A Review on Routing Protocols in Wireless Sensor Networks

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Abstract- A wireless sensor network is a collection of some smart sensor nodes which collaborate among themselves to form a sensing network. Smart sensors are wireless computing devices that sense information in variety of environments to provide a multidimensional view of the environment. This paper briefly explains the routing protocols involved in wireless sensor networks, its classification and comparison.

Keywords – Wireless sensor Networks, Routing Protocols

I. INTRODUCTION

Recent advances in wireless sensor networks have led to many new protocols specifically designed for sensor networks. The manufacturing of small and low-cost sensors has become technically and economically feasible. A large number of these sensors can be networked in many applications that require unattended operations, hence producing a wireless sensor network (WSN). WSN is widely used in military and civil applications such as target field imaging, intrusion detection, weather monitoring, security and tactical surveillance.

The sensor nodes are constrained in energy supply and bandwidth. Such constraints are combined with a typical deployment of large number of sensor nodes, which have many challenges to the design and management of sensor networks. These challenges create energy awareness at all layers of networking protocol stack. The issues related to physical and link layers are generally common for all kind of sensor applications, therefore the research on these areas has been focused on system-level power awareness such as dynamic voltage scaling, radio communication hardware, low duty cycle issues, system partitioning, energy-aware MAC protocols [1–5]. At the network layer, the main aim is to find ways for energy-efficient route setup and reliable relaying of data from the sensor nodes to the sink so that the lifetime of the network is maximized.

Routing in sensor networks is very challenging due to several characteristics that distinguish them from contemporary communication and wireless ad hoc networks. First, it is not possible to build a global addressing scheme for the deployment of sheer number of sensor nodes. Second, almost all applications of sensor networks require the flow of sensed data from multiple regions (sources) to a particular sink. Third, generated data traffic has significant redundancy in it since multiple sensors may generate same data within the vicinity of a phenomenon. Such redundancy needs to be exploited the routing protocols to improve energy and bandwidth utilization. Fourth, sensor nodes are tightly constrained in terms of transmission power, on-board energy, processing capacity and storage and thus require careful resource management.

Due to such differences, many new algorithms have been proposed for the problem of routing data in sensor networks. These routing mechanisms have considered the characteristics of sensor nodes along with the application and architecture requirements. Almost all of the routing protocols can be classified as data-centric, hierarchical or location based routing.

II. RELATED WORK

The growing interest in wireless sensor networks and the continual emergence of new architectural techniques inspired some previous efforts for surveying the characteristics, applications and communication protocols for such a technical area[6,7]. In this subsection I highlight the features that distinguish the survey and hint the difference in scope.

The goal of [6] is to make a comprehensive survey of design issues and techniques for sensor networks describing the physical constraints on sensor nodes and the protocols proposed in all layers of network stack. Possible applications of sensor networks are also discussed. That survey is a good introductory for readers interested in the broad area. Although a number of routing protocols for sensor networks are covered, the paper does not make a classification for such routing protocols and the list of discussed protocols is not meant to be complete given the scope of the survey. In this paper, classifications and comparison of routing protocols are defined.

III. CLASSIFICATION

The routing protocols are broadly classified into Data-centric protocols, Hierarchical protocols and Location based protocols.

A. Data-centric Routing Protocol

Data-centric protocols are query-based and depend on the naming of desired data, which helps in eliminating many redundant transmissions.

1) SPIN: SPIN[8] is the first data-centric protocol, which considers data negotiation between nodes in order to eliminate redundant data and save energy. Later, Directed Diffusion [9] has been developed and has become a breakthrough in data-centric routing. Then, many other protocols have been proposed based on Directed Diffusion [10–12].

2) Direction Diffusion routing: In Directed Diffusion the sink queries the sensor nodes if a specific data is available by flooding some tasks. In SPIN, sensors advertise the availability 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. 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.

3) Energy aware routing: Shah and Rabaey [13] proposed to use a set of sub-optimal paths occasionally to increase the lifetime of the network. These paths are chosen by means of a probability function, which depends on the energy consumption of each path. Network survivability is the main metric that the approach is concerned with. The approach argues that using the minimum energy path all the time will deplete the energy of nodes on that path. Instead, one of the multiple paths is used with a certain probability so that the whole network lifetime increases. The protocol assumes that each node is addressable through a class-based addressing which includes the location and types of the nodes.

