A Survey on Routing Protocols in Wireless Sensor Networks

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Abstract— Extensive usage of wireless sensor network (WSN) is the reason of development of many routing protocols. Recent advances in WSN now witness the increased interest in the potential use in applications like Military, Environmental, Health (Scanning), Space Exploration, Vehicular Movement, Mechanical stress levels on attached objects, disaster management, combat field reconnaissance etc. Sensors are expected to be remotely deployed in unattended environments. Routing as one key technologies of wireless sensor network has now become a hot research because the applications of WSN is everywhere, it is impossible that there is a routing protocol suitable for all applications. In this paper, the various routing protocol are classified and described. The growing interest in WSN and the continual emergence of new architectural techniques inspired surveying the characteristics, applications and communication protocols for such a technical area.

Keywords- Energy Awareness, Hierarchical Routing Protocols, Routing Protocols Wireless Sensor Networks.

I. INTRODUCTION

With the development of the MEMS (micro-electro-mechanical system), processor, radio and memory technologies, it is possible to produce micro sensor nodes. Being characterized by their low power, small size, and cheap price, these nodes are capable of wireless communication, sensing and computation. So, we can say the sensor network is the product of the combination of the sensor techniques, distributed information processing and communication techniques [1, 2]. A Wireless sensor network contains hundreds or thousands of these sensor nodes that are densely deployed in a large geographical area. These sensors measure ambient conditions in the environment surrounding them and then transform these data into electrical signals which can be processed to reveal some characteristics about the phenomena located in the area around these sensors [3]. Each of these scattered sensor nodes has the capability to collect and route data either to other sensors or back to an external base station. A base station may be a fixed node or a mobile node capable of connecting the sensor network to an existing communications infrastructure or to the Internet where a user can have access to the data. Therefore, we can get the information about the area which is far away from us. Other applications may be environment control in office buildings, robot control and guidance in automatic manufacturing environments, and high security smart homes [4]. In fact, the applications of the wireless sensor networks are quite numerous. For example, wireless sensor networks have profound effects on military and civil application. In a disaster scene, a great number of sensors can be dropped by a helicopter. Networking these sensors can assist rescue operations by locating survivors, identifying risky areas and making the rescue crew more aware of the overall situation. Such application of sensor networks not only can increase the efficiency of rescue operations but also ensure the safety of the rescue crew. On the military side, applications of sensor networks are numerous too. For instance, the use of networked set of sensors can limit the need for personnel involvement in the usually dangerous reconnaissance missions. In addition, sensor networks can enable a more civic use of landmines by making them remotely controllable and target-specific in order to prevent harming civilians and animals. Security applications of sensor networks include intrusion detection and criminal hunting [4]. However, sensor nodes are constrained in energy supply and bandwidth. Such constraints combined with a typical deployment of large number of sensor nodes pose many challenges to the design and management of sensor networks. Developing energy-efficient routing protocol on wireless sensor networks is one of the important challenges. Therefore, a key area of WSN research is to develop a routing protocol that consumes low energy [5]. In this paper, we present a thorough review of recent research of routing protocols for wireless sensor networks, including their advantages and drawbacks. Then our aim is to develop better understanding of the current routing protocols for wireless sensor network and highlight some issues that can be subject to future research

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II. ROUTING PROTOCOLS

Routing in sensor networks is very challenging due to several characteristics that distinguish them from contemporary wireless mobile ad-hoc networks (MANET):

A) The number of sensor nodes in wireless sensor networks can be several orders of magnitude higher than that in MANET.
B) Unlike a node in a MANET, sensor node may not have unique ID
C) Sensor nodes are much cheaper than nodes in a MANET and are usually deployed in thousands.
D) Power resource of sensor nodes could be very limited; however, MANET's nodes can be recharged.
E) Sensor nodes are more limited in their computation and communication capabilities than their MANET counter parts because of their low cost.(6) Sensor nodes are prone to failures.
F) The topology of a sensor network changes very frequently.
G) Sensor nodes mainly use a broadcast communication paradigm, whereas most Ad-hoc networks are based on point-to-point communications

