A Cooperative Broadcast Algorithm Based on the Successful Broadcasting Ratio and Residual Energy of Neighbor Nodes in Mobile Ad Hoc Networks

Yichen Deng, Yanping Yu(✉), and Zhengqing Yan

College of Information and Electronic Engineering,
Zhejiang Gongshang University, Hangzhou 310018, China
ycdeng26@163.com, yuyanping@zjgsu.edu.cn,
1162865308@qq.com

Abstract. In order to suppress the broadcast storm, balance the energy consumption of the nodes and provide certain reliability, we propose a cooperative broadcast algorithm based on the successful broadcasting ratio and residual energy of neighbor nodes (BSRREN). In this algorithm, each node in a network calculates the broadcasting coefficient according to the successful broadcasting ratio and residual energy. Then, the broadcasting coefficient encapsulated in the broadcast packets is exchanged between neighbor nodes. Each node constructs a neighbor information table (NIT) to store the broadcasting coefficient. Each node dynamically selects up to four neighbor nodes which have the highest broadcast coefficients as the forwarding nodes. The addresses of the four forwarding nodes which are designated as the next hop forwarding nodes are encapsulated in the broadcast packet headers. The transmissions of each node are randomly delayed to reduce the probability of channel contention and message collision. The simulation results show the BSRREN algorithm has lower forwarding node ratio and higher network lifetime, which indicates the algorithm can effectively suppress broadcast storm and balance the energy consumption.

Keywords: Mobile ad hoc networks · Broadcast algorithms · Broadcast storm
Broadcast reliability · Energy balance · Successful broadcasting ratio

1 Introduction

Mobile ad hoc networks are a type of wireless communication networks which are composed of a group of mobile nodes with wireless communication transceivers. They are also called multi-hop and self-organizing networks. Broadcast is a technology by which a source node sends the same message to all nodes in a network. It is widely used in resource scheduling, transmission of network control information, route discovery and maintenance, sending alarm signals and other applications in mobile ad hoc networks.

Flooding is one of the simplest broadcasting schemes in mobile ad hoc networks. In flooding, each node transmits a broadcast packet to its neighbor node immediately

B. Li et al. (Eds.): ChinaCom 2017, LNICST 237, pp. 82–92, 2018.
https://doi.org/10.1007/978-3-319-78139-6_9

when the node receives the broadcast packet for the first time. But traditional flooding introduces a large number of redundant transmissions which is usually referred to as broadcast storm problem [1, 2]. Broadcast storm has a serious impact on network throughput, channel utilization, QoS (Quality of Service) and other network performance. Meanwhile, channel contending and packet collisions may exist during the transmissions which lead to the unreliable broadcast problem [3]. In addition, due to the limited energy of nodes, how to prolong the network lifetime is another issue that is needed to be considered [4].

Currently, most researches are focused on suppressing the broadcast storm [5]. The broadcast suppression schemes are basically classified as the probabilistic schemes, neighbor information based schemes, hybrid schemes. All of them aim to suppress the broadcast storm to certain extent. The probabilistic scheme is simple but it introduces the problem of lower coverage problem. The neighbor information based scheme is effective but complex. Some schemes need GPS (Global Positioning System) to determine the distance or location, which leads to limited applications.

Broadcast unreliability may be caused by channel contending, packet collision, channel and noise interruption. Broadcast unreliability may lead to the failure of network routing, etc. Therefore, improving broadcast reliability is essential in ad hoc networks [3]. Reliable broadcast algorithms are classified into the following categories: acknowledgment based algorithms [6], spanning tree based broadcasting (such as RMST [7]), time-division based broadcasting (such as RAPID reliable probability broadcast algorithm [8]), and hybrid reliable broadcasting.

In the mobile Ad hoc network, each node is equipped with a battery whose energy is limited. In order to prolong the lifetime of the entire network as much as possible, it is important to improve the energy efficiency. The most common strategies to prolong the network lifetime is minimizing energy consumption [4] and balancing the energy consumption [9].

The BSRN algorithm can adjust the forwarding probability of the current node in real time according to the averaged successful broadcasting ratio of the neighbor nodes [10]. The algorithm can improve the network reachability and reduce the network delay. But the strategy might cause the traffic concentrating to some nodes, which results in unevenly energy consumption of nodes and thus a shorter network lifetime. In the BSREB algorithm, a node determines its own forwarding probability according to the node's successful broadcasting ratio and the residual energy [9]. It does not need any neighbor information. The algorithm can balance the energy consumption. However, the forwarding probability is only determined by its own successful broadcasting ratio and residual energy which leads to the lower reachability of BSREB than that of BSRN. In the DP algorithm, a node dynamically adjusts its own forwarding probability according to the number of neighbors [11]. So it can mitigate the redundant retransmission. However, the forwarding probability does not associate with the load of the network. The improvement of performance in terms of reachability is limited.