4) Rumor routing: Rumor routing [10] is another variation of Directed Diffusion and is mainly intended for contexts in which geographic routing criteria are not applicable. Generally Directed Diffusion floods the query to the 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. The idea is to route the queries to the nodes that have observed a particular event rather than flooding the entire network to retrieve information about the occurring events.

5) Gradient-based routing: Schurgers et al. [11] 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 nodes 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.

6) CADR: Constrained anisotropic diffusion routing (CADR) [12] is a protocol, which strives to be a general form of Directed Diffusion. Two techniques namely information-driven sensor querying (IDSQ) and constrained anisotropic diffusion routing are proposed. The idea is to query sensors and route data in a network in order to maximize the information gain, while minimizing the latency and bandwidth. This is achieved by activating only the sensors that are close to a particular event and dynamically adjusting data routes. The major difference from Directed Diffusion is the consideration of information gain in addition to the communication cost. In CADR, each node evaluates an information/cost objective and routes data based on the local information/cost gradient and end-user requirements. The information utility measure is modeled using standard estimation theory.

7) COUGAR: A data-centric protocol that views the network as a huge distributed database system is proposed in [14]. The main idea is to use declarative queries in order to abstract query processing from the network layer functions such as selection of relevant sensors etc. and utilize in-network data aggregation to save energy. The abstraction is supported through a new query layer between the network and application layers.

*8) ACQUIRE:*A fairly new data-centric mechanism for querying sensor networks is ACtive QUery forwarding In sensoR nEtworks (ACQUIRE)[15]. As in [14], the approach views the sensor network as a distributed database and is well-suited for complex queries which consist of several sub queries. The querying mechanism works as follows: the query is forwarded by the sink and each node receiving the query, tries to respond partially by using its pre cached information and forward it to another sensor. If the pre-cached information is not up-to date, the nodes gather information from its neighbors within a look-ahead of d hops. Once the query is being resolved completely, it is sent back through either the reverse or shortest-path to the sink.

B. Hierarchical Protocols

Hierarchical protocols aim at clustering the nodes so that cluster heads can do some aggregation and reduction of data in order to save energy. 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. Cluster formation is typically based on the energy reserve of sensors and sensors proximity to the cluster head [16,17].

1) LEACH: Low-energy adaptive clustering hierarchy (LEACH) [18] is one of the most popular hierarchical routing algorithms for sensor networks. The idea is to form clusters of the sensor nodes based on the received signal strength and use local cluster heads as routers to the sink. This will save energy since the transmissions will only be done by such cluster heads rather than all sensor nodes. Optimal number of cluster heads is estimated to be 5% of the total number of nodes. Power-Efficient GAthering in Sensor Information Systems (PEGASIS) [19] is 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.

2) TEEN and APTEEN: Threshold sensitive Energy Efficient sensor Network protocol (TEEN) [20] is a hierarchical protocol designed to be responsive to sudden changes in the sensed attributes such as temperature. Responsiveness is important for time-critical applications, in which the network operated in a reactive mode. TEEN pursues a hierarchical approach along with the use of a data-centric mechanism. The sensor network architecture is based on a hierarchical grouping where closer nodes form clusters and this process goes on the second level until base station (sink) is reached. The Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN) [17] is an extension to TEEN and aims at both capturing periodic data collections and reacting to time critical events. The architecture is same as in TEEN. When the base station forms the clusters, the cluster heads broadcast the attributes, the threshold values, and the transmission schedule to all nodes. Cluster heads also perform data aggregation in order to save energy. APTEEN supports three different query types: historical, to analyze past data values; one-time, to take a snapshot view of the network; and persistent to monitor an event for a period of time.

3) Energy-aware routing: Energy aware routing for cluster-based sensor networks Younis et al. [21] have proposed a different hierarchical routing algorithm based on a three tier architecture. Sensors are grouped into clusters prior to network operation. The algorithm employs cluster heads, namely gateways, which are less energy constrained than sensors and assumed to know the location of sensor nodes. Gateways maintain the states of the sensors and sets up multi-hop routes for collecting sensors data. A TDMA based MAC is used for nodes to send data to the gateway. The gateway informs each node about slots in which it should listen to other nodes transmission and slots, which the node can use for its own transmission. The command node (sink) communicates only with the gateways.

4) Self-organizing protocol: Subramanian and Katz [22] not only describe a self-organizing protocol but develop taxonomy of sensor applications as well. Based on such taxonomy, they have proposed architectural and infrastructural 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.

C. Location-Based Protocols
Location based protocols utilize the position information to relay the data to the desired regions rather than the whole network.

1) MECN and SMECN: Minimum energy communication network (MECN) [23] sets up and maintains a minimum energy network for wireless networks by utilizing low power GPS. Although, the protocol assumes a mobile network, it is best applicable to sensor networks, which are not mobile. A minimum power topology for stationary nodes including a master node is found. MECN assumes a master site as the information sink, which is always the case for sensor networks.

2) GAF: Geographic adaptive fidelity (GAF) [24] 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.

3) GEAR: Yu et al. [25] have suggested the use of geographic information while disseminating queries to appropriate regions since data queries often includes geographic attributes. The protocol, namely geographic and energy-aware routing (GEAR), uses energy aware and geographically informed neighbor selection heuristics to route a packet towards the target region. The 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. GEAR compliments Directed Diffusion in this way and thus conserves more energy.

IV. COMPARISON OF ROUTING PROTOCOLS

In this section all design issues [26-29] in WSN and of the routing protocols are compared.

A. Design issues in WSN
The design issues that affect the routing process in wireless sensor networks are,

1) Node deployment: Node deployment in WSNs is application dependent and affects the performance of the routing protocol. The deployment can be either deterministic or randomized. In deterministic situations, the sensors are manually placed and data is routed through pre-determined paths. However in self organizing systems, the sensor nodes are scattered randomly creating an infrastructure in an Ad-hoc manner. In that infrastructure, the position of the sink or the cluster head is also crucial in terms of energy efficiency and performance. When the distribution of nodes is not uniform, optimal positioning of cluster head becomes a pressing issue to enable energy efficient network operation.

2) Energy consumption: Sensor nodes can use up their limited energy to perform transmissions and computations. Such, Energy-conserving forms are essential. Sensor nodes are equipped with limited power source (<0.5 Ah 1.2V).Node lifetime is strongly dependent on its battery lifetime.

3) Fault Tolerance: Some sensor nodes may fail or be blocked due to lack of power or environmental interference. The failure of sensor nodes should not affect the sensor network. This is the reliability or fault tolerance issue.

4) Data Aggregation: Data aggregation is the combinations of data from different sources and this is used to achieve energy efficiency. As computation would be less energy consuming than communication, substantial energy savings can be obtained through data aggregation.

5) Scalability: Sensor network routing protocols should be scalable enough to respond to events in the environment. Until an event occurs, most of the sensors can remain in the sleep state, with data from the few remaining sensors providing a coarse quality.

6) Coverage: In WSNs, each sensor node obtains a certain view of the environment. A given sensor's view of the environment is limited both in range and in accuracy; it can only cover a limited physical area of the environment.

7) Quality of Service: In some applications, data should be delivered within a certain period of time from the moment it is sensed. The quality of service means the quality service required by the application, it could be the length of life time, the data reliable, energy efficiency, and location-awareness, collaborative-processing. These factors will affect the selection of routing protocols for a particular application.

B. Comparison of Routing Protocols

The routing protocols are compared on the basis of the design issues specified above in table1.

Table -1 Comparison of Routing Protocols

Routing Protocols	Node Deployment	Energy consumption	Data Aggregation	Scalability	Quality of Service
Spin	Manual	Ltd.	Yes	Ltd	No
Direction diffusion routing	Manual	Ltd	Yes	Ltd	No
Rumor routing	Random	Low	Yes	Good	No
Gradient based routing	Manual	Low	Yes	Ltd	No
CADR	Manual	Ltd	Yes	Ltd	No
COUGAR	Manual	Ltd	Yes	Ltd	No
ACQUIRE	Manual	Low	Yes	Ltd	No
LEACH	Manual	High	Yes	Good	No
TEEN and APTEEN	Manual	High	Yes	Good	No
Self organizing protocol	Random	Low	No	Good	No
MECN and SMECN	Random	Low	Yes	Good	No
GAF	Random	Ltd	No	Good	No
GEAR	Iterative	Ltd	No	Ltd	No

V. CONCLUSION

Routing 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, I 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. New routing algorithms are needed in order to handle the overhead of mobility and topology changes in such energy constrained environment. Future research for routing protocols includes the integration of sensor networks with wired networks (i.e. Internet). Most of the applications in security and environmental monitoring require the data collected from the sensor nodes to be transmitted to a server so that further analysis can be done. On the other hand, the requests from the user should be made to the sink through Internet. Since the routing requirements of each environment are different, further research is necessary for handling these kinds of situations.

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