Due to such differences, many new algorithms have been proposed for routing data in sensor networks. So it is important to study routing protocols for wireless sensor networks. Now a day's both academia and industries have shown great interest in the wireless sensor networks and have focused on the issues involved in the development of energy-efficient, low-cost, secure and fault-tolerant sensor networks. Recently many new algorithms have been proposed for the problem of routing data in sensor networks. We classify the routing protocols for the sensor networks first, and then analyze the existing routing protocols.

III. CLASSIFICATION OF ROUTING PROTOCOLS IN WSN

There are many ways to classify the routing protocols. Almost all of the routing protocols can be classified as data-centric, hierarchical and location based according to the network structure. In data-centric routing all nodes are typically assigned equal roles or functionality. In hierarchical-based routing, however, nodes will play different role in the network. In location-based routing sensor node's positions are exploited to route data in the network [2]

A. Data-centric Routing Protocols

Data-centric paradigm promises to combine the applications needed to access data (instead of individual nodes) with a natural framework for in-network processing [4]. In many applications of wireless sensor networks, due to lack of global identification along with random deployment of sensor nodes, it is hard to select a specific set of sensor nodes to be queried. This consideration has led to data-centric routing, which is different from traditional address-based routing where routes are created between addressable nodes. SPIN [5] is the first data-centric protocol, which considers data negotiation between nodes in order to eliminate redundant data and save energy. Later, Directed diffusion has been developed and has become a breakthrough in data-centric routing

B. SPIN (Sensor Protocols for Information via Negotiation):

SPIN is among the early work to pursue a data-centric routing mechanism. The idea behind SPIN is to name the data using meta-data that highly describes the characteristics of the data, which is the key feature of this routing protocol. SPIN has three types of messages, that is, ADV, REQ, and DATA.

ADV- When a node has data to send; it advertises this message containing meta-data.

REQ- A node sends this message when it wishes to receive some data.

DATA- Data message contains the data with a meta-data header. Before sending a DATA message, the sensor node broadcasts an ADV message containing a descriptor (i.e. meta-data) of the DATA. If a neighbor is interested in the data, it sends a REQ message for the DATA, and then DATA is sent to this neighbor node. Respectively, the neighbor node repeats the same process until the data is sent to the sink (or BS). One of the advantages of SPIN is that topological changes are localized since each node needs to know only its single-hop neighbors. However, SPIN's disadvantages are clear. First of all, it is not scalable. Secondly, the nodes around a sink could deplete their energy if the sink is interested in too many events. Finally, SPIN's data advertisement mechanism cannot guarantee the delivery of data. For example, if the nodes that are interested in the data are far away from the source node and the nodes between source and destination are not interested in that data, such data will not be delivered to the destination at all.

C. Hierarchical Routing Protocols

Similar to a cellular telephone network, sensor nodes in a hierarchical routing approach send their data to a central cluster-head and the cluster head then forwards the data to the desired recipient. The main aim of hierarchical routing is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink. Among numerous hierarchical routing protocols LEACH [4] and PEGASIS [4] are discussed in brief below

LEACH (Low Energy Adaptive Clustering Hierarchy):

LEACH is a cluster-based routing protocol in which a cluster head collects data from sensor node belonging to the cluster and sends the data to the sink node after data aggregation process. To make all sensor nodes in this network consume their node energy equally and extend the life time of the network, this algorithm randomly changes the cluster head, which in turn uses more energy than any other node belonging to the cluster, every time period. To reduce overall communication costs, the cluster head performs data aggregation and then sends the data to the sink node. This decision is made by the node choosing a random number between 0 and 1. The node becomes a cluster head for the current round if the number is less than the following threshold:

$$T\text{ (n)} = \begin{cases} \frac{P_t}{1-P_t\left(r \bmod \frac{1}{P}\right)} & n \in G \\ 0 & otherwise \end{cases}$$

