A Review of Routing Protocols in Wireless Sensor Networks

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***Abstract*—Different from traditional networks, wireless sensor networks (WSNs) are highly dependent on specific applications and are severely constrained by energy, storage capacity and computing power. To prolong the lifetime of the whole networks, energy awareness is an essential consideration when we design or analyze routing protocols. In this paper, we present a review of recent routing protocols in WSNs and classify them into three categories based on the network structure in WSNs. Then we describe the existing routing protocols and discuss their advantages and disadvantages of each routing algorithm. Finally we conclude this paper with open research issues and challenges.**

Keywords- wireless sensor networks, routing protocols, network structure

I. INTRODUCTION

With electronic device manufacturing process and the development of wireless communications technologies, composed of a large number of micro-sensor nodes, wireless sensor networks has become the hot issues in industry and academia recently. Those sensor nodes characteristic of low-cost, low-power and multi-functional have been widely used in the military, industry, traffic, environmental protection and many other fields. Especially in the absence of the existence of the backbone network, such as the dangerous region that man cannot get there, the battlefield, and other destructive areas, the applications prospect of wireless sensor networks surely will be great. Presently, the relevant researchers have gained rich achievements.

And the ways how to effectively route the collected data among nodes are the utmost important topics in WSNs.

Followings are some of the key features of a sensor network related with routing techniques:

(1) Sensor nodes are limited in resources (energy, on-chip computing ability，storage space, communicating distance) and is deployed in a pre-defined or random way;

(2) Nodes in a sensor network may not have global identification (ID) because of the large amount of over head and large number of sensors [1].

(3) Usually, the data in sensor networks are bound either downstream to nodes from a sink or upstream to a sink from nodes. And wireless sensor networks are a kind of application-specified network.

Based on those routing techniques and characteristics in WSNs, researchers have proposed a lot of routing protocols at present. In this paper, we survey the current representative routing protocols and classify them into three categories on the basis of network structure. The reminder of this paper is organized as follows. First we identified the wireless sensor networks routing protocols. Then we present the existing routing protocols and analyze their advantages and disadvantages. And we extend those routing protocols to discuss the latest research trends. At last, we conclude this paper by talking about the existing open research issue and many other aspects worth considering.

II. CLASSIFICATION OF ROUTING PROTOCOLS IN WIRELESS SENSOR NETWORKS

The sensor nodes are constrained to limited resources itself, so the current research mainly focuses on how to design an effective and energy-awareness protocols in order to prolong the lifetime of the whole networks for specific application environments. Because the physical layer and data link layer are independent of specific application, our attention should focus on the energy-awareness protocols, especially the network layer with energy efficient routing protocols. However, the design of routing protocols in the network layer depends on the specific application and is constrained to the nodes' limitations, such as energy, memory and computing power. Since sensor nodes are not given a unified ID for identification, and much redundant data get together in destination nodes, there exist the following aspects: Energy Efficiency, Scalability, Latency, Fault-Tolerance, Accuracy, and Quality of Service (QoS), which we must carefully consider when we design or choose the routing protocols in WSNs. Yet the common aim is to build a steady transmission path in a quick-rapid and low-cost manner.

From plenty of current routing protocols, on the basis of the network structure in WSNs and data transmission model, in general, we can classify routing protocols into three categories: Flat-based routing (Flooding), Hierarchical-based routing (Clustering) and Location-based routing (Geographic).

1) Flat-based routing (Flooding). In flat-based routing, all nodes are typically equal and acts the same functionality. Each node not only can collect the data from the interesting events, but also can relay the information data by serving as a relay-node. The initial routing table is builded by flooding. According to whether the establishment and maintenance of routing table is initially sponsored by the sink nodes, flat-based routing can be classified into three modes:

a) Traditional flooding mode: the most fundamental flooding, sensor nodes transmmit the received messages to their neighbor nodes by brodcasting until the messages reach the sink nodes.

b) Event-driven mode: when the sensor nodes sense the interesting data, they actively broadcast those messages to sink nodes and choose the next hop according to routing table.

c) Query-drive mode: sink node broadcasts a application-specified request (interest) to its neighbor nodes by flooding the entire network. The requested nodes then choose a appropriate path to answer this query.

