Routing protocols based on network structure in wireless sensor networks -A survey

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ABSTRACT - *Wireless sensor networks (WSN) applications comprised in a wide variety of areas. The network is composed of a significant number of nodes which are deployed in an extensive area in which not all nodes are directly connected. Here, the data exchange is performed by multi hop communications. Route discovery and maintenance in the network are the work of routing protocols. However, the importance of a particular routing protocol depends on the capabilities of the nodes and on the application requirements. This paper presents a review of the routing protocols which is based on the network structure proposed for WSNs.*

Keywords: *Routing protocol; wireless sensor network*

I. INTRODUCTION

A typical WSN encountered in the research literature consist of a large number of small, cheap, and resource constrained sensor as well as a few base stations or sinks. In most WSN settings sensors collect data from the environment and forward it hop by hop to the sink. A sink is a powerful entity that may serve as a gateway to another network, a data processing or storage center, or an access point for human interface. The WSN might be often deployment on a large scale throughout a geographic region in hostile environments. While many sensors connect to controllers and processing stations directly (e.g., using local area networks), an increasing number of sensors communicate the collected data wirelessly to a centralized processing station. This is important since many network applications require hundreds or thousands of sensor nodes, often deployed in remote and inaccessible areas [2].

A wireless sensor has not only a sensing component, but also on-board processing, communication, and storage capabilities. With these enhancements, a sensor node is often not only responsible for data collection, but also for in-network analysis, correlation, and fusion of its own sensor data and data from other sensor nodes. When many sensors cooperatively monitor large physical environments, they form a WSN. Sensor nodes communicate not only with each other but also with a base station (BS) using their wireless radios, allowing them to disseminate their sensor data to remote processing, visualization, analysis, and storage systems. Wireless networks is an emerging new technology that will allow users to access information and services electronically, regardless of their geographic position.[3] The sensor nodes have significantly lower communication and computation capabilities than do the full-featured computers participating in ad hoc networks. The problem of energy resources is especially difficult [4].

Due to their deployment model, the energy source of the sensor node is considered nonrenewable although some sensor nodes might be able to scavenge resources from their environment). Routing protocols deployed in sensor networks need to consider the problem of efficient use of power resources. Sensor networks are composed of resource constrained sensor nodes and more resourced base stations. All nodes in a network communicate with each other via wireless links, where the communication cost is much higher than the computational cost. Moreover, the energy needed to transmit a message is about twice as great as the energy needed to receive the same message. Consequently, the route of each message destined to the base station is really crucial in terms network lifetime: e.g., using short routes to the base station that contains nodes with depleted batteries may yield decreased network lifetime. On the other hand, using a long route composed of many sensor nodes can significantly increase the network delay.

II. ROUTING PROTOCOLS BASED ON NETWORK STRUCTURE IN WSN

The underlying network structure can play significant role in the operation of the routing protocol in WSNs. In this section, we survey in details most of the protocols that fall below this category.

1. Flat Routing Protocols

In flat networks, each node typically plays the same role and sensor nodes collaborate together to perform the sensing task. Due to the large number of such nodes, it is not feasible to assign a global identifier to each node. This consideration has led to data centric routing, where the BS sends queries to certain regions and waits for data from the sensors located in the selected regions. Some of the protocols in case of flat networks are as below,

- Sensor Protocols for Information via Negotiation (SPIN)
- Directed Diffusion (DD)
- Rumor Routing (RR)
- Minimum Cost Forwarding Algorithm (MCFA)

The following subsections summarize some protocols and highlight their advantages and their performance issues.

1.1 Sensor Protocols for Information via Negotiation (SPIN)

This protocol disseminates all the information at each node to every node in the network assuming that all nodes in the network are potential BSs.

Basic operation

SPIN is a 3-stage protocol as sensor nodes use three types of messages ADV, REQ and DATA to communicate. ADV is used to advertise new data, REQ to request data, and DATA is the actual message itself. The protocol starts when a SPIN node obtains new data that it is willing to share. It does so by broadcasting an ADV message containing meta-data. If a neighbor is interested in the data, it sends a REQ message for the DATA and the DATA is sent to this neighbor node. The neighbor sensor node then repeats this process with its neighbors. As a result, the entire sensor area will receive a copy of the data.

