A Low Overhead, Energy Efficient, Sink-initiated Multipath Routing Protocol for Static Wireless Sensor Networks

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Abstract

Multipath routing in wireless sensor networks has been proven to provide with increased data delivery ratio, security, robustness to node and link failures, network throughput, etc. However, the energy cost for multiple routes construction and their maintenance is very high. This paper proposes a sink-initiated, node-disjoint multipath routing protocol for static wireless sensor networks that significantly minimizes the route construction messages and thereby saves the critical batter energy of sensor nodes. It also distributes the traffic load spatially over many nodes in the forwarding paths, which ensures balanced energy consumption in the network and thereby increases the network lifetime. The simulation results show that it decreases the routing overhead as well as the standard deviation of nodes' residual energies.

1. Introduction

The increasing diversity of application areas of Wireless Sensor Network (WSN) brings new challenges and thus it gets much research interest all over the world. Multipath routing in WSN has been proven to provide with higher reliability, robustness, security and network lifetime [1][2][3]. The term multipath routing has been used in the literature to describe the class of routing mechanisms that allow the establishment of multiple paths between a source and a destination. In WSN, all the source sensor nodes forward their sensed data packets towards the base station, commonly referred to as the sink node, over multihop wireless channel. Therefore, the construction of multiple paths from each source sensor node to the sink and their maintenance is a major challenge for energy critical sensor nodes.

In [1], authors propose a braided-multipath routing protocol where a source node broadcasts a route request and neighbor nodes also rebroadcast this message. Eventually, the sink node receives multiple copies of the route request packet from its neighbor nodes and finds the disjoint or braided paths and thus sends back the reply messages to the source node. The protocols works fine for both the static and mobile WSNs, but it has large overhead of exchanging a significant number of messages for route construction.

An AODV based resilient multipath routing protocol is proposed in [2], namely RMRP, in which sensor nodes setup double routing paths toward sink nodes in an AODV fashion and select one of them randomly for forwarding a packet. RMRP also proposes a resilient route maintenance scheme which repairs broken links by utilizing localized information around neighbor nodes of the broken link and thereby reducing the flooding range of control messages.

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In [3], an energy-aware multipath routing algorithm, namely EMRA, is proposed for WSN, where HELLO messages are exchanged among all the nodes and the destination node replies back with a REPLY message only. The key problem with this routing algorithm is that the HELLO messages initiated by all the sensor nodes of the network might consume a huge amount of energy.

Unlike the above works, in this paper, we propose a sink-initiated multipath routing protocol for static wireless sensor networks, i.e., once deployed all the nodes of the network including the sink node do not change their locations. This assumption is frequently seen in sensor networks because the mobility is seldom found in WSN applications (except military applications). The sink node broadcasts route construction messages, the intermediary nodes also broadcast the received route request packets and thus they are propagated throughout the network nodes. Each node is responsible for selecting node-disjoint paths to the sink. The protocol has low operation overhead and high energy efficiency as compared with previous works. The rest of the paper is organized as follows. In section 2, we describe the proposed multipath routing protocol. The performance evaluation is carried out in section 3 and the paper concludes in section 4 including the direction of future works.

2. Sink-initiated Multipath Routing Protocol

In a typical WSN, the sink node collects data from all the nodes, and analyzes this data to take decisions about the activity in the area of interest. It has powerful resources to perform any tasks or communicate with the sensor nodes. We assume that all sensor nodes in the network are assigned with a unique ID and they are assumed to be fixed for their lifetimes. Additionally, these sensor nodes have limited power, storage and energy. For such a network environment, a low overhead, energy efficient multipath routing protocol is described below.

After the deployment of the network, at first the sink node broadcasts a route request message with the hop count field (**HopCount**) value '0', level field (**Level**) value '0' and an integer sequence number (**SeqNo**) of the broadcasted message. The structure of the broadcast message is shown in Fig. 1. The first hop nodes, that hear this message, identify themselves as level 1 nodes, i.e., set their local variable, $L=1$, and inserts an routing entry (to the routing table), the sink as the next hop node. If the residual energy level of a first hop node is greater than the certain minimum threshold value (**EnrgyTh**), it increases the **HopCount** and **Level** value by 1, appends its **ID** in the string of node IDs field (**strNodeIDs**) and rebroadcasts the message. The farther nodes that hear this message (and did not hear the previous broadcast message), set their level $L=2$ and repeat the above procedure.

Note here that if an intermediate node receives broadcast message from a neighbor node having larger level number than it's own, the node will drop the message in order to avoid routing loops in the network.

SeqNo.	HopCount	Level	SinkID	strNodeIDs	EnrgyTh

Fig. 1: Format of the route request message

Thus, eventually each sensor node receives multiple route request broadcast messages from its lower level neighbor nodes. Then, the node will first set its next hop node from which it gets the message with lowest **HopCount** field. We term this one as the primary path. Thereafter, the node extracts the **strNodeIDs** fields in other route request broadcast messages one after another and compare with that of the primary one, it inserts another entry into the routing table as the secondary path if it does not find any common node among them; otherwise, the message is deleted from its temporary storage. Thus, each sensor node establishes its routing table, which contains one shortest hop primary path and other multiple secondary paths (having longer hops). Since sensor nodes are typically deployed with very high density, each node may have more than 3 entries in the routing table except the first level nodes. Also, all the paths are node disjoint, i.e., failure of a node only affects one path from the source sensor node. Each node maintains this routing table for the routing protocol to function.

When a route is broken due to failure of a node or a link, the node that detects it sends a route error message in backward direction, so that all the upstream nodes can update their routing table accordingly. Until a source node has at least two alternate paths, it uses the existing routes; otherwise, it sends a route construction request message to the sink node. The key shortcoming of the proposed multipath routing algorithm is that it does not consider the joining of new nodes in the network.

