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Multipoint relay selection for robust broadcast in ad hoc networks

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ABSTRACT

Broadcasting is a frequently used technique in a wireless ad hoc network not only to deliver protocol control information but also application data. Optimized Link State Routing (OLSR) uses Multipoint Relay (MPR) to flood Topology Control (TC) message while reducing redundant retransmissions. The downside of reducing duplicated retransmission is vulnerability of the transmitted packet to the packet error, collision, or hidden nodes. In this paper, we propose a multipoint relay selection method for robust broadcast in a wireless ad hoc network. The proposed method selects additional MPR nodes so that it can cover 2-hop MPR nodes m times not to cover all 2-hop neighbor nodes m times. The number of additional MPR nodes is analyzed using mathematical modeling and simulations. The proposed method can improve network throughput as well as delivery ratio compared with the original MPR selection method of OLSR.

1. Introduction

Wireless ad hoc networks provide peer-to-peer communications between nodes without the aid of communication infrastructure. The nodes in a wireless ad hoc network can be connected in a distributed way avoiding single point of failure for the network availability. Due to its easy deployment and flexibility of network operation, wireless ad hoc networks are used in a wide range of areas, such as tactical communication networks, or search and rescue operation in infrastructure-less regions. The strength of wireless signal, or electromagnetic wave, decreases drastically as it travels along the air and a mobile node has a limited battery life. So communications between two independent nodes may be limited by distance or energy source. Nevertheless, any two nodes in the same network should be able to communicate with each other by a multi-hop routing path. In a wireless ad hoc network, since there are no dedicated central points of connection, e.g., Access Point (AP) or Base Station (BS), every node is supposed to work as a terminal and a router. Thus, a routing protocol connecting two nodes which cannot communicate with each other directly is playing a major role in a wireless ad hoc network [1].

Routing protocols used in a wireless ad hoc network can be categorized as table-driven (proactive) routing protocols and on-demand (reactive) routing protocols [2]. In a table-driven routing protocol, all nodes in a network periodically exchange topology information so as to use them to find routes to other nodes and store (or maintain) routes in a routing table. A node can refer to its own routing table and find a route to a specific node instantly. On the other hand, an on-demand routing protocol does not maintain a routing table in each node. A node with an on-demand routing protocol broadcasts a route request message to find a route when it is needed.

Broadcast, one-to-all communications, is frequently used in a routing protocol for a wireless ad hoc network, especially for route request or propagation of topology information. One of the most dominant broadcast mechanisms is simple flooding. In simple flooding, a broadcast

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packet is retransmitted at each of intermediate nodes if it has not been heard before. One drawback of simple flooding is the redundancy of retransmissions, which eventually lowers the protocol efficiency. This is a more important issue in proactive routing protocols than that in reactive routing protocols, since the former disseminates periodic control messages for routing table maintenance, while the latter exchanges control messages only when it is needed.

Optimized Link State Routing (OLSR) [3,4] is one of the table-driven routing protocols for an ad hoc network. OLSR introduces Multipoint Relay (MPR) to reduce the protocol overhead in broadcasting control messages. In OLSR, each node chooses its MPR nodes among its 1-hop neighbor nodes to cover (reach) whole 2-hop neighbor nodes at least once. When a node receives a broadcast packet, it looks for the address of a sender node in the packet header, and only if the sender node had chosen the node as its MPR, it retransmits the received packet. In OLSR, by utilizing MPRs, the number of retransmissions to deliver broadcast packets, e.g., Topology Control (TC) messages in OLSR, to an entire network can be reduced. It is also possible to use the concept of MPR to broadcast not only control messages but also data, which is called MPR flooding [5].

