Distance and Cooperation Based Broadcast in Wireless Ad Hoc Networks

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Abstract. Broadcasting is one of common data dissemination techniques in wireless ad hoc networks. Thus, it is critical to improve the broadcast efficiency. Flooding, which is simple but has reliable coverage, results in high broadcast redundancy, channel contending and message collision when the network is densely distributed. In this paper, a new broadcast algorithm named as distance and cooperation based broadcast (DCBB) is proposed. In DCBB, four neighbor nodes at most are determined to forward broadcast packets based on the number of neighbors and the distance between neighbors. Redundancy can be reduced by limiting the number of relay nodes. And, through the time-division forwarding scheme, channel contending is reduced and the network utilization is improved effectively. Moreover, due to the limited number of relay nodes, DCBB saves energy of nodes and prolongs the network lifetime. The simulation results show that DCBB achieves higher reachability and lower retransmitted ratio compared to dynamic probabilistic broadcasting algorithms (DP). Meanwhile, the average maximum end-to-end delay is significantly decreased. Therefore, DCBB is applicable to densely distributed network environment.

Keywords: Wireless ad hoc networks · Broadcasting · Distance and corporation based broadcasting

1 Introduction

A wireless ad hoc network is a multi-hop and temporary autonomous system, which consists of mobile devices, equipped with wireless communication capacities. One of the fundamental operations in wireless ad hoc networks is broadcasting by which a source node disseminates a message to all other nodes. Broadcasting is widely used in many ad hoc network protocols. For instance, it can be used to find a route in Ad hoc On-Demand Distance Vector Routing (AODV) and Dynamic Source Routing (DSR) protocols. It can also be used to update network topology, to deliver multi-media information, to release control and warning messages, etc. [1, 2].

In wireless ad hoc networks, flooding is the simplest way to broadcast. In flooding, every node retransmits the broadcast message received first time. In general, flooding achieves high coverage. However, blind flooding causes significant redundant

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transmissions, which results in substantial waste of network resource in densely distributed networks [3, 4]. The main problems caused by flooding are redundant transmissions, channel contentions and packet collisions, which are called as the broadcast storm problem. Redundant transmissions refer to that a node receives the same messages more than once. Upon receiving a message, a node retransmits the message to its neighbors. Those neighbors, which are adjacent to each other, receive and retransmit the messages almost in the same time, which result in the contending for the channel. With the number of neighbors increasing, the probability of contending increases. Signal collision may be caused by hidden or neighbor nodes. For example, if the distributed coordination function (DCF) of medium access control (MAC) in IEEE 802.11 is used in ad hoc networks, hidden terminal problems as well as collisions are unavoidable. Moreover, collisions lead to broadcasting unreliability [3, 5].

To achieve reliable broadcast in wireless ad hoc networks, we propose a distance and cooperation based broadcasting algorithm (DCBB), in which the broadcast storm and unreliability are resolved simultaneously. In DCBB, every node selects four neighbor nodes at most, acting as relay nodes to transmit the packet at different time point according to the distribution of nodes. Redundancy is reduced by limiting the number of relay nodes. At the same time, collisions are avoided by transmitting at different time slots for those relay nodes, which mitigate the channel contentions. Moreover, due to the limited number of relay nodes, DCBB saves the energy of nodes and prolongs the network lifetime, which are crucial for wireless ad hoc networks since nodes in the networks have limited energy and frequent retransmission consumes a large amount of energy.

The rest of the paper is organized as follows: related work is presented in Sect. 2, and the design of the DCBB algorithm is presented in Sect. 3. Its performance is examined via simulation in Sect. 4. Finally, the conclusion is given in Sect. 5.

2 Related Work

Broadcast is a fundamental communication operation in wireless ad hoc networks. However, the broadcasting storm problem, caused by flooding, severely deteriorates the performance of networks in terms of the throughput and other QoS metrics. The broadcasting unreliability, caused by collisions, also affects the performance. Therefore, it is crucial to develop efficient broadcasting algorithms to solve the above problems. Currently, researches on wireless network broadcast mainly focus on the broadcast storm mitigating technique [5–11], followed by the reliable broadcast and its acknowledgement storm [12, 13].

