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A probabilistic and opportunistic flooding algorithm in wireless sensor networks

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ABSTRACT

In wireless sensor networks, many communication protocols and applications rely on flooding for various networking purposes. Prior efforts focus on how to design efficient flooding algorithms; that is, they seek to achieve full reliability while reducing the number of redundant broadcasting across the network. To achieve efficient flooding, most of the existing protocols try to reduce the number of transmissions, which is decided without considering any online transmission *result*. In this paper, we propose a probabilistic and opportunistic flooding algorithm that controls rebroadcasts and retransmissions opportunistically. It seeks to achieve a target reliability required by an application. For this purpose, it makes a given node select only the subset of its one-hop neighbors to rebroadcast the same message. It considers node relations such as link error rates among nodes in selecting eligible neighbors to rebroadcast. The sender controls the number of retransmissions opportunistically by tracking the current status of message reception at its neighbors. Simulation is carried out to reveal that our proposed scheme achieves the given target reliability with less overhead than other flooding algorithms in most cases, thus prolonging the network lifetime.

1. Introduction

Flooding is one of key mechanisms that are widely used in various wireless networks. It propagates a message throughout a network for various purposes. Especially, flooding is usually leveraged to establish a route to the destination for unicast routing (e.g. AODV [1], DSR [2]). Similarly, when a node should inform other nodes of its link state, its latest link information is flooded across the network (e.g. OLSR [3]). Due to its viability, diverse flooding algorithms have been proposed in various wireless networks including wireless sensor networks (WSNs).

Since the objective of flooding is to make it sure that all the nodes in a network receive the same message, flooding is generally performed by making all the nodes rebroadcast the received message. However, this becomes inefficient as the node density increases, which is a typical case in WSNs. Another issue is that it is hard to achieve high reliability because wireless links generally suffer from high error rates. Thus, to achieve high reliability, retransmissions are often exploited. It is crucial to decide which node to rebroadcast and how many times to retransmit the message in a flooding mechanism, since the rebroadcasting of too many nodes and/or redundant retransmissions may cause traffic implosion [4], which leads to unreliability and energy inefficiency. Prior studies have proposed several flooding schemes that seek to achieve high reliability while reducing redundant traffic by controlling the number of broadcasts.[1] However, the existing approaches have not considered the effect of a transmission (or a retransmission) of a given node on the message reception by its neighbor nodes quantitatively.

Furthermore, in wireless sensor networks, the network-wide full reliability[2] may not always be required according to the application requirements. For example, many sensor network applications such as temperature monitoring or intrusion detection system deploy many sensors redundantly to cover the monitoring area for high reliability [5,6]. In this situation, a sink may want to disseminate a query with *partial reliability*. If the sink can achieve its own purpose only with *R*% of sensors, it may want to disseminate the query to only *R*% of sensors to reduce the number of rebroadcasts and thus energy consumption. Therefore, supporting flooding with partial reliability is another important technique to prolong lifetime of the

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[1] For clarity purposes, we use the following definition in this paper. The number of 'broadcasts' is the total number of transmissions of the same message throughout the network. The number of 'rebroadcasts' means how many nodes in the network have rebroadcasted the same message; thus, a node who transmits the message multiple times is counted only once. The number of 'transmissions' of a given node is how many times the node has transmitted the same message.

[2] In reality, a network-wide 100% reliability is often infeasible; thus, we target a sufficiently high reliability (say 95%) that can satisfy the application requirements. In this paper, the full reliability refers to a sufficiently high reliability.

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sensor network.

Some schemes aiming to provide partial reliability in WSNs have been proposed in various contexts. For example, MMSPEED [7] seeks to deliver unicast packets with partial reliability required by applications in a decentralized and probabilistic fashion. However, MMSPEED only deals with unicast flows and does not consider the reliability of flooding. In addition to the partial reliability, GARUDA [8] considers a few other semantics of reliability. For example, sensor network applications may necessitate reliable delivery to sensors such that the entire sensing field is covered, not to all the sensors in the field. ESRT [9] redefines "reliability" somewhat differently. ESRT first assumes that sensory data packets are periodically reported from sensors to the sink. During a session, depending on the level of network congestion, the sensors can adjust the reporting rate (or "reliability") to adapt to the network traffic load. However, the meaning of reliability in ESRT is different from our definition of partial reliability in this paper. To the best of our knowledge, how to support flooding with a target reliability has been missing in the literature.

In this paper, we seek to achieve a target reliability given by an application, ranging from full to partial reliability, while minimizing the number of broadcasts in a probabilistic and opportunistic manner. In other words, each node selects the subset of its one-hop neighbors, that will rebroadcast the same message by considering link error rates among the node itself, its one-hop neighbors and its two-hop neighbors for the target reliability. After a source node or a rebroadcasting node transmits a message once, it decides to retransmit or not by estimating the locally achieved reliability probabilistically and opportunistically. We note that OLSR tries to minimize the number of transmissions in flooding by making only selected nodes (called multi-point relays) rebroadcast the message. We extend the notion of multi-point relays (MPRs) to control flooding to achieve a target reliability required by applications. That is, depending on the target reliability and the link error rates[3] of neighbors, the set of MPRs of a sender will be dynamically adjusted.