Advantages

Topological changes are localized since each node needs to know only its single-hop neighbors. SPIN provides much energy savings than flooding and metadata negotiation almost halves the redundant data.

Disadvantages

SPINs data advertisement mechanism cannot guarantee the delivery of data.

1.2 Directed Diffusion (DD)

Basic operation

This is popular data aggregation paradigm for WSNs. The main idea of the Data Centric (DC) paradigm is to combine the data coming from different sources, en route by eliminating redundancy, minimizing the number of transmissions; thus saving network energy and prolonging its lifetime. Working of directed diffusion

a. Sending interests,
b. Building gradients, and
c. Data dissemination.

Advantages

1. Directed diffusion allows on demand data queries while SPIN allows only interested nodes to query.
2. Unlike SPIN, there is no need to maintain global network topology in directed diffusion.

Disadvantage

Directed diffusion may not be applied to applications (e.g., environmental monitoring) that require continuous data delivery to the BS.

1.3 Rumor Routing (RR)

Basic operation

This routing technique will route queries to the nodes that have observed a particular event rather than flooding the entire network. 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, called events 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, may respond to the query by inspecting its event table.

Advantage

Simulation results showed that rumor routing can achieve significant energy savings when compared to event flooding and can also handle node's failure.

Disadvantage

Rumor routing technique fails in case of large number of nodes since the cost of maintaining agents and event-tables in each node becomes infeasible.

1.4 Minimum Cost Forwarding Algorithm (MCFA)

The MCFA algorithm [18] exploits the fact that the direction of routing is always known, that is, towards the fixed external base-station. Hence, a sensor node need not have a unique ID nor maintain a routing table. Instead, each node maintains the least cost estimate from itself to the base-station. Each message to be forwarded by the sensor node is broadcast to its neighbors. When a node receives the message, it checks if it is on the least cost path between the source sensor node and the base-station. If this is the case, it re-broadcasts the message to its neighbors. This process repeats until the base-station is reached.

Advantage

The base-station broadcasts a message with the cost set to zero while every node initially set its least cost to the base-station to infinity

Disadvantage

This may result in some nodes having multiple updates and those nodes far away from the base-station will get more updates from those closer to the base-station.

2. Hierarchical Routing Protocols

In a hierarchical architecture, higher energy nodes can be used to process and send the information while low energy nodes can be used to perform the sensing in the proximity of the target. This means that creation of clusters and assigning special tasks to Cluster Heads (CHs) can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is mainly two-layer routing where one layer is used to select cluster heads and the other layer is used for routing.
Some of the protocols in case of Hierarchical Routing networks are as below,

- Threshold-sensitive Energy Efficient Protocols (TEEN and APTEEN)
- Virtual Grid Architecture routing (VGA)
- Hierarchical Power-aware Routing (HPAR)

The following subsections summarize some protocols and highlight their advantages and their performance issues.

2.1 Threshold-sensitive Energy Efficient Protocols (TEEN and APTEEN)

Basic operation

In TEEN, (Threshold-sensitive Energy Efficient sensor Network protocol) sensor nodes sense the medium continuously, but the data transmission is done less frequently. A cluster head sensor sends its members a hard threshold, which is the threshold value of the sensed attribute and a soft threshold, which is a small change in the value of the sensed attribute that triggers the node to switch on its transmitter and transmit.

In APTEEN (Adaptive Periodic Threshold-sensitive Energy Efficient sensor Network protocol), the cluster-heads broadcasts the following parameters:

- Attributes
- Thresholds
- Schedule
- Count Time

Once a node senses a value beyond hard threshold (HT), it transmits data only when the value of that attributes changes by an amount equal to or greater than the soft threshold (ST). If a node does not send data for a time period equal to the count time, it is forced to sense and retransmit the data.

Advantages

TEEN includes its suitability for time critical sensing applications. At every cluster change time, fresh parameters are broadcasted and the user can change them as required.