At present, algorithms for broadcast storm mitigation can be classified into four categories: probability based [2, 7, 8], area based [2, 14, 15], neighborhood based [6] and hybrid algorithms [16]. Although the above algorithms reduce broadcasting redundancy to some extent, they are still not satisfied in many scenarios. The probability based algorithms are simple, but their efficiency to reduce redundancy are not good enough or they have lower coverages. The neighborhood based algorithms which are sensitive to topological change and are involved in the NP problem, are complex. The area based algorithms need the support of GPS and have their limitation in applications.

Compared with the broadcast storm problem, fewer researches focus on unreliable broadcasting. Some routes are not discovered and route information is out of date due to unreliable broadcasting. In wireless ad hoc networks, upon an upstream node sending a message, a collision occurs at some receivers if all neighbors forward the message at the same time. Ultimately, the receivers are unable to receive the message correctly, i.e., the unreliable broadcasting problem. Reliable broadcast schemes can be classified into four categories: flooding based algorithms, the minimum spanning tree based algorithms, hybrid algorithms and acknowledgement based algorithms. The flooding based algorithms are simple but highly reliable. However, the broadcasting storm problem is severe. The reliable minimum spanning tree (RMST) algorithm [5] is the most popular one among the minimum spanning tree based algorithms. In wireless ad hoc networks, however, it needs a large amount of calculations to construct the minimum spanning tree and is hard to realize the distributed computation. In the acknowledgement based algorithms, the acknowledgement storm problem emerges.

Due to the importance of broadcasting in wireless ad hoc networks, many novel approaches for broadcast have been proposed recently. We are going to elaborate the most recent advancements to this issue as following.

A. Hybrid algorithms: neighborhood and probability based

Abdalla et al. [16] proposed a hybrid approach based on probability and neighbor information, named as Dynamic Probabilistic broadcasting algorithms (DP). In DP, every node periodically sends HELLO packets to acquire network topology information. Each node dynamically adjusts rebroadcasting probability P_i according to the number of neighbors. P_i varies with the density of network nodes. P_i is larger in a sparse area and is smaller in a dense area. Therefore, the transmission redundancy is reduced.

B. Neighborhood based algorithms

S. Leu proposed a distributed algorithm to construct a connected dominating set [17]. Node S periodically sends probe packets to acquire the information from relay nodes. Each node randomly decides whether to be a relay node, and sends the response to node S. Node S maintains a table for relaying nodes. If there are more than two nodes in the table, node S will stop sending probe packets. This scheme can reduce the broadcasting redundancy and avoid the NP problem which is essential in other conventional CDS (connected dominating set) algorithms.

C. Underlying broadcasting protocols

Recently, many scholars have begun to study the broadcasting algorithms suitable to MAC or physical layer. Zhang and Shin [18] proposed a scheme named carrier sensing multiple access/collision resolution (CSMA/CR), which can be applied to solve the collision in wireless ad hoc networks. Upon receiving a packet, the node transmits the packet directly without sensing the channel or delay. CSMA/CR performs collision resolution and recovers the packet by a symbol–level iterative decoding. Thus, higher reachability and lower latency is achieved.

D. Position based algorithms

Liu et al. [19] proposed a space-covered broadcast (SCB) algorithm which does not need any neighbor information to mitigate the broadcast storm. With the location obtained by GPS, SCB utilizes the minimal number of forwarding nodes to cover a network by optimizing the spatial distribution of the forwarding nodes.

E. Energy based algorithms

While nodes in wireless ad hoc networks usually run on battery with limited power. Related studies show that data transmission consume more energy than data receiving. Thus, it is necessary to propose an energy efficient broadcasting algorithm to increase the lifetime of ad hoc networks. Many scholars have studied broadcast by taking energy consumption and broadcasting storm suppression into consideration. In [11], the author proposed an algorithm based on residual energy and distance threshold (SED). According to its own residual energy and neighbors' information, the receiving nodes dynamically adjust the retransmission probability *PI*. The waiting time for a retransmission is determined by *PI*. Based on different retransmission probability, SED can balance the nodes' energy and improve the network lifetime.