The rest of this paper is organized as follows. Prior studies are discussed in Section 2. In Section 3, we propose a novel flooding algorithm, called POFA. Simulation results are shown in Section 4. Finally, Section 5 concludes this paper.

2. Related work

OLSR [3] is a proactive routing protocol for mobile ad hoc networks. OLSR relies on flooding to disseminate each node's local link information throughout the network to help other nodes build/update their routing tables. If every node participates in flooding, its signaling overhead would be substantial. Hence, OLSR seeks to minimize the number of broadcasts[4] by making only selected nodes (called as multipoint relays) rebroadcast the routing message. For this purpose, each node designates the subset of its one-hop neighbors as multipoint relays (MPRs), so that MPRs' rebroadcasting the message will reach all of its two-hop neighbors. However, in selecting MPRs, OLSR considers only coverage; link error rates and reliability level are not major concerns. One of reasons is that routing messages are periodically disseminated. Overall, OLSR is not adequate for broadcasting applications that require a target reliability.

As for flooding, numerous algorithms have been proposed to improve reliability or reduce redundancy or both. In gossip-based routing [10] and probabilistic broadcasting schemes [11], a node rebroadcasts messages with a certain probability, say *r*. By adjusting *r*, gossip-based routing tries to reduce the number of broadcasts in the network layer, while probabilistic broadcasting focuses on reducing both collisions and energy consumption in the MAC layer. Although these protocols effectively reduce the number of broadcasts, it is difficult to decide *r* to achieve the given target reliability.

RBP [12] improves reliability by controlling the number of retransmissions carefully. Each node rebroadcasts a received message at least once, and then decides whether to retransmit the received message or not by comparing the number of received (implicit or explicit) ACKs with some threshold, which is determined based on the number of its one-hop neighbors. If there are many one-hop neighbors, the probability of rebroadcasting by other nodes is high, which makes the threshold smaller. However, as the node density increases, making every node rebroadcast at least once will become inefficient.

RAFA [13] extends RBP in the sense that it takes the network topology further into account. RAFA notices that two nodes with the same number of one-hop neighbors can have distinct connectivity patterns among their respective one-hop neighbors. That is, rebroadcasting a message from a one-hop neighbor may effect other one-hop neighbors. In RAFA, connectivity among one-hop neighbors is taken into consideration to further reduce the number of retransmissions. In other words, it decides whether to retransmit the received message by comparing an expected reliability of 1-hop and 2-hop neighbors with a threshold. However, also in RAFA, every node rebroadcasts at least once, which is inappropriate to satisfy partial target reliability efficiently, although a threshold is adjusted by a target reliability. That is shown in the numerical results of this paper.

LAF [14] and BPS [15] are flooding protocols for WSNs, which leverage the locations of sensors to flood packets efficiently. LAF divides sensor nodes into virtual grids depending on their positions. In each grid, there is a gateway node responsible for forwarding messages across virtual grids. And if messages are relevant to a given grid, the gateway node will forward the messages to other sensor nodes within the given grid. In BPS, only a few nodes which cover all sensor nodes are selected to forward messages by exploiting their location information. Even though these protocols reduce the number of broadcasts, they require obtaining location information for every sensor node.

3. Probabilistic and opportunistic flooding algorithm (POFA)

In this section, we explain a probabilistic and opportunistic flooding algorithm (POFA) that reduces the number of broadcasts while satisfying the given target reliability. In OLSR, every link is presumed to be error-free and the subset of one-hop neighbors that cover all of the two-hop neighbors is selected as MPRs from the viewpoint of a sender. By contrast, our proposed scheme assumes each link has its own link error rate. Thus, the sender is aware of (i) link error rates between its one-hop neighbors and itself, and (ii) link error rates between its one-hop and two-hop neighbors. We assume that the link error rates can be calculated based on periodic message exchanges between sensor nodes for neighbor discovery and/or synchronization [16] or in a similar way as [13,17,18]. Our assumptions stand on some researches for these issues. Woo et al. [17], Woo and Culler [19] proposed the stable estimation methods of the link error rate using moving averages which can be used even when the link state is changed rapidly. With the stable estimation of link error rate, the exchanges of link information between neighbor nodes need not to be occurred frequently. This implies that piggybacked flooding packets or periodic messages are sufficient to exchange the link state in POFA. In addition, other works proposed estimation methods which used RSSI, LQI or distances between neighbor nodes

[3] The link error rate refers to the probability that a single transmission is not successful between a pair of nodes in communication range and is often called packet error rate in the literature.

[4] In this paper, a broadcast means a single transmission of a message to one-hop neighbors, while flooding refers to network wide dissemination of a message through hop-by-hop broadcasting.