemes:

- Blood flooding (BF): each node forwards the packet when it receives the packet.
- AV Reliable broadcast (AVR) [1].
- Broadcast with selected acknowledgements (BSA) [5].

Two important performance metrics are investigated:

- Broadcast delivery ratio: The ratio of the nodes that received the broadcast packet to the number of the network.
- Broadcast forwarding ratio: The fraction of the total number of nodes in the network that retransmit the broadcast packet at least once.

Fig. 7, Fig. 8, and Fig. 9 show the broadcast delivery ratio of BEAM, blind flooding (BF), AVR, and BSA in different retry counts. BF can't guarantee the data transmits correctly due to it lacks the ACK mechanism. Therefore, the delivery ratio of BF is not good. Besides, BEAM, AVR, and BSA have ACK mechanism, along with the retry increase, the broadcast packet may a more widespread dissemination. If broadcast, each receivers must sends ACKs to source in AVR. But in BSA, only selected forward node sends ACKs to source and broadcast, the delivery ratio of AVR is obvious lower than BSA. Regardless of in which environments, BSA use fewer nodes to broadcast the message, but its delivery ratio is not excellent. Due to our scheme to use schedule method to send ACKs and to avoid other nodes influence the broadcast. We can see our proposed scheme have highly delivery ratio.

In Fig. 10, the BSA only selects some forward node to reply ACKs and broadcast it, so his forwarding ratio lower than AVR and the BEAM. However, the BSA is a network layer approach and could combine our BEAM for further enhancement. Fig. 11 and Fig. 12 show that the combination of BSA and BEAM have low broadcast forwarding ratio and highly broadcast delivery ratio. The result indicates that the BEAM can achieve higher reliability broadcast transmissions.

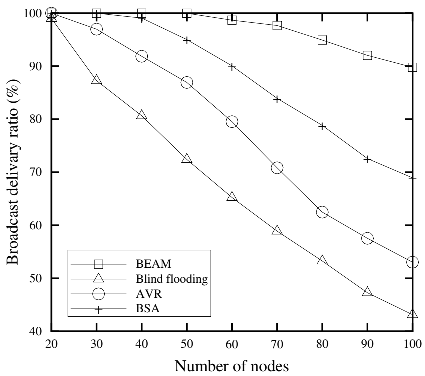

Fig. 9. Broadcast delivery ratio of BEAM, Blind flooding, AVR, and BSA where retry count set to 3.

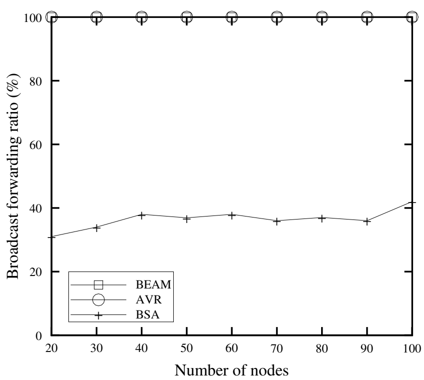

Fig. 10. Broadcast forwarding ratio of BEAM, AVR, and BSA where retry count set to 3.

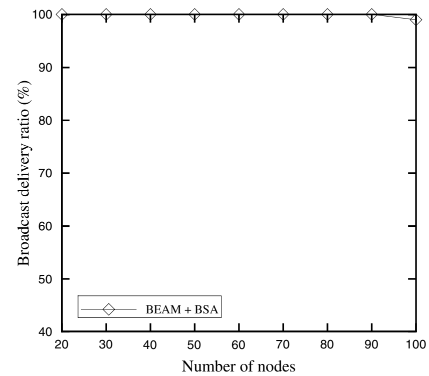

Fig. 11. Broadcast delivery ratio of BEAM+BSA where the retry count is set to 3.