In [20], to maximize the network lifetime, a Minimum Energy-consumption Broadcast Scheme (MEBS) is proposed based on modified version of Efficient Minimum CDS algorithm (EMCDS). Simulation results show that MEBS can help improve the network lifetime by effectively balancing the energy among nodes in a network.

In conclusion, broadcasting protocols with satisfactory performance should have fewer contentions and collisions, fewer redundant retransmissions, lower reliable reachability, low latency and overhead, as well as wide range of applications. In this paper, we propose a broadcast scheme called as Distance and Cooperation Based Broadcast (DCBB). In DCBB, every node selects four nodes at most to forward the packet at different time point according to the distribution of nodes. It reduces the channel contention and increases the broadcasting reliability. Meanwhile, it does not need any GPS to obtain the distance between nodes.

3 The DCBB Algorithm

The objective of DCBB is to mitigate the broadcast redundancy and improve broadcast reliability. Each node in the network periodically sends HELLO packets to exchange neighbor information. According to the distance to all neighbors, a node determines a distance threshold. Let d be the distance between a receiving node and an immediate upstream node. A neighbor node that receives a broadcast packet will not forward it to its own neighbors if d is less than the distance threshold. The node will be a candidate for broadcast transmitting if d is larger than the threshold and closed to $2/3R$ (R is the radius of a node's transmission range). Four candidates at most will be selected as the forwarding nodes to forward the broadcast packet received for the first time in distinct time slot if the combinations of their coverage can cover more next-hop nodes. In the light of research experience, the nodes whose distance to the sender are closed to $2/3R$ will receive packets more reliably and they can also get larger extra coverage.

However, nodes whose distances to the sender are closed to R will not be the candidates for broadcast transmitting because signal amplitude they received is lower and not reliable in the reality. Having taken the above factors into consideration, DCBB can achieve higher coverage and lower collision by the time division forwarding.

A. Obtaining the distance between neighbors

Distances between neighbors are obtained by measuring the signal power of a transmitter and a receiver. There are many models to measure the signal power, such as free space propagation model, two ray propagation model, etc. In this paper, we assume that the wireless channel model is free space propagation mode. Then,

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \tag{1}$$

P_t, P_r denote the transmitting power and the receiving power, respectively. d is the distance between a transmitter and its corresponding immediate receiver. G_r is the transmitting antenna gain and G_r is the receiving antenna gain. L is the loss factor and has no relation with the system ($L \geq 1$). A is the wavelength (m). From the Eq. (1), d is obtained as:

$$d = \frac{\lambda}{2\pi} * \sqrt{\frac{P_t G_t G_r}{L P_r(d)}} \tag{2}$$

B. Determining the distance threshold

Every node periodically sends HELLO packets each other. Node S determines its distance to all neighbors according to the amplitude of the signal it received from its neighbors. On the basis of these distances, node S determines a distance threshold D_{th}.

If all neighbors are uniformly distributed, D_{th} is set to be the average of all neighbors' distances. If nodes are unevenly distributed, it will not only need to determine the average distance $aver(d)$, but also set a specific value r ($r = R/5$, for example). For nodes whose d is less than r (those nodes in A1 as shown in Fig. 1) will not retransmit the broadcasting packet because the additional coverages of these nodes are small and cause high redundancy. The final value of D_{th} is determined by the value of average distance $aver(d)$ and r. If $aver(d)$ is smaller than r, D_{th} is set to $aver(d)$. And if $aver(d)$ is larger than r, D_{th} is set to r. That is:

If $aver(d) \leq r$, then $D_{th} = aver(d)$;
If $aver(d) \geq r$, then $D_{th} = r$.

Here are two special situation of nodes' distribution:

- When node S has only one neighbor H, there is no need to determine the threshold. H will definitely be the retransmitted node.