Where, P_t is the desired percentage of clusterheads (0.05), r is the current round number, G is the set of nodes that have not been cluster-heads in the last $1/p_t$ rounds. LEACH is organized into rounds, where each of them begins with a set-up phase, and is followed by a steady-state phase. In cluster set-up phase, each non-cluster head node tells its cluster-head its decision by using CSMA MAC protocol. Then the cluster-heads create TDMA schedules and broadcast them back to their members in steady state phase. In data transmission phase, each node waits for its turn to send data if needed. LEACH achieves over a factor of 7reduction in energy dissipation compared to direct communication. The nodes die randomly and dynamic clustering increases lifetime of the system. LEACH is completely distributed and requires no global knowledge of network. However, LEACH uses single-hop routing where each node can transmit directly to the cluster-head and the sink. Therefore, it is not applicable to networks deployed in large regions. Furthermore, the idea of dynamic clustering brings extra overhead, e.g. head changes, advertisements etc., which may diminish the gain in energy consumption.

PEGASIS (Power-Efficient Gathering in Sensor Information Systems):

PEGASIS is a chain-based power efficient protocol based on LEACH. It is also an improvement of the LEACH protocol. Rather than forming multiple clusters, PEGASIS forms chains from sensor nodes so that each node transmits and receives from a neighbor and only one node is selected from that chain to transmit to the base station (sink). Gathered data moves from node to node, aggregated and eventually sent to the base station. The chain construction is performed in a greedy way. PEGASIS outperforms LEACH by eliminating the overhead of dynamic cluster formation, minimizing the sum of distances that non-leader nodes must transmit, and limiting the number of transmissions. However, PEGASIS introduces excessive delay for distant node on the chain. In addition the single leader can become a bottleneck.

D. Data-centric protocols

In many applications of sensor networks, it is not feasible to assign global identifiers to each node due to the sheer number of nodes deployed. Such lack of global identification along with random deployment of sensor nodes makes it hard to select a specific set of sensor nodes to be queried. Therefore, data is usually transmitted from every sensor node within the deployment region with significant redundancy. Since this is very inefficient in terms of energy consumption, routing protocols that will be able to select a set of sensor nodes and utilize data aggregation during the relaying of data have been considered. This consideration has led to data-centric routing, which is different from traditional address-based routing where routes are created between addressable nodes managed in the network layer of the communication stack. In data-centric routing, the sink sends queries to certain regions and waits for data from the sensors located in the selected regions. Since data is being requested through queries, attribute-based naming is necessary to specify the properties of data. SPIN [6] is the first data-centric protocol, which considers data negotiation between nodes in order to eliminate redundant data and save energy. Later, Directed Diffusion [7] has been developed and has become a breakthrough in data-centric routing. Then, many other protocols have been proposed either based on Directed Diffusion [8–9] or following a similar concept [10,11, 12]. In this section, we will describe these protocols in details and highlight the key ideas.

E. Flooding and gossiping

Flooding and gossiping [13] are two classical mechanisms to relay data in sensor networks without the need for any routing algorithms and topology maintenance. In flooding, each sensor receiving a data packet broadcasts it to all of its neighbors and this process continues until the packet arrives at the destination or the maximum number of hops for the packet is reached. On the other hand, gossiping is a slightly enhanced version of flooding where the receiving node sends the packet to a randomly selected neighbor, which picks another random neighbor to forward the packet to and so on.
Although flooding is very easy to implement, it has several drawbacks, redrawn from [6]. Such drawbacks include implosion caused by duplicated messages sent to same node, overlap when two nodes sensing the same region send similar packets to the same neighbor and resource blindness by consuming large amount of energy without consideration for the energy constraints [6]. Gossiping avoids the problem of implosion by just selecting a random node to send the packet rather than broadcasting. However, this cause delays in propagation of data through the nodes.