In order to suppress broadcast storm, balance the energy consumption of a network and provide network reliability, a cooperative broadcast algorithm based on the successful broadcasting ratio and residual energy of neighbor nodes (BSRREN) in mobile ad hoc networks is proposed in this paper.

The rest of the paper is organized as follows: BSRREN is described in detail in Sect. 2. The simulation scenarios and simulation results are presented in Sect. 3. Section 4 concludes this paper.

2 BSRREN

In BSRREN, each node in a network needs to calculate its own broadcast coefficient is determined by the successful broadcasting ratio and the residual energy before sending a broadcast packet and encapsulate the broadcast coefficient into the broadcast packet header.

Each node in the network maintains a NIT (Neighbor Information Table) which is used to record the most recent broadcast coefficient of the neighbor nodes. After receiving a broadcast packet, a node first judges the addresses of four forwarding nodes. If its own address matches one of the addresses of the four forwarding nodes in the packet header, the node will forward the packet just received. Or, if all of the addresses of four forwarding nodes in the packet header are special addresses (254.255.255.255), the packet is forwarded according to the probability. Before sending the packet, the current node needs to select up to four next hop forwarding nodes according to the broadcast coefficients of neighbor nodes which are stored in NIT. Because the degree of usual networks is generally around four, up to four forwarding nodes are selected.

2.1 Calculation of Parameters

Take node k as an example, N_k denotes the number of packets broadcasted. Set S_k denotes the number of packets that have been successfully broadcasted. Suppose the initial value of N_k and S_k are 0. Increment N_k by one after the node k broadcasts a packet and increment S_k by one after node k sends a broadcast packet successfully. R_k denotes the successful broadcasting ratio which is initialized as $A(0 < A \leq 1)$.

$$R_k = S_k/N_k(N_k > 0, S_k \geq 0). \tag{1}$$

$R_k \in [0, 1]$, the greater the value of R_k is, the higher the reliability of the network is.

Assume the maximum energy of each node is $E_{\max}$. E_{kc} denotes the energy consumed by node k and E_k denotes the residual energy of node k. Then the residual energy of the node is calculated as in Eq. (2).

$$E_k = E_{\max} - E_{kc}\,. \tag{2}$$

Assume that the energy consumed by the node when sending a broadcast packet is E_{ks}, the energy consumed by the node when receiving a broadcast packet is E_{kr}. Then,

$$E_k = E_{\max} - (M_{ks}E_{ks} + M_{kr}E_{kr}). \tag{3}$$

Here M_{ks} is the number of the broadcast packets sent from node k. M_{kr} is the number of broadcast packets received by node k.

We set a threshold of residual energy E_{th} under which the node is not allowed to forward any packet to save energy for receiving packets.

Node k, according to the successful broadcasting ratio R_k and the residual energy E_k, calculates its own broadcast coefficient B_k as shown in Eq. (4)

$$B_k = \begin{cases} (1-\alpha)R_k + \alpha\frac{E_k}{E_{\max}} & E_k \geq E_{th} \\ 0 & E_k < E_{th} \end{cases}. \quad (4)$$

Where α is the weighting coefficient ($0 < \alpha < 1$). The smaller the value of α is, the more the forwarding probability is determined by the successful broadcasting ratio of the node, which means more attention is paid to the broadcast reliability. The greater the value of α is, the more the forwarding probability is determined by the residual energy of the node, which means more attention is paid to the energy consumption and the network lifetime.

2.2 Table Maintaining

The format of NIT is shown in Table 1. When a node receives a broadcast packet from a neighbor node, it creates a new entry in the NIT for the neighbor node if it receives a broadcast packet from this neighbor node for the first time. Otherwise, it updates the corresponding entry for the neighbor node in the NIT. Meanwhile, set the timeout in the entry for the neighbor node. The timeout is set to the initial value after the entry is established or updated. If an entry in NIT is not refreshed within the timeout period, it is not considered as the neighbor node of the current node neighbor node. Therefore, the corresponding entry is removed from the NIT.

Table 1. The format of NIT in a node

IP address (node: k)
IP address (neighbor 1: k_1)
B_{k1}
t_{k1}
IP address (neighbor 2: k_2)
B_{k2}
t_{k2}
……

where:

IP address (current node: k): the IP address of node k;
IP address (neighbor node: j): the IP address of the jth neighbor node of node k;
B_{kj}: the broadcast coefficient of the jth neighbor node of node k;
t_{kj}: the timeout of the jth neighbor node of node k.