*2) Hierarchical-based routing (Clustering).*Nodes play different roles in the network. Clustering alogrithm mainly includes two-layer routing where one layer is used to select clusterheads and the other layer is used for routing. Algorithm is based on the large number of high-density sensor nodes and focus on the routing scalability. The main features is to divide the whole WSNs into a number of clusters in terms with the specific rules.

3) Location-based routing (Geographic). Usually assuming that sensor nodes knowing or able to computer their location, so the transmitting data can be directly sent to the designated zone. Thereby those alogithms can avoid data transmission problems such as broadcasting storm caused by flooding.

III. FLAT-BASED ROUTING (FLOODING)

A. Traditional flooding model

Flooding and gossiping [2] are the most basic traditional network routing. They do not need to know the network topology. Each sensor nodes will transfer those messages received to their neighbors nodes, and this process will be repeated until the messages arrive at sink nodes or is overtime due TTL (usually defined as the largest hop in WSNs). Gossiping improves flooding algorithm in some ways, and each sensor nodes only transfer the messages to a random neighbor node. However, even though flooding and gossiping is very simple and suitable for any network structure, but both algorithms are not practical in application-specified network, and they can easily bring implosion and overlap problems.

B. Event-driven mode

1) Sensor Protocols for information via Negotiation (SPIN): SPIN [3] is the first data-centric routing protocol. The protocol considers the similarity of the data sensed by neighbour nodes; and every sensor node only broadcasts the unique data that neighbor nodes do not own. In this way, SPIN eliminates redundancy of transmitted data and thus effectively reduces energy consumption. At the same time, every node uses meta-data to name their data, and every node can make its communication decisions based on both application-specified knowledge of the data and knowledge of the available resources, which enables the sensor nodes to efficiently distribute data with limited energy.

SPIN uses three Message Data: ADV, REQ, and DATA. ADV is used to broadcast their own meta-data to the adjacent nodes for interesting event nodes; REQ give a notice to the neighbor nodes that the nodes will send the raw data; DATA refers to the original data.

Before any data is really transmitted, a node performs meta-data negotiation. The negotiation is done by exchanging ADV and REQ messages between the sender and the receiver.

As SPIN don't need maintain neighbor information; it can adapt itself to the situation that nodes will often moved in a certain degree; simulation results show that SPIN is more energy-efficient than the traditional model. However, the algorithm can not ensure that the data certainly reach the target node, especially not suit for high-density distribution of nodes.

2) Rumor Routing [4]

Each node maintain a event table, the table entries contain the basic description of events, source node, last hop node; in addition, there exists a long lifetime message, which is used to broadcast the description of events in WSNs. Rumor routing is the same as SPIN in essence; the main difference is that it maintain a list of events information table, therefore it maintains a path to source nodes. So after initialization of flooding, corresponding path information has been established. Thus it avoids a large number of flooding process in SPIN, and then significantly save energy.

The protocol is mainly applied to those scenarios with a large number of queries and a small number of events. If network topology frequently changes, performance of rumor routing will be substantially reduced.

3) Energy-aware routing

Energy-aware routing [5] considers that if all data are transmitted through several optimal paths, energy of the nodes related with those paths will be exhausted soon. So in the process of establishing routing path, a number of suboptimal paths and probability model will be maintained at the same time. Then we select transmission paths based on the probability value of each path to make the initial network load balancing; thereby the whole network lifetime will be prolonged. The disadvantage is that energy-aware routing needs to exchange local information between neighbor nodes and all nodes have a unified address, which enlarges the price of building routing paths. And the failure of single node has not been fully considered, it is not suitable for sensor nodes with mobile features.

C. Query-driven mode

1) Directed Diffusion

After named, data will be directly transmitted between nodes, and sponsored by sink nodes.