Directed Diffusion

Directed Diffusion [7,14] is an important milestone in the data-centric routing research of sensor networks. The idea aims at diffusing data through sensor nodes by using a naming scheme for the data. The main reason behind using such a scheme is to get rid of unnecessary operations of network layer routing in order to save energy. Direct Diffusion suggests the use of attribute-value pairs for the data and queries the sensors in an on demand basis by using those pairs. In order to create a query, an interest is defined using a list of attribute value pairs such as name of objects, interval, duration, geographical area, etc. The interest is broadcast by a sink through its neighbors. Each node receiving the interest can do caching for later use. The nodes also have the ability to do in-network data aggregation, which is modeled as a minimum Steiner tree problem [15]. The interests in the caches are then used to com-pare the received data with the values in the interests. The interest entry also contains several gradient fields. A gradient is a reply link to a neighbor from which the interest was received. It is characterized by the data rate, duration and expiration time derived from the received interest s fields. Hence, by utilizing interest and gradients, paths are established between sink and sources. Several paths can be established so that one of them is selected by reinforcement. The sink resends the original interest message through the selected path with a smaller interval hence reinforces the source node on that path to send data more frequently. redrawn from [7], summarizes the Directed Diffusion protocol. Path repairs are also possible in Directed Diffusion. When a path between a source and the sink fails, a new or alternative path should be identified. For this, Directed Diffusion basically reinitiates reinforcement by searching among other paths, which are sending data in lower rates. Ganesanet al. [16] suggests employing multiple paths in advance so that in case of a failure of a path, one of the alternative paths is chosen without any cost for searching for another one. There is of course extra overhead of keeping these alternative paths alive by using low data rate, which will definitely use extra energy but more energy can be saved when a path fails and a new path should be chosen.
Directed Diffusion differs from SPIN in terms of the on demand data querying mechanism it has. In Directed Diffusion the sink queries the sensor nodes if a specific data is available by flooding some tasks. In SPIN, sensors advertise the avail-ability of data allowing interested nodes to query that data. Directed Diffusion has many advantages. Since it is data centric, all communication is neighbor-to-neighbor with no need for a node addressing mechanism. Each node can do aggregation and caching, in addition to sensing. Caching is a big advantage in terms of energy efficiency and delay. In addition, Direct Diffusion is highly energy efficient since it is on demand and there is no need for maintaining global network topology.
However, Directed Diffusion cannot be applied to all sensor network applications since it is based on a query-driven data delivery model. The applications that require continuous data delivery to the sink will not work efficiently with a query driven on demand data model. Therefore, Directed Diffusion is not a good choice as a routing protocol for the applications such as environmental monitoring. In addition, the naming schemes used in Directed Diffusion are application dependent and each time should be defined a priori. Moreover, the matching process for data and queries might require some extra overhead at the sensors.

F. Rumor routing

Rumor routing [8] is another variation of Directed Diffusion and is mainly intended for con-texts in which geographic routing criteria are not applicable. Generally Directed Diffusion floods the query to the

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entire network when there is no geographic criterion to diffuse tasks. However, in some cases there is only a little amount of data requested from the nodes and thus the use of flooding is unnecessary. An alternative approach is to flood the events if number of events is small and number of queries is large. Rumor routing is between event flooding and query flooding. The idea is to route the queries to the nodes that have ob-served a particular event rather than flooding the entire network to retrieve information about the occurring events.

