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A Review of Routing Protocols for Wireless Sensor Network

Vikas Chaudhary[1], Aasiya Khatoon[2], Nalin Chaudhary[3]

[1.] M.Tech (C.S) (Assistant Professor, Bhagwant University, Ajmer, India)

[2.] M.Tech (C.S) (Scholar, Bhagwant University, Ajmer, India)

[3.] M.Tech (C.S) (Scholar, Bhagwant University, Ajmer, India)

Abstract- *A wireless sensor network is a collection of nodes organized into a cooperative network. Each node consists of processing capability, may contain multiple types of memory, have a RF transceiver, have a power source, and accommodate various sensors and actuators. The nodes communicate wirelessly and often self-organize after being deployed in an ad hoc fashion.*

Routing protocols for wireless sensor networks are responsible for maintaining the routes in the network and have to ensure reliable multi-hop communication .The performance of the network is greatly influenced by the routing techniques. Routing is to find out the path to route the sensed data to the base station. In this paper the features of WSNs are introduced and routing protocols are reviewed for Wireless Sensor Network.

Keywords- *Wireless Sensor Networks, Routing Protocols, Hierarchical Routing Protocols*

I. Introduction

Wireless sensor networks are quickly gaining popularity due to the fact that they are potentially low cost solutions to a variety of real-world challenges [1]. Their low cost provides a means to deploy large sensor arrays in a variety of conditions capable of performing both military and civilian tasks. Wireless Sensor Network (WSN) is intended for monitoring an environment. Wireless sensor network (WSN) is widely considered as one of the most important technologies for the twenty-first century [2]. In the past decades, it has received tremendous attention from both academia and industry all over the world. A WSN typically consists of a large number of low-cost, low-power, and multifunctional wireless sensor nodes, with sensing, wireless communications and computation capabilities [3, 4]. