Comparative Study of Multipath- Based Routing Techniques for Wireless Sensor Network

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ABSTRACT
Wireless Sensor Networks (WSNs) are consisting of many small and low-cost sensor devices which are densely deployed in a physical area. The nodes are capable of sensing physical phenomenon, computation on that and reporting to the central base station. In WSNs, the sensor nodes have limited transmission range so the data will be transmitted in a multi-hop fashion. Also sensor nodes are limited in energy resources, processing and storage capacity. Routing protocols in WSNs are responsible in maintaining routes in the network and have to ensure reliable multi-hop communication under this condition. In this paper we have present an overview of some multipath-based routing protocols and compare them based on various factor like, energy efficiency, low delay, high data accuracy and fault tolerance. Finally, we conclude the paper by defining some future directions.

General Terms
Multipath-based routing, ad-hoc network, sensor network

Keywords
Energy efficiency, fault-tolerance, low delay, multipath based routing, wireless sensor networks.

1. INTRODUCTION
WIRELESS sensor networks are composed of a collection of un-tethered sensors that are deployed densely in a targeted physical area [6]. Sensor nodes are able to sense physical phenomenon and transmit the information towards some base station, also called sink. Sensor nodes are restricted in terms of resources available to them [1]. Firstly, energy constrain is the most crucial problem in WSNs as sensor nodes are powered by usually a small battery. In order to prolong the lifetime of WSNs the protocols designed for WSNs must be energy efficient. Second it is very difficult to manage the locations of sensor nodes as it's very expensive to deploy sensor nodes with global positioning system (GPS) systems. Third, the nature of the field in which the sensor nodes are deployed also affects the working of WSNs. Sensor nodes are deployed randomly in a physical area and there is no deterministic deployment strategy. Fourth, the sensor networks have dynamic topology; the nodes are added and removed dynamically. Due to this it becomes difficult to maintain the exact route between sensor nodes and the base station. In particular, connectivity to the sink is very important. If the sensed data cannot reach the sink or there is no communication path between the source sensors (or data generators) and the sink, maintaining coverage would become not meaningful. Therefore, connectivity between all source sensors and the sink, either directly or indirectly, should be guaranteed for the proper operation of the network. Also the routing protocols should provide scalability in terms of number sensor nodes. Sensor nodes may not necessarily have same capability in terms of energy, processing and bandwidth. Hence, communication links between sensor nodes may not be symmetric, that is, the pair of sensor nodes may not have same communication path in both the directions. Also due to the energy constrained nature of sensor node, it may deplete its energy during work. Routing protocol designed for WSNs should be fault tolerant. Also some application requires accurate data delivery and some requires that redundancy is added in to the data. Routing protocols for WSNs should also consider this application specific nature of WSNs.

Major focus in this paper is on multipath-based routing protocols for WSNs. Over the past few years, many routing protocols for WSNs are developed and proposed in the literature. They are classified in seven categories based on various characteristics of the protocols [8]. They are: location-based protocols, data-centric protocols, hierarchical protocols, mobility based protocols, multipath-based protocols, heterogeneity based protocols, and QoS based protocols. In location-based protocols, sensor nodes are addressed by their locations. Based on the location information they predict the better path, in terms of energy efficiency, between source and the sink.

In data-centric approach, when source sends data to the sink, intermediate nodes can perform some form of aggregation on the data and sends the aggregated data to the sinks. This way they minimize the energy consumption by sending the less data.

In hierarchical protocols, the nearest sensor nodes form a cluster and a special node is selected as a cluster head. The cluster head is responsible for coordinating data transmission activities of all sensors in its cluster.

In mobility-based protocols, the mobile sink is suggested for gathering sensed data from source sensors. In this case each sensor gets the chance to relay data to the sink on behalf of other sensors and thus balancing the load of data routing in all other sensors.

In heterogeneity based protocols, there are two types of sensor nodes. One is line-powered sensors which have no energy limitation and other is battery-powered sensors which are energy constrained. The battery-powered sensor becomes active only when it is required. This way it saves energy of those nodes.

QoS-based protocols consider quality-of- service parameter like fault-tolerance, reliability and delay etc. for taking routing decisions.

In all other protocols, except multipath-based protocols, each sensor nodes sends its data to the sinks via the shortest path. In multipath-based routing, each sensor source finds first k shortest path and divides the load between these paths evenly. Figure 1 shows the scenario.

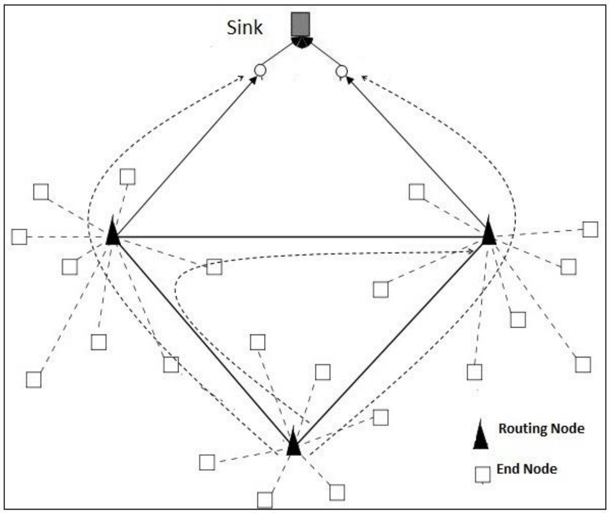

Figure 1 Multipath-based Routing in Wireless Sensor Networks

The remainder of this paper is organized as follows: In section II, we discuss various existing multipath-based routing protocols for WSNs. In section III, we compare them based on various factors like energy efficiency, low delay, high data accuracy and fault tolerance. Finally, section IV concludes the paper with some future research enhancement.

2. OVERVIEW OF VARIOUS MULTI-PATH BASED ROUTING PROTOCOL

Recently, many routing protocols for WSNs are developed and proposed in the literature. Here we present a brief overview of some multipath-based routing protocols for WSNs.

2.1 Sensor-disjoint multipath routing

The simplest multipath based routing technique is sensor disjoint multipath routing [2]. In this technique, small numbers of alternate paths from sensor to sink are construct ted. These alternate paths do not have any sensor common with the primary path. Primary path is the best available path whereas alternate paths are less desirable in terms of delay. If the failure occurs in the primary path, alternate paths are still available to send data. In sensor disjoint routing, first of all sink determines the best node available in its neighbored in terms of low delay and high quality by sending primary-path reinforcement. The sensor node also applies same mechanism to identify its most proffered neighbor. This reinforcement process repeats until the primary path is constructed. After this, the sink repeats the same process by sending out the alternate-path reinforcement to the next most preferable sensor node. If each sensor node accepts only the first reinforcement the alternate paths are guaranteed to be disjoint with each other and with the primary path. This way a sensor negatively reinforces all the reinforcement that follows the first one. But there is no guarantee that this procedure will identify the same alternate path that can be constructed using global knowledge of the network topology. Another disadvantage is that, alternate paths constructed using this methods will be longer than the primary path and hence less energy efficient. The advantage of this technique is, it provides higher fault tolerance by identifying alternate disjoint paths.

2.2 Braided multipath routing

Another technique to create partially disjoint paths is braided multipath [2, 3]. In this technique, alternate paths to the primary path are constructed but they are not necessarily required to be disjoint. To construct the braided multipath, the first step is to compute the primary path. Then, for each node (or sensor) on the primary path, the best path from a source sensor to the sink that does not include that node is computed. The alternate paths constructed using this method will lie on or geographically close to the primary path hence they are comparable in terms of energy consumption than mutually disjoint paths. Disadvantage of this method is whenever the sensor node that is common in more than one path is failed all the paths that contains that sensor node will become faulty hence lowers the fault tolerance.

2.3 N-to-1 Multipath Discovery

N-to-1 multipath protocol [4] uses flooding to find multiple node-disjoint paths from each sensor to sink simultaneously. The mechanism is composed of two phases namely, branch aware flooding and multipath extension of flooding. In both the phases it broadcasts the same messages which are flooded in the network. The message format is given by {mtype, mid, nid, bid, cst, path}. Where mtype defines the type of message, mid represents the sequence number of the current routing update, nid is the ID of the sender, bid is the ID of the branch defines as the ID of the closest node to the sink in the branch, path is a sequence of node visited by this message, and cst is the cost of the path. Any node receiving this message will broadcast the updated version of the message to its neighbors appending its own id to the path and updating the cost of the path. This protocol generates multiple node-disjoint paths for every sensor.

2.4 Multiplicative-increase/Additive-decrease Multipath Routing Control (M2RC)

M2RC [5] is a based on two phases: mesh establishment phase and data forwarding phase. In the first stage, routing state of forwarding node is setup. First, it assigns a cost value to each node. The cost of any node is the minimum amount of power needed to go from this node to the sink. Also during this stage, all nodes prepare a list of its neighbors. In data forwarding phase, initially, the node sends packets to its closest forwarding node using the minimum power required. If it gets ACK back the job is done otherwise, the node will continue resending the packet using more power until it gets the ACK. In each subsequent attempt, the node tries to reach more neighbors to maximize the probability of successful delivery. Even when sending with maximum power, if node doesn't get the ACK, it gives up on this packet.