In order to flood events through the network, the rumor routing algorithm employs long-lived packets, called agents. When a node detects an event, it adds such event to its local table and generates an agent. Agents travel the network in order to propagate information about local events to distant nodes. When a node generates a query for an event, the nodes that know the route, can respond to the query by referring its event table. Hence, the cost of flooding the whole network is avoided. Rumor routing maintains only one path between source and destination as opposed to Directed Diffusion where data can be sent through multiple paths at low rates. Simulation results have shown that rumor routing achieves significant energy saving over event flooding and can also handle node s failure. However, rumor routing performs well only when the number of events is small. For large number of events, the cost of maintaining agents and event-tables in each node may not be amortized if there is not enough interest on those events from the sink. Another issue to deal with is tuning the overhead through adjusting parameters used in the algorithm such as time-to-live for queries and agents.

G. Gradient-based routing

Schurgersetal. [17] have proposed a slightly changed version of Directed Diffusion, called Gradient-based routing (GBR). The idea is to keep the number of hops when the interest is diffused through the network. Hence, each node can discover the minimum number of hops to the sink, which is called height of the node. The difference between a node s height and that of its neighbor is considered the gradient on that link. A packet is forwarded on a link with the largest gradient. The authors aim at using some auxiliary techniques such as data aggregation and traffic spreading along with GBR in order to balance the traffic uniformly over the network. Nodes acting as a relay for multiple paths can create a data combining entity in order to aggregate data. On the other hand, three different data spreading techniques have been presented:

Stochastic scheme: When there are two or more next hops with the same gradient, the node chooses one of them at random.

Energy-based scheme: When a node's energy drops below a certain threshold, it increases its height so that other sensors are discouraged from sending data to that node.

Stream-based scheme: The idea is to divert new streams away from nodes that are currently part of the path of other streams. The data spreading schemes strives to achieve an even distribution of the traffic throughout the whole network, which helps in balancing the load on sensor nodes and increases the network life-time. The employed techniques for traffic load balancing and data fusion are also applicable to other routing protocols for enhanced performance. Through simulation GBR has been shown to outperform Directed Diffusion in terms of total communication energy. Self-organizing protocol Subramanian and Katz [18] not only describe a self-organizing protocol but develop taxonomy of sensor applications as well. Based on such taxonomy, they have proposed architectural and infra-structural components necessary for building sensor applications. The architecture supports heterogeneous sensors that can be mobile or stationary. Some sensors, which can be either stationary or mobile, probe the environment and forward the data to designated set of nodes that act as routers. Router nodes are stationary and form the backbone for communication. Collected data are forwarded through the routers to more powerful sink nodes. Each sensing node should be reachable to a router node in order to be part of the network. A routing architecture that requires addressing of each sensor node has been proposed. Sensing nodes are identifiable through the address of the router node it is connected to. The routing architecture is hierarchical where groups of nodes are formed and merge when needed. In order to sup-port fault tolerance, local Markov loops (LML) algorithm, which performs a random walk on spanning trees of a graph, is used in broadcasting. The algorithm for self-organizing the router nodes and creating the routing tables consists of four phases:

Discovery phase: The nodes in the neighborhood of each sensor are discovered.

Organization phase: Groups are formed and merged by forming a hierarchy. Each node is allocated an address based on its position in the hierarchy. Routing tables of size O(log N) are created for each node. Broadcast trees that span all the nodes are constructed.

Maintenance phase: Updating of routing tables and energy levels of nodes is made in this phase.

Each node informs the neighbors about its routing table and energy level. LML are used to maintain broadcast trees.

Self-reorganization phase: In case of partition or node failures, group reorganizations are per-formed.

The proposed algorithm utilizes the router nodes to keep all the sensors connected by forming a dominating set. Such approach is similar to the idea of virtual grid used in GAF [19], which will be discussed later under location-based protocols. Both approaches achieve energy saving through utilization of a limited subset of nodes. Since sensor nodes can be addressed individually in the routing architecture, the proposed algorithm is suitable for applications such as parking-lot net-works where communication to a particular node is required [18]. The major advantage of using the algorithm is the small cost of maintaining routing tables and keeping routing hierarchy being strictly balanced. Moreover, the energy consumed for broadcasting a message is less than that consumed in SPIN protocol [6] due to the broadcast trees utilized in the algorithm. Fault tolerance is also achieved by using LML in broadcast trees.