The record table of broadcast packet received and sent is shown in Table 2.

Table 2. The record format of broadcast packet received and sent

IP address (current node: *k*)
IP address (source node: *i*)
Packet sequence number *x* (from source node *i*)
Be received (Yes or No)
Be broadcasted (Yes or No)
Be successfully broadcasted (Yes or No)
IP address (current node: *m*)
Packet sequence number *y* (from source node: *m*)
Be received (Yes or No)
Be broadcasted (Yes or No)
Be successfully broadcasted (Yes or No)
……

Where,

IP address (current node: *k*): IP address of the current node *k*.
IP address (source node: *i*): IP address of the source node *i*.
Packet sequence number *x* (from source node *i*): the broadcast packet with sequence number *x* sent from the source node *i*.
Be received: whether the broadcast packet has been received, "Yes" indicates that it has been received, "No" indicates that it has not been received.
Be broadcasted: whether the broadcast packet has been broadcasted, "Yes" indicates that it has been broadcasted, "No" indicates that it has not been broadcasted.
Be successfully broadcasted: whether the broadcast packet has been successfully broadcasted, "Yes" indicates that it has been successfully broadcasted, "No" indicates that it has not been successfully broadcasted.

2.3 Sending Process of a Source Node

When the source node *i* receives a broadcast packet from the upper layer, it firstly determines whether there is a NIT at node *i*. If not, use 254.255.255.255 as the addresses of four forwarding nodes. Or, at most four neighbor nodes whose broadcasting coefficients are maximum are selected as the forwarding nodes when the number of neighbor nodes is greater than 4. Otherwise, all of neighbor nodes are selected as forwarding nodes when the number of neighbor nodes is less than or equal to 4. Then, node *i* calculates its own broadcast coefficient according to its successful broadcasting ratio and the residual energy. After that, node *i* encapsulates the source node address, the broadcast packet sequence number, the address of current node *i*, the broadcast coefficient of node *i* and addresses of four forwarding nodes. Finally, node *i* ends out the packet with probability 1. After that, node *i* updates the residual energy of the node i, and increments the number of the packets broadcasted N_i by one, updates the record of the packets broadcasted in the table of broadcast packet received and sent.

After sending the broadcast packet, the source node adopts the retransmission mechanism when it does not receive the packet it originated to improve the reliability. Whenever the source node i sends its own broadcast packet, it initializes response time T_{ack}, which is the sum of the broadcast packet transmission time, the maximum waiting delay for forwarding and twice of the propagation delay. That the node does not receive the broadcast packet it originates within T_{ack} indicates the broadcast packet transmission is unsuccessful and it is necessary to retransmit the broadcast packet. Otherwise, the packet broadcast transmission is successful. Thus, increment the number of the broadcast packet successfully transmitted S_i by one, update the table of the broadcast packet received and sent, and record the packet which has been successfully broadcasted by the source node, stop the timer of T_{ack}. In this algorithm, the maximum retransmission number of the source node is one.

2.4 Processing Process of a Relay Node

After a relay node k receives a packet from a neighbor node j, it processes as follows.

(1) Node k updates its own residual energy after receiving the broadcast packet from the neighbor node j.

(2) If node k receives the broadcast packet from the neighbor node j for the first time, it extracts IP address of the upstream neighbor node and the broadcast coefficient B_j from the header of the received broadcast packet, establishes a new entry in the NIT of node k. Then, the IP address of the neighbor node, the broadcast coefficient of the neighbor node and the timeout t_{kj} are written into the new entry established, jump to (3). Otherwise, the current node updates the broadcast coefficient and the timeout t_{kj} in the corresponding entry of node j in the NIT, jump to (3). If the timeout t_{kj} expired, the entry of node j in the NIT is required to be deleted.

(3) Comparing the IP address of the source node and the sequence number of the broadcast packet to the records in the record table of broadcast packet received and sent, judge whether the current node has received the packet. If yes, jump to (6). If not, it indicates that the current node received the packet for the first time. Then, the current node first records that the packet has been received in the record table of broadcast packet received and sent. Next, judge whether the addresses of the four forwarding nodes in the received broadcast packet header are all 254.255.255.255. If yes, node k forwards the packet with probability of 0.7. Node k uses a uniformly distributed function to generate a random number α. If $\alpha > 0.7$, discard the packet directly and jump to (8). If $\alpha < 0.7$, the node forwards the broadcast packet and then turn to (5).