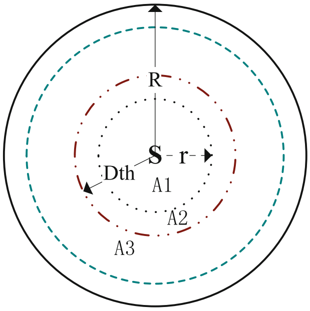

Fig. 1. Areas for different coverage

- When all neighbors of node *S* are closely distributed around node S, which means node *S* has to select the relay nodes among these neighbors although the retransmitted coverage they gain are very small.

In both cases, the distance threshold can be determined in accordance with the conditions we described above. In other cases, such as the uneven distribution, the threshold can also be determined. Namely, no matter how many neighbors there are, no matter how they are distributed, a node can determine a distance threshold and relay nodes according to the above approach.

C. Determining the forwarding nodes

We determine the forwarding nodes according to the following rules: usually nodes within the distance threshold will not retransmit, and nodes outside the threshold will be candidates to forward the packet with high probability. If there are more qualified candidates than required and all of these candidates retransmit the packet, it will result in collision at the receiving nodes, which is one form of unreliability. Therefore, to avoid collision, we select four nodes at most to forward the packet in a cooperative way in our protocol. These nodes start to forward at different time point.

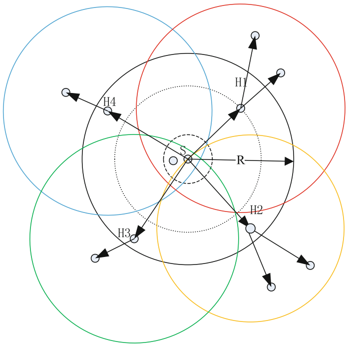

Fig. 2. Determining the forwarding nodes

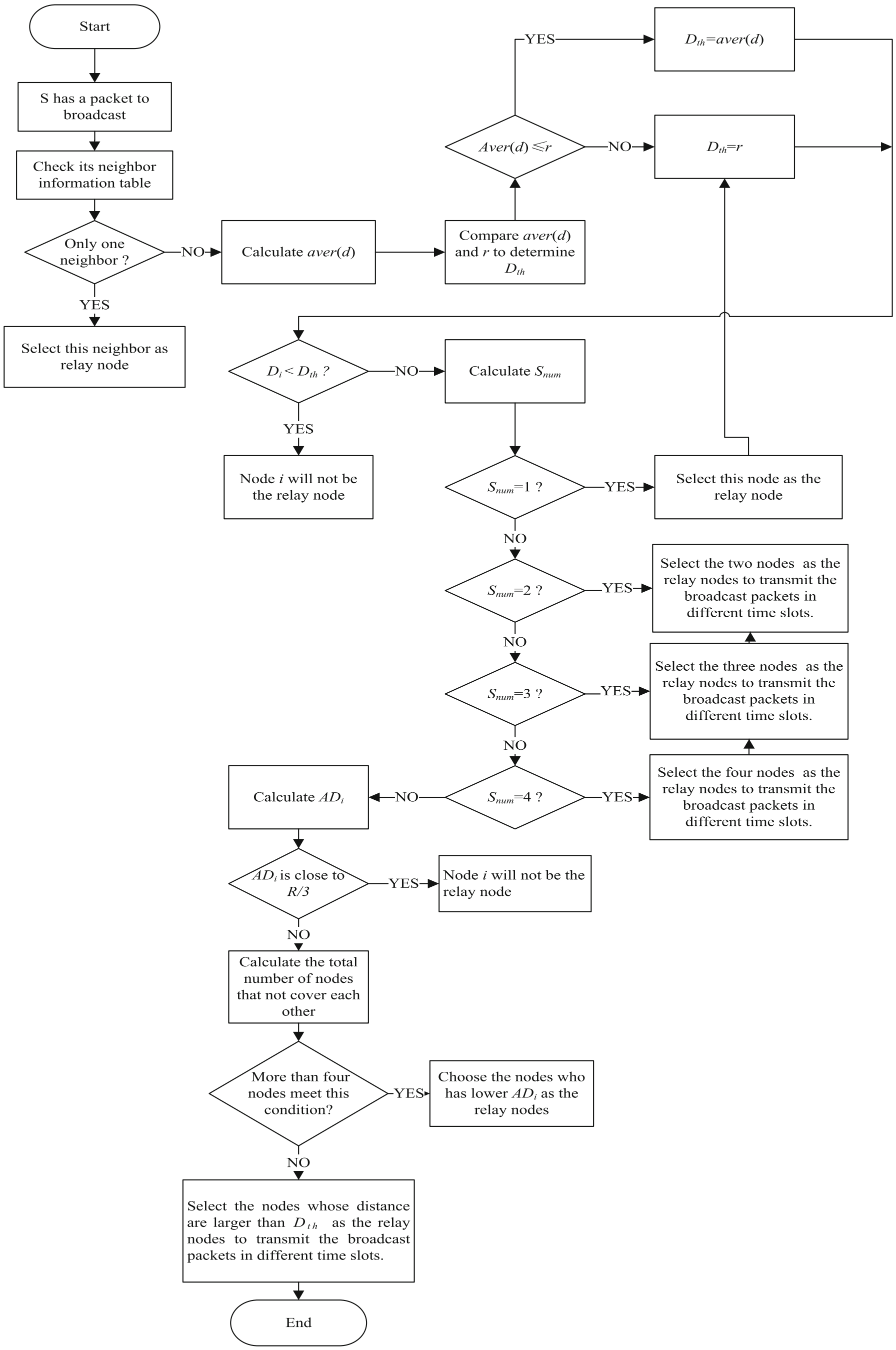

Fig. 3. The flow chart for determining the forwarding nodes

For example, in Fig. 1, nodes in A2 will not forward the broadcasting packet, while nodes in A3 will be the candidates to forward the packet. Among these candidates, four nodes whose distances d from S are closed to $2/3R$ will be selected to forward the broadcast packet in distinct time slots. There might be more than four candidates close to $2/3R$, the criteria to select the forwarding nodes is as follows: firstly, calculate the absolute values between d of these candidates and $2/3R$. The less the absolute value is, the closer it is to $2/3R$, and the higher possibility it is to transmit the packet. Secondly, node S should do the best to make that