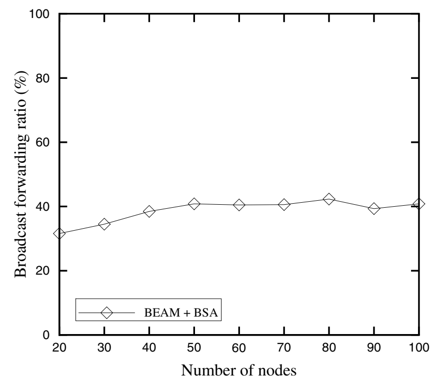

Fig. 12. Broadcast forwarding ratio of BEAM+BSA where the retry count is set to 3.

IV. CONCLUSIONS

In this work, we proposed a reliable broadcast transmission scheme named broadcast engagement acknowledgment mechanism (BEAM) for broadcast transmission in ad hoc networks. The proposed BEAM not only achieved high flooding delivery ratio but was fully compatible with the IEEE 802.11 MAC protocol. The BEAM enhanced the broadcast fraction of IEEE 802.11 to 100% even in heavy traffic load. This was achieved by enforcing the neighboring nodes to confirm their receipt of the broadcast frame accordingly. Besides, the BEAM was the data link layer protocol rather than the network layer protocol and thus reduced a lot of control overheads in achieving reliability. Simulation results showed that the BEAM approaches higher broadcast delivery ratio as well as reduces bandwidth consumption efficiently.

REFERENCES

[1] S. Alagar, S. Venkatesan, and J. R. Cleveland, "Reliable Broadcast in Mobile Wireless Networks," in *Proc. IEEE MILCOM'95*, vol. 1, pp. 236–240, San Diego, CA, Nov. 1995.

[2] IEEE 802.11 Working Group, "Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," ANSI/IEEE Std. 802.11, Sept. 1999.

[3] M. Impett, M. S. Corson, and V. Park, "A Receiver-orinted Approach to Reliable Broadcast Ad Hoc Networks," *Proc. IEEE WCNC'2000*, vol. 1, pp. 117–122, Chicago, IL, Sept. 2000.

[4] D. B. Johnson and D. A. Maltz, "Dynamic Source Routing in Ad-Hoc Wireless Networks," *Mobile Computing*, T. Imielinski and H. Korth, Eds., chapter 5, pp. 153–181, Kluwer Academic Publisher, 1996.

[5] W. Lou and J. Wu, "A Reliable Broadcast Algorithm with Selected Acknowledgements in Mobile Ad Hoc Networks," in *Proc. IEEE GLOBECOM'03*, vol. 6, pp. 3536–3541, San Francisco, CA, Dec. 2003.

[6] ——, "On Reducing Broadcast Redundancy in Ad Hoc Wireless Networks," *IEEE Trans. Mobile Computing*, vol. 1, no. 2, pp. 111–122, Apr./Jun. 2002.

[7] C. E. Perkins and E. M. Royer, "Ad-Hoc On-Demand Distance Vector Routing," in *Proc. IEEE WMCSA'99*, pp. 90–100, New Orleans, LA, Feb. 1999.

[8] A. Qayyum, L. Viennot, and A. Laouiti, "Multipoint Relaying for Flooding Broadcat Message in Mobile Wireless Networks," in *Proc. IEEE HICSS'02*, pp. 3898–3907, Hawaii, Jan. 2002.

[9] K. Tang and M. Gerla, "Random Access MAC for Efficient Broadcast Support in Ad Hoc Networks," in *Proc. IEEE WCNC'2000*, vol. 1, pp. 454–459, Chicago, IL, Sept. 2000.

[10] ——, "MAC Reliable Broadcast in Ad Hoc Networks," in *Proc. IEEE MILCOM'01*, vol. 2, pp. 1008–1013, Washington, DC, Oct. 2001.

[11] S.-T. Sheu, Y. Tsai, and J. Chen, "A Highly Reliable Broadcast Scheme for IEEE 802.11 Multi-hop Ad Hoc Networks," in *Proc. IEEE ICC'02*, vol. 1, pp. 610–615, New York, Apr./May 2002.

[12] Y.-C. Tseng, S.-Y. Ni, Y.-S. Chen, and J.-P. Sheu, "The Broadcast Storm Problem in a Mobile Ad Hoc Network," *ACM/Kluwer Wireless Networks (WINET)*, vol. 8, no. 2–3, pp. 153–167, 2002.