(4) If all addresses of four forwarding node in the broadcast packet header are not 254.255.255.255, node k judge whether the address of node k matches one of the four addresses. If not, discard the packet and jump to (8). If yes, continues.

(5) Node k selects up to four neighbors as the forwarding nodes which have the maximum broadcast coefficient. If the number of neighbors is less than or equal to 4, all of these neighbors are selected as the forwarding nodes. If the number of

neighbors is greater than four, exclude the node with the broadcast coefficient which is 0, select the four neighbor nodes with the highest broadcast coefficient as the forwarding nodes from the rest of neighbors, calculate the broadcast coefficient of node k according to its own successful broadcasting ratio and residual energy, encapsulate the packet and send the broadcast packet. After that, record the packet which has been broadcasted in the record table of packet received and sent, update the number of packets broadcasted N_k and the residual energy E_k, jump to (8).

(6) If the *broadcast* packet received has been received for more than one time, node k judges whether the broadcast packet has been broadcasted in the record table of packet received and sent. If not, it illustrates that the packet has been received but not been broadcasted. This time it is processed in the same way. So discard the packet directly, jump to (8).

(7) If the broadcast packet has been received and broadcasted, judge whether the packet has been successfully broadcasted according to the record table of packet received and sent. If not, node k records that the packet has been successfully broadcasted in the record table of packet received and sent, increments S_k by 1, discards the packet received. If yes, node k discards the packet received.

(8) End.

3 Simulation

3.1 The Simulation Scenario and Parameter Setting

To verify the performance of BSRREN, we conducted the simulations. BSRN, BSREB and DP are used for comparison. The simulation parameters are set as follows. A network covers an area of 1.0 km * 1.0 km. The rate of wireless interface is 11 Mb/s. Each node in the network uses IEEE802.11DCF as the MAC layer protocol. Nodes in a network are randomly evenly distributed. Each source node uses the constant bit rate (CBR) to send the broadcast packets. The size of each broadcast packet is 64 bytes, and the simulation time is 3 h. The wireless coverage of every node is 250 m. The mobility model of nodes is the random waypoint model [12]. In this simulation, the node pause time is 20 s, and the movement speed is selected from 0 to 10 m/s randomly.

Scenario 1: The value of weight coefficient α is 0.5. CBR of sources is set to 4 packets/s. The number of network nodes is 30, 60, 90, 120 and 150, respectively.

Scenario 2: All parameters are the same as those in the Scenario 2 with exception that the weight coefficient α is 0.3.

The simulations are conducted to acquire the performance in terms of ratio of forwarding nodes, network lifetime, averaged end-to-end delay and reachability.

(1) Ratio of forwarding nodes
Ratio of forwarding nodes is defined as the ratio of the number of nodes participating in forwarding to the total number of nodes in the network during the

simulation. The lower ratio of forwarding nodes is, the lower the number of redundant transmission is, the less channel contending and the less collision have.

(2) Network lifetime
Network lifetime is the duration from the beginning of the simulation to the time when a node first depletes its energy. Assume the total energy of each node in a network is equal, and the energy consumed by each node for sending or receiving a broadcast packet is equal.

(3) Average end-to-end delay
Average end-to-end delay is the averaged delay between the time when a source node sending a broadcast packet to the time when each destination receiving the packet.

(4) Reachability
Reachability is the ratio of the number of broadcast packets actually received by all destination nodes to the number of broadcast packets that should be received by all destinations. Assume the number of nodes in the network is N, the number of the broadcast packets sent by the source node i is M, and the number of the broadcast packets received by node k is D_k. The reachability of the network is

$$REA_{aver} = \sum_{k=0\&k\neq i}^{N-1} D_k/(M*(N-1)). \quad (5)$$

3.2 Simulation Results and Analysis

(1) Ratio of forwarding nodes
Figure 1 shows the ratio of forwarding nodes versus the number of nodes in a network. As is seen, BSRREN and DP have better performance than BSRN and BSREB in terms of the ratio of forwarding nodes. In the BSRREN algorithm, maximum four nodes with high successful broadcasting ratio and high residual energy are selected to forward the broadcast packets. It can effectively avoid that too many nodes involve in forwarding broadcast packets. Thus, BSRREN can effectively reduce the transmission redundancy and channel contending which may lead to the broadcast storm. The DP algorithm can adjust the forwarding probability of nodes in real time according to the density of network nodes, and thus ratio of forwarding nodes is reduced.