Disadvantages

The main drawback of this scheme is that, if the thresholds are not received, the nodes will never communicate, and the user will not get any data from the network at all. These two approaches are the overhead and complexity associated with forming clusters at multiple levels, the method of implementing threshold-based functions, and how to deal with attribute based naming of queries.

2.2 Virtual Grid Architecture routing (VGA)

Basic operation

It is an energy-efficient routing paradigm that utilizes data aggregation and in-network processing to maximize the network lifetime. Due to the node stationary and extremely low mobility in many applications in WSNs, a reasonable approach is to arrange nodes in a fixed topology. A group of sensor nodes is made as square clusters, from which an optimally selected node acts as cluster head which perform the local aggregation, while a subset of these LAs are used to perform global aggregation. Determination of an optimal selection of global aggregation points, called Master Aggregators (MA). However this is NP-hard problem.

Regular shape tessellation applied to the network area. In each zone, a cluster head is selected for local aggregation. A subset of those cluster heads, called Master nodes, is optimally selected to do global aggregation. Two solution strategies for the routing with data aggregation problem are presented in [31]: an exact algorithm using an Integer Linear Program (ILP) formulation and several near optimal, but simple and efficient, approximate algorithms, namely, genetics algorithms based heuristic, a k-means heuristic, and a greedy based heuristic. In [48], another efficient heuristic, called Clustering-Based Aggregation Heuristic (CBAH), was also proposed to minimize energy consumption in the network, and hence prolong the network lifetime. The objective of all algorithms is to select a number of MAs out of the LAs that maximize the network lifetime.

Advantages

The location of the base station is not necessarily at the extreme corner of the grid; rather it can be located at any arbitrary place.

Disadvantages

In each zone, cluster head is selected for local aggregation. A subset of those cluster heads, called Master nodes, is optimally selected to do global aggregation.

2.3 Hierarchical Power-aware Routing (HPAR)

Basic operation

The protocol divides the network into groups of sensors. Each group of sensors in geographic proximity is clustered together as a zone and each zone is treated as an entity. To perform routing, each zone is allowed to decide how it will route a message hierarchically across the other Zones such that the battery lives of the nodes in the system are maximized. Messages are routed along the path which has the maximum over all the minimum of the remaining power, called the max-min path. The sensors in a zone autonomously direct local routing and participate in estimating the zone power level. Each message is routed across the zones using information about the zone power estimates. Many algorithms like Dijkstra algorithm, zone based routing algorithms were proposed to accomplish the task of routing across a particular node.

Advantage

It works well with respect to network of large number of nodes.

Disadvantage

Maintaining global data is quite infeasible task.

3. Location Based Routing Protocols

In this kind of routing, sensor nodes are addressed by means of their locations. The distance between neighboring nodes can be estimated on the basis of incoming signal strengths. Relative coordinates of neighboring nodes can be obtained by exchanging such information between neighbors. Some of the protocols in case of Location based routing networks are as below,

- Geographic Adaptive Fidelity (GAF)

- Geographic and Energy Aware Routing (GEAR)
- SPAN

The following subsections summarize some of the above protocols and highlight their advantages and their performance issues.

3.1 Geographic Adaptive Fidelity (GAF)

Basic operation

This is an energy-aware location-based routing algorithm. The network area is first divided into fixed zones and forms a virtual grid. Inside each zone, nodes collaborate with each other to play different roles. For example, nodes will elect one sensor node to stay awake for a certain period of time and then they go to sleep. This node is responsible for monitoring and reporting data to the BS on behalf of the nodes in the zone. The sleeping neighbors adjust their sleeping time accordingly in order to keep the routing fidelity. Before the leaving time of the active node expires, sleeping nodes wake up and one of them becomes active. GAF conserves energy by turning off unnecessary nodes in the network without affecting the level of routing fidelity. 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.

Advantage

Results show that GAF performs at least normal ad hoc routing protocol in terms of latency and packet loss and increases the lifetime of the network by saving energy.