In Directed Diffusion, there exist Interest messages, in an attribute-value way, which contains the relevant attributes for query and gradient field, which will be continuously updated in the process of transmission. A query is transformed into an interest that is diffused or flooded towards nodes in the interested region. When a sensor node in that region receives the interest, it activates its sensors and begins to monitor interested events. The sensed data are then returned in the reverse path of the interest propagation. Interest issued by the sink node through flooding will reach all sensor network nodes;

then nodes maintain interest messages in the local cache. If the data are fit for interest request, then it will be forwarded along the path.

The most obvious feature of Directed Diffusion is to broadcast query interest messages in advance and build paths between sink node and all other sensor nodes in a flooding way. However, this also limits the scope of the application of this protocol. For example, when specific application requires sink node can access various types of data, then the cached cost maintained by each sensor node will increase dramatically.

2) Gradient-based Routing

The algorithm [6] makes an improvement on Directed Diffusion, in order to get the total minimum hop numbers other than the total shortest time. In the process of transmitting Interest messages, the algorithm takes the minimum hops between sink nodes and sensor nodes as its height value, and calculates the height difference with its neighbor node as a link Gradient of two nodes. When routing data, nodes select the link with the largest Gradient to forward data. While being flooded, Interest messages record the number of hops taken. This allows a node to discover the minimum number of hops to sink, called the node's height. The difference between a node's height and that of its neighbor is considered the gradient on that link. A packet is forwarded on the link with the largest gradient. Although the techniques to increase the network lifetime are built upon GBR, the main principles are general enough to also apply them to other ad-hoc routing protocols.

The algorithm also introduced some complementary measures, such as data integration and load balancing to increase the maximum life cycle in WSNs.

IV. Hierarchical-Based routing(Clustering)

A. Single-layer Mode (single-tie)

1) LEACH(Low-Energy Adaptive Clustering Hierarchy)

The algorithm [7] is mainly based on the idea of choosing a node as Cluster Head during a group of nodes. The Cluster Head is responsible for communicating with sink node and data aggregation of its group nodes. In this way, the amount of data for exchanging during sensor nodes is largely reduced. Therefore this algorithm has an effect upon saving energy. The node becomes a cluster head for the current round if the number is less than the threshold. Each elected CH broadcast an advertisement message to the rest of the nodes in the network that they are the new cluster-heads.

LEACH is fully distributed and its data transmission delay is very small. However, the algorithm take the assumption that all the Cluster Head can directly communicate with the sink, so the assumption may not be practical, and then it cannot be much suitable for large-scale applications. At the same time, this approach of dividing clusters may bring additional costs and overlay issues.

2) PEGASIS and Hierarchical-PEGASIS

Taking account of the overhead of dividing clusters, PEGASIS makes an improvement on LEACH by constructing a node chain instead of cluster group. In all sensor nodes, only one chose node as a gateway to communicate with sink, the other nodes in the chain take turn to be gateway. After receiving message, each node takes an aggregation with its own sensing data. At last those data are transmitted to gateway node.

Although PEGASIS [8] performs better than LEACH by eliminating the overhead of dynamic cluster formation, because transmission is asynchronous, the time of transmission will be prolonged too much. Hierarchical-PEGASIS conducts a further improvement, it allows concurrent transmission when the nodes are not adjacent.

Compared with LEACH, the two algorithms eliminate the overhead of forming cluster, but both of them do not take the energy condition of next hop into consideration when choosing a routing path, so they are not suitable for heavy-loaded network. When the amount of nodes is very large in WSNs, the delay of data transmission is very obvious, so they do not scale well and also are not suitable for sensor networks where such global knowledge is not easy to obtain.

B. Hierarchical Mode (Hierarchical-tie)

1) TEEN and APTEEN

Based on LEACH, TEEN (Threshold sensitive Energy Efficient sensor Network protocol) [9] divides sensor nodes twice for grouping cluster in order to detect the scene of sudden changes in the sensed attributes such as temperature. After the clusters are formed, TEEN separates the Cluster Head into the second-level Cluster Head and uses Hard-threshold and Soft-threshold to detect the sudden changes. Hard-threshold is used to trigger a sensor node when the sensing value of an attribute responses to the data query; Soft-threshold will further reduce the number of transmissions if there is little or no change in the value of sensed attribute.