However, reducing the number of broadcasts may not necessarily advantageous for reliable packet delivery in an ad hoc network [6]. Due to the characteristics of the wireless medium, frame errors may happen during communications. Another reliability issue comes from the Medium Access Control (MAC) layer. The retransmission of a packet by an MPR node is realized by broadcasting the frame containing the packet at the MAC layer [7]. In IEEE 802.11, with the Carrier Sense Multiple Access (CSMA) MAC protocol, a transmitting node and a receiving node exchange a short Request-to-Send (RTS) frame and a Clear-to-Send (CTS) frame before transmitting an actual unicast data frame. RTS and CTS frames can prevent the neighbor nodes from becoming hidden interfering nodes. After the successful data frame transmission, the receiving node responds to the transmitting node with a short Acknowledgment (ACK) frame. For the broadcast frame delivery, the basic access method (i.e., data frame and ACK frame transmission without RTS–CTS frame exchange) is used instead. So, the hidden node problem can easily occur, causing frequent MAC layer frame collisions [8,9]. Since the broadcast frames cannot be acknowledged, the backoff window size is fixed to the minimum and it does not increase as time evolves even if there are collisions [10]. Thus reduction of broadcast transmissions without taking care of reliability may introduce an adverse effect.

In this paper, we propose a new MPR selection method to improve the reliability of broadcast packet delivery in MPR flooding in an ad hoc network. Since an MPR node plays an important role in delivering broadcast packets to its next MPR nodes as well as to its neighbor nodes, failure to receive the broadcast packets by an MPR node can greatly affect the reliability, i.e., delivery ratio. In other words, MPR nodes can work as a "hub" in the broadcast packet delivery. In our proposed MPR selection method, a node chooses its additional 1-hop MPR nodes so that they can cover the next 2-hop MPR nodes m-times. So the reliability of broadcast packet delivery is improved with small increase of MPR nodes since the redundancy in broadcast packet reception is limited to m. Thus our protocol well balances the overhead and the reliability.

The organization of the paper is as follows. In Section 2, we review the MPR selection method and OLSR. Section 3 describes the proposed MPR selection method. In Section 4, the number of MPR nodes and the MAC throughput performances for different MPR selection methods are analyzed. Simulations of several MPR selection methods are presented in Sections 5 and 6 concludes.

2. OLSR and MPR selection

The MPR selection method in OLSR is designed for the MPR nodes of a node to cover all 2-hop neighbor nodes with the smallest number of MPR nodes. First, a node selects an MPR node which connects the node with some 2-hop neighbor nodes, and the node repeatedly selects such MPR nodes until all 2-hop neighbor nodes are covered by the MPR nodes at least once. An example of MPR selection in OLSR is depicted in Fig. 1. Node 6 has four 2-hop neighbor nodes, i.e., nodes 1, 10, 11, and 12. Among its 1-hop neighbor nodes, node 4 is the only node who can cover node 1, so node 6 chooses node 4 as its MPR node. Node 6 still has an uncovered 2-hop neighbor nodes, i.e., nodes 10, 11, and 12, so it chooses node 9 to cover all of them. In the same manner, node 9 chooses node 6 and node 10 as its MPR nodes. Control messages for MPR selection in OLSR is flooded into an entire network via MPR nodes in the hop-by-hop manner. Fig. 1 shows the case of failure in packet delivery using the MPR nodes selected in OLSR. Node 9 (MPR of node 6) retransmits the packet originated from the node 6. If node 10 fails to receive the packet, then nodes 8 and 13 are also blocked from receiving the packet.

A general solution to achieve the minimal set of MPR nodes is known to be an NP-complete problem [11]. There has been several researches to modify MPR selection methods and reduce the number of MPR nodes. In Cooperative MPR selection [12], every node tries to choose its MPR nodes in a way to reuse the MPR nodes of its neighbor nodes as

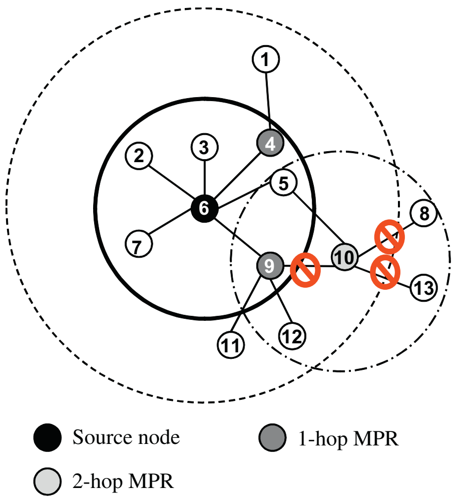

Fig. 1. An example of the MPR selection method of OLSR.