Disadvantage

GAF strives to keep the network connected by keeping a representative node always in active mode for each region on its virtual grid.

3.2 Geographic and Energy Aware Routing (GEAR)

Basic operation

This protocol uses energy aware and geographically informed neighbor selection heuristics to route a packet towards the destination region. The key idea is to restrict the number of interests in directed diffusion by only considering a certain region rather than sending the interests to the whole network. Each node in GEAR keeps an estimated cost and a learning cost of reaching the destination through its neighbors. The estimated cost is a combination of residual energy and distance to destination. The learned cost is a refinement of the estimated cost that accounts for routing around holes in the network. There are two phases in the algorithm:

- Forwarding packets towards the target region: Where a node upon receiving a packet will route it to the node which is the nearest node for target node or it will route it based on the learning cost.
- Forwarding the packets within the region: If the packet has reached the region, it can be diffused in that region by either recursive geographic forwarding or restricted flooding.

Advantages

GEAR reduces the energy consumption for the route setup. Results show that for an uneven traffic distribution, GEAR transfers effectively more number of packets with respect to other routing techniques.

Disadvantage

A hole occurs when a node does not have any closer neighbor to the target region than itself. If there are no holes, the estimated cost is equal to the learned cost. The learned cost is propagated one hop back every time a packet reaches the destination so that route setup for next packet will be adjusted.

3.3 SPAN

Another position based algorithm called SPAN selects some nodes as coordinators based on their positions. The coordinators form a network backbone that is used to forward messages. A node should become a coordinator if two neighbors of a non-coordinator node cannot reach each other directly or via one or two coordinators (3 hop reach ability). New and existing coordinators are not necessarily neighbors

Advantages

It makes the design less energy efficient because of the need to maintain the positions of two or three hop neighbors in the complicated SPAN algorithm.

Disadvantage

Overhead in selecting coordinator node among non-coordinator nodes

III. COMPARISON OF ROUTING ROTOCOLS

In this paper we compared the following routing protocols according to their design characteristics.

- SPIN [11][12] : Sensor Protocols for Information via Negotiation.
- DD[13].: Directed Diffusion
- RR[14].: Rumor Routing
- TEEN & APTEEN [20] :[Adaptive] Threshold sensitive Energy Efficient sensor Network.
- VGA [7]:Virtual Grid Architecture Routing .
- Hierarchical Power-aware Routing (HPAR)
- GAF [23]: Geographic Adaptive Fidelity.
- GEAR[25]: Geographical and Energy Aware Routing
- SPAN[24]

Table1 represents Classification and Comparison of routing protocols in WSNs

Table1: Classification and Comparison of routing protocols in WSNs.

Routing Protocols	Classification	Power Usage	Data Aggregation	Scalability	Over head	Data delivery model
SPIN	Flat/Data-centric	Ltd	Yes	Ltd	Low	Event driven
DD	Flat/Data-centric	Ltd	Yes	Ltd	Low	Demand Driven
RR	Flat	Low	Yes	Good	Low	Demand Driven
TEEN& APTEEN	Hierarchical	High	Yes	Good	High	Active threshold
VGA	Hierarchical	Low	Yes	Good	High	Good
GAF	Hierarchical/Location	Ltd	No	Good	Mod	Virtual grid
GEAR	Location	Ltd	No	Ltd	Mod	Demand Driven
SPAN	Hierarchical/Location	Ltd	Yes	Ltd	High	Continuously

IV. CONCLUSIONS

Routing in sensor networks is a new area of research, with a limited, but rapidly growing set of research results. In this paper, we presented a comprehensive survey of routing techniques based on network structure in wireless sensor networks which have been presented in the literature. They have the common objective of trying to extend the lifetime of the sensor network, while not compromising data delivery. Overall, the routing techniques are classified based on the network structure into three categories: flat, hierarchical, and location based routing protocols. Protocol operations are highlighted between energy and communication overhead savings in some of the routing paradigm, as well as the advantages and disadvantages of each routing technique. Although many of these routing techniques look promising, there are still many challenges that need to be solved in the sensor networks.

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