2.5 Priority-based Multipath routing protocol (PRIMP)

PRIMP [6] is a probabilistic multipath routing strategy for WSNs. PRIMP can be generalized into two stages: interest dissemination stage and priority-based path selection stage. Interest dissemination is initiated by sink periodically to establish up-to-date multiple data path from sensors to sink.

Also in this stage, the priority of all the sensor nodes will be decided based on the energy resource condition of the data paths from that node to sink. In priority-based path selection stage the event data is sent back to the sink via multiple paths based on the priority of the gradients assigned to the paths. High priority gradients are preferred to low priority ones. Each gradient is assigned a weight based on the number of accumulated hop count. The gradients are used based on the value of weight. The interest dissemination stage is invoked periodically to update the knowledge of sink. PRIMP also solves the issue of slow startup occurred in data-centric routing protocols.

2.6 Label-based Multipath Routing (LMR)

LMR [7] can efficiently find a disjoint or segmented backup path to provide protection to the working path. In LMR, sink broadcasts the control message throughout the network to find possible alternate path. During this process, labels are assigned to the paths the message passes through. The label information is used to search segmented backup path if disjoint path is not available. LMR only uses localized information to find the alternate paths. The flooding overhead can be minimized by employing associated schemes.

2.7 Secure and Energy-Efficient Multipath Routing (SEEM)

SEEM [9] consists of three phases: Topology Construction, Data Transmission, and Topology Maintenance. In Topology Construction phase, the base station collects neighbors' information of each node by flooding several control packets throughout the sensor network. Then the base station constructs weighted graph based on the neighbors' information collected earlier. Once the network topology is set up, the base station starts querying data in Data Transmission phase. Node satisfying the query will acknowledge to the base station. Immediately, the base station calculates a shortest path according to current energy residue on each node. SEEM does not allow multiple sensor nodes to send data to the base station at the same time. Therefore SEEM is not suitable for applications having multiple sources that send data at the same time. SEEM is well designed for query-driven applications.

2.8 Robust and Energy Efficient Multipath Routing (REER)

REER [10] is a robust and energy efficient multipath routing protocol for WSNs. It provides fault-tolerance and achieves load balancing through the distribution of the traffic over a set of available node-disjoint paths in order to efficiently use the node's battery power. REER uses the residual energy, available buffer size, and Signal-to-Noise Ratio (SNR) to predict the next hop through the path construction phase.

2.9 Sequential Assignment Routing (SAR)

SAR uses energy resources and QoS metrics to decide the priority level of the different paths from sensor nodes to the sink. SAR creates a tree, based on this priority level. Also the packets are given priority specific to application. Higher priority packages can use higher priority paths at run time which has lower delay and lower energy consumption. SAR[11] is to minimize the average weighted QoS metric throughout the lifetime of the network.

Table 1. COMPARISION OF VARIOUS ROUTING TECHNIQUES FOR WSNs

Protocols	Fault Tolerance	Load balancing	Energy efficiency	Delay	Data accuracy
Sensor-disjoint multipath routing [2]	High	High	Low	High	Yes
Braided multipath routing [2, 3]	Medium	Medium	High	Low	Yes
N-to-1 Multipath Discovery. [4]	Medium	High	Medium	Medium	Yes
M2RC [5]	Low	-	High	Medium	-
PRIMP [6]	High	High	Low	Low	-
LMR [7]	High	High	High	High	Yes
SEEM [9]	High	High	High	Low	-
REER [10]	High	High	High	Low	-
SAR [11]	High	High	High	Low	Yes

3. COMPARISION OF VARIOUS ROUTING TECHNIQUES

In the previous section, we discussed various multipath based routing techniques. Now in this section we present a comparison of those techniques based on various factors like energy efficiency, low delay, fault tolerance and high data accuracy. TABLE I shows the comparison between various routing techniques. As we can see they all strives to find the multiple paths between sensor node and sink. They differ in the way they provide amount of fault tolerance and energy conservation.

4. CONCLUSION

In this paper we discussed various routing techniques n available for wireless sensor networks. These techniques have made significant effort to solve the routing issue in WSNs. However the future research is possible to improve the energy efficiency and minimize the delay. Future research enhancements can be made in the following aspects.

1. Sensor nodes can learn from past behavior and based on that they can take the routing decisions.
2. Some cross layer optimization can be employed to take routing decisions.

Existing techniques can still be improved to provide low delay and high fault tolerance.

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