the four forwarding nodes are not in each other's coverage. This way can extend the coverage, reduce the broadcast redundancy and improve the reliability. As shown in the Fig. 2, node S is the source node, and $H1$, $H2$, $H3$, $H4$ are next-hop nodes to forward the packet in a cooperation manner and they do not cover each other.

Figure 3 is the flow chart for determining the forwarding nodes. Let D_i be the distance between the sending node and the neighbor i, S_{num} be he number of neighbors whose distance is larger than D_{th}, and AD_i represent the absolute difference between D_i and $2/3R$. In the flow chart, It can be seen that the occasions of less than four neighbor nodes is taken into consideration as well.

4 Simulation Results and Analysis

We conducted the simulation to test the performance of DCBB. DP is an algorithm which adjusts forwarding probability dynamically based on the number of neighbors [16]. Both DP and DCBB are based on neighbor information, so we selected DP as the reference.

The simulation settings are as follows. The area is a 1.0 km*1.0 km square field with 20, 40, 80 and 100 nodes randomly uniformly deployed. The MAC protocol of each node is IEEE802.11 DCF, and the bandwidth of wireless interface is 11 Mb/s. The transmission range of a node is set to R = 250 m. And there is one source node in the networks which generates broadcast packets. The Data flow sent by the source is in constant bit rate, and it generates 5 packets per second. The size of each packet is set to 64bytes.

The following performance metrics are used for evaluation and comparison: (1) Retransmitted ratio is defined as the ratio of the number of forwarding nodes over the total number of nodes in the network. (2) Reachability is the proportion of nodes in the entire network which can receive a broadcast packet. (3) Average maximum end-to-end delay is the average maximum delay for a broadcasting packet. We record the start time of a broadcast packet as well as the time when the broadcast packet reaches a destination node. The difference between these two values is the end-to-end delay of broadcast.