TEEN is not suitable for the applications model that needs periodic report. APTEEN (Adaptive Threshold sensitive Energy Efficient sensor Network protocol) makes an improvement aiming at supporting periodic report for time-critical events. The main disadvantages of the two algorithms are the overhead and complexity of forming clusters.

2) Energy-aware for cluster-based networks

The algorithm [10] is also an extension to LEACH and introduces a kind of resource-unlimited Gateway nodes. By means of two-level cluster, Gateway node can aggregate data and change node’s state: dormancy, sensing or relay in accord with detected energy of sensor node.

In order to overcome ambiguity in signal propagation or get a better routing performance in terms of network throughput and end-to-end delay, many variants of this routing approach has been proposed. Due to limited space, here we do not analyze them one by one.

V. Location-based routing (Geographic protocol)

Those algorithms require location information for sensor nodes. We assume sensor nodes can directly obtain their position or calculate the distance according to other position-known nodes. It is worth noting that there have been many location-based protocols in Ad Hoc networks and it makes great effects when we transplant those research achievements for wireless sensor networks in some ways.

A. GEAR (Geographic and Energy Aware Routing)

The idea is to restrict the number of Interest in Directed Diffusion and add geographic information into Interest packet by only considering a certain region rather than sending Interest to the whole network by means of flooding. GEAR [11] uses energy aware and geographically informed neighbor selection heuristics to route a packet towards the target region. Therefore GEAR save energy consumption significantly in this way.

GEAR introduces an estimated cost and a learning cost and chooses next hop by calculating the difference between the estimated cost and the learning cost.

B. MECN (Minimum Energy Communication Network)

MECN [12] is firstly designed for wireless networks and found that it also can be directly applied to WSNs by the researchers. It is noticed that the cost of direct communication between two nodes is higher than forwarding data by several relay-nodes. So MECN identifies a relay region for every node, which consists of all relay-nodes that are more energy efficient than direct transmission. When two nodes need to exchange messages, MECN will choose a minimum energy path to transmit data according to Bellman-Ford shortest path method.

Thus, MECN is self-reconfiguring and can dynamically solve the node's failure problem or the deployment of new sensors. However, the algorithm is best applicable to sensor networks which are not mobile; under the circumstance of mobility in WSNs, the energy cost of calculating path in the relay region will rise sharply

There exist lots of other location-based routing protocols such as GEDIR, GOAFR and SPAN which can be directly applied to wireless sensor networks. However those algorithms will not be discussed by this paper for the restriction of length and content.

VI. CONCLUSION AND OPEN ISSUES

In recent years, the routing protocol in WSNs has become one of the most important research area, and there have been existed a large number of research achievements. In this paper, we make a great deal of analysis and research, and classify the routing protocols into three categories: Flat-based routing (Flooding), Hierarchical-based routing (Clustering) and Location-based routing (Geographic) on the basis of network structure. There are also a number of researchers from other point of view, who give other kind of taxonomy that we are not discussed here as for restriction of length and content. Nevertheless, there still exist a series of challenges for routing protocols in WSNs.

As our study reveals, it is not possible that a routing algorithm is suitable for all scenarios and for all applications. Although many routing protocols have been proposed in WSNs, many issues still exist and there are still many challenges that need to be solved in the sensor networks. The following parts describe some of those issues and challenges:

- Effectiveness: how to effectively utilize bandwidth and energy for specific application; how to efficiently divide the whole networks into clusters and coordinate the workloads of all sensor nodes.
- Adaptability: how to adapt the mobile sensor networks and make sensor nodes self-organizing and self-reconfigurable.
- Scalability: how to satisfy dense sensor networks with a large number of nodes and try to prolong the lifetime.
- Security: how to make routing protocols secure in WSNs and assure that the transmitted messages are not eavesdropped and tampered.

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