(2) Network lifetime
Figure 2 presents the network lifetime versus the number of network nodes. From Fig. 2, we can see that the network lifetime drops down with the increase of the number of nodes in the network. The network lifetime of BSRREN is much larger than that of BSRN and BSREB and is slightly larger than that of DP. The first reason is that less energy is consumed since fewer nodes involve in forwarding. Secondly, the energy balance strategy is adopted in BERREN, which prolongs the network lifetime. Thirdly, higher successful broadcasting ratio is one of the factors when determining forwarding nodes. As a result, fewer channel contending and packet collision occur, which also leads to a longer network lifetime. Instead,

BSRN, BSREB and DP are all probabilistic algorithm. More forwarding nodes involve in forwarding. Thus they have shorter network lifetime.

(3) Average end-to-end delay
Figure 3 is the average end-to-end delay versus the number of nodes in a network. From Fig. 3, the average end-to-end delay of BSRREN is larger than that of the other three algorithms. This can be explained by observing that packets do not usually travel over the shortest path since fewer nodes are selected as the forwarding nodes in BSRREN. The other three algorithms, however, are probabilistic algorithms which are more likely to select shorter path for packet forwarding.

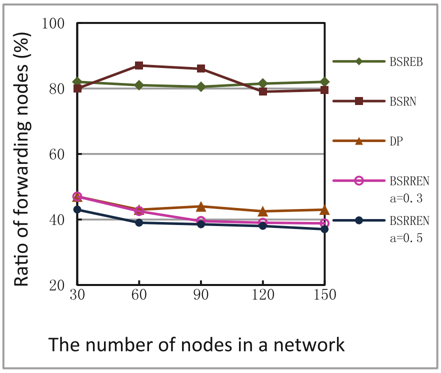

Fig. 1. Ratio of forwarding nodes versus the number of nodes in a network

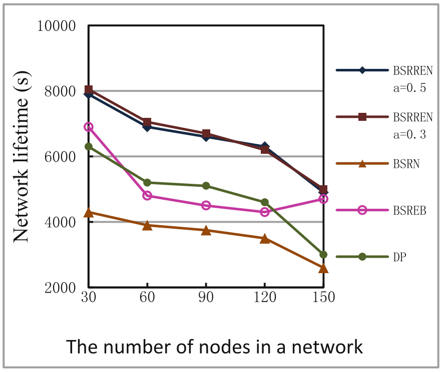

Fig. 2. Network lifetime versus the number of nodes in a network

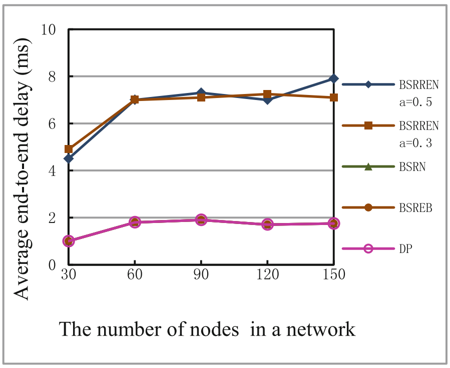

Fig. 3. Average end-to-end delay versus the number of nodes in a network

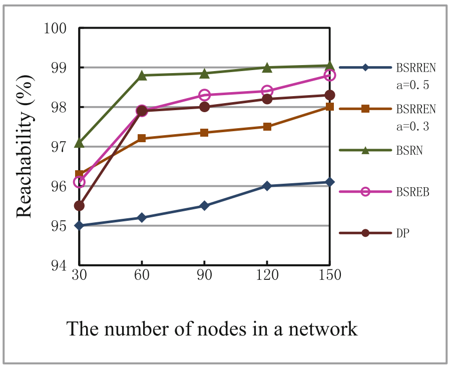

Fig. 4. Reachability versus the number of nodes in a network

(4) Reachability

Figure 4 shows the reachability of the four algorithms versus the number of nodes in a network. When α is 0.3, the reachability of BSRREN is comparable to that of BSREB, but it is still lower than that of BSRN and DP. The reason is that fewer nodes involve in forwarding in BSRREN and therefore less broadcast coverage is acquired.

4 Conclusions

In this paper, to suppress the broadcast storm, balance energy consumption and provide broadcast reliability, a cooperative broadcast algorithm based on the successful broadcasting ratio and residual energy of neighbor nodes in mobile ad hoc networks is presented. Simulation results show that BSRREN is effective to suppress broadcast storm, prolong network lifetime and provide broadcast reliability to certain extent.

Acknowledgments. The work is partially supported by The Graduate Science and Technology Innovation Project of Zhejiang Gongshang University (virtual force based cooperative broadcast algorithm in wireless ad hoc networks).

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