Figure 4 shows the retransmitted ratio versus different number of nodes in a network. As shown in the figure, retransmitted ratio of DCBB is significantly lower than that of DP because DCBB suggests that few nodes are involved to forward the broadcasting packet. In order to save energy of nodes and prolong the lifetime, it is important for networks to reduce the retransmitted ratio. By reducing the number of forwarding nodes, DCBB can decrease the redundancy and improve broadcast efficiency efficiently.

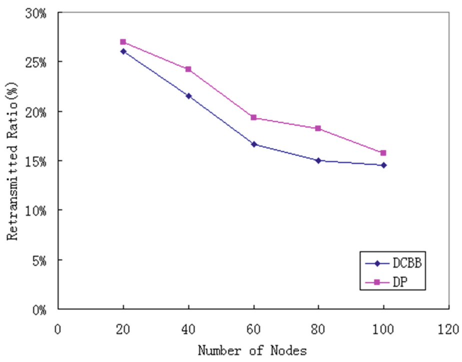

Fig. 4. Retransmitted ratio VS. Number of Nodes

Figure 5 indicates the reachability versus different number of nodes in a network. We can see that the reachability for DP decreases rapidly and is significantly lower than DCBB when the number of nodes in the network is larger than 40. Considering the additional coverage, DCBB selects four relay nodes at most to retransmit the broadcasting packet. Moreover, to ensure the reachability, the relay nodes will forward the packet at different time slots. However, the relay nodes in DP will retransmit the broadcasting packet at the same time, which lead to collision and unreliable broadcast. The simulation results are consistent with the theoretical analysis.

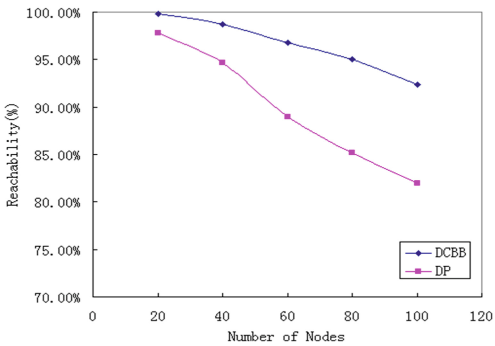

Fig. 5. Reachability VS. Number of Nodes

Figure 6 shows the average maximum end-to-end delay of networks. In DCBB, each forwarding nodes will select a delay time randomly to avoid contending the channel if they transmit the broadcasting packet at the same time. As indicated in the figure, the value of average maximum end-to-end delay of DCBB is a little greater than that of DP. That is because DCBB will select a random waiting time before retransmit the packet to avoid collision. But the delay of DCBB is still very small and does not make a sense to the overall delay of applications.

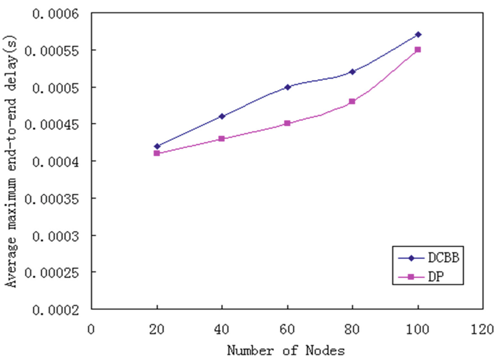

Fig. 6. Average maximum end-to-end delay VS. Number of Nodes

5 Conclusions

In this paper, we propose a distance and cooperation based broadcasting algorithm suitable for wireless ad hoc networks. Theoretical analysis and simulation results show that higher reachability, lower retransmitted ratio and reasonable end-to-end delay have been obtained by DCBB. Therefore, DCBB has achieved the goal of reducing redundancy and the broadcast traffic to a network. It increases the efficiency of broadcast. In general, the algorithm we proposed is applicable to the densely distributed network environment. Through time-division forwarding scheme, every node can reduce channel contending and improve the network utilization effectively. For future work, we wish to apply DCBB to the AODV routing protocol to further demonstrate its performance in the practical scenario.

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