The disadvantage is in the organization phase of algorithm, which is not on-demand, therefore introducing extra overhead. Another possible problem is in case of hierarchy forming when there are many cuts in the network. This will be expensive since network-cuts increase the probability of applying reorganization phase. Each node informs the neighbors about its routing table and energy level. LML are used to maintain broadcast trees.

H. GAF

Geographic adaptive fidelity (GAF) [19] is an energy-aware location-based routing algorithm designed primarily for mobile ad hoc networks, but may be applicable to sensor networks as well. GAF conserves energy by turning off unnecessary nodes in the network without affecting the level of routing fidelity. It forms a virtual grid for the covered area. Each node uses its GPS-indicated location to associate itself with a point in the virtual grid. Nodes associated with the same point on the grid are considered equivalent in terms of the cost of packet routing. Such equivalence is exploited in keeping some nodes located in a particular grid area in sleeping state in order to save energy. Thus, GAF can substantially increase the network lifetime as the number of nodes increases. A sample situation is depicted in Fig. 11, which is redrawn from [19]. In this figure, node 1 can reach any of 2, 3 and 4 and nodes 2, 3, and 4 can reach 5. Therefore nodes 2, 3 and 4 are equivalent and two of them can sleep. Nodes change states from sleeping to active in turn so that the load is balanced. There are three states defined in GAF. These states are discovery, for determining the neighbors in the grid, active reflecting participation in routing and sleep when the radio is turned off.

I. COUGAR

Under this approach, the network is foreseen as a distributed database where some nodes containing the information are temporary unreachable [20]. Since node stores historic values, the network behaves as a data warehouse. Additionally, it is worth noting that poor propagation conditions may lead to the storage of erroneous information in the nodes. Taking into account this circumstance, COUGAR provides a SQL-like interface extended to incorporate some clauses to model the probability distribution. The sink is responsible for generating a query plan which provides the hints to select a special node called the leader. The network leaders perform aggregation and transmit the results to the sink.

J. TEEN (Threshold Sensitive Energy Efficient Sensor Network Protocol)

TEEN [21] is other hierarchical protocol for reactive networks that responds immediately to changes in the relevant parameters. In this protocol a clusters head (CH) sends a hard threshold value and a soft one. The nodes sense their environment continuously. The first time a parameter from the attribute set reaches its hard threshold value, the node switches on its transmitter and sends its data. The nodes then transmits data in the current cluster period if the following conditions are true: the current value of the sensed attribute is greater than the hard threshold, and the current value of the sensed attribute differs from sensed value by an amount equal to or greater than the soft threshold. Both strategy looks to reduce energy spend transmitting messages. The main drawback of this scheme is that, if the thresholds are not reached, the nodes will never communicate the user will not get any data from the network at all and will not come to know even if all the nodes die. Thus, this scheme is not well suited for applications where the user needs to get data on a regular basis.

IV. CONCLUSION AND OPEN ISSUES

Routing protocols in sensor networks has attracted a lot of attention in the recent years and introduced unique challenges compared to traditional data routing in wired networks. In this paper, we have summarized recent research results on data routing in sensor networks and classified the approaches into three main categories, namely data-centric, hierarchical and location-based. Some more protocols followed the traditional network flow and QoS modeling methodology. However, we have also observed that there are some hybrid protocols that fit under more than one category. Protocols, which name the data and query the nodes based on some attributes of the data are categorized as data-centric. Many of the researchers follow this paradigm in order to avoid the overhead of forming clusters, the use of specialized nodes etc. However, the naming schemes such as attribute-value pairs might not be sufficient for complex queries and they are usually dependent on the application. Efficient standard naming schemes are one of the most interesting future re- search direction related to this category.

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