However, in the following we present a supporting method that could come up with a solution to the above problem. When a new node joins the network, it broadcasts a special route request message to its neighbors and all the neighbor nodes reply back with route information. The node sets its level number using that of neighbor node having lowest level among all neighbors. Accordingly, it can reject all other messages having higher level numbers and insert route entries according to the hop count values of the neighbor nodes. Therefore, for establishing routing table of a newly joined node does not necessitate the sink node to broadcast route request message and flood the network. The main problem of the above procedure is that it can't ensure the newly joined to have node-disjoint paths. Hence, the new node has to wait until the sink initiates its next route request broadcast message to establish node-disjoint multiple paths for all nodes in the network. We keep this problem as our future work that will address how to reduce the waiting time with minimum overhead.

We summarize the key features of the proposed routing algorithm as follows:

- The paths, constructed using the algorithm, are node disjoint and hence more robust and energy efficient.
- Since only the sink node broadcasts the route request message, it minimizes the number of broadcast messages in the network. Further reduction of messages is guaranteed by the intermediary nodes since they forward only those request messages that form node disjoint paths,i.e., it provides low overhead.
- The checking of minimum threshold energy levels at the intermediary nodes ensures that the route will not be broken soon due to energy exhaust of nodes.

Each source sensor node equally splits its data traffic over two forwarding paths: one primary path and another secondary path having least hop count. This traffic forwarding approach ensures higher delivery ratio and energy efficiency. In the following section, we show the performance evaluation results.

3. Simulation Results

We have executed simulations in *ns*-2[4] and compared the performance of the proposed multipath routing protocol with that of EMRA[3]. An area of 200mX200m is considered where the sink node is placed at the centre of the area. The sensor nodes (50~200) are uniformly distributed over the area. Each sensor's transmission range is 40m. The underlying MAC protocol is IEEE 802.11 DCF and the channel bandwidth is 40Kbps. The initial energy of each node is 5.0 Joule and minimum threshold energy is set at 0.3 Joule. The transmit power is 8.5872×10^{-4} Watt and receive threshold power is 3.66152×10^{-10} Watt. The data packet size is 64 bytes and initial route request packet size 12 bytes. The simulation time is 60 seconds and the graph data points are the average values of 10 simulation runs.

The routing overhead of a protocol is generally measured as the number of messages or more explicitly, the amount of data bytes required for constructing the routes. As shown in Fig. 2, the overhead of the proposed routing protocol is much less than the EMRA and the gap between the two increases with the number of nodes in the network. This is because, the number of non-forwarding nodes increases with the size of the network and many nodes expend less energy as compared to the active forwarder nodes. Thus, the gap increases. Since the intermediary nodes in the proposed protocol suppress the route request broadcast messages those form non-disjoint paths, it can significantly decrease the broadcast messages.

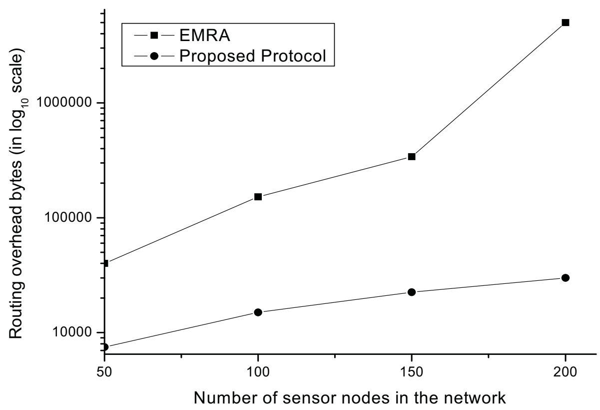

Fig. 2: Number of nodes vs. routing overhead

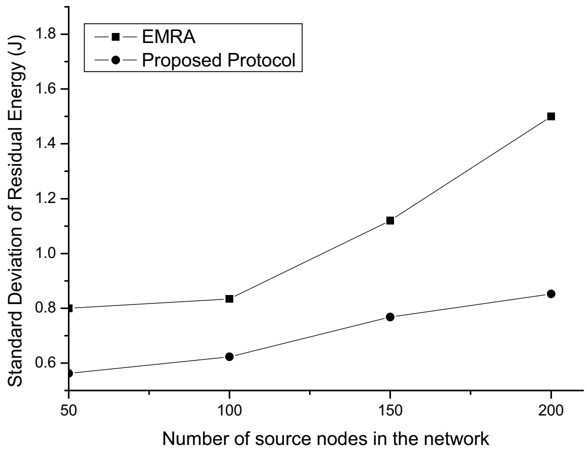

Fig. 3: Number of nodes vs. energy deviation of nodes

A routing protocol is energy efficient if it consumes less total energy and the standard deviation of the residual energies of nodes is minimum. It is easy to understand that the total energy consumption of the proposed protocol will be less than EMRA since it reduces the message broadcasts by a significant amount. In Fig. 3, we plot the standard deviation of residual energies of the nodes and it shows that EMRA has much higher deviation than the proposed protocol. This is due to minimum threshold energy awareness and node disjointedness properties of the proposed protocol. The lower deviation also indicates the increased lifetime of the network.

4. Conclusion

This paper proposes a sink-initiated energy-aware multipath routing protocol that minimizes the overhead of route construction significantly. It is capable to distribute traffic loads diversely and thus increases the network lifetime. However, multipath fading and interference have not been considered and this poses a limitation of this work. How to further increase the performance under a real world scenario considering interferences, fading, non-uniform transmission ranges, etc. will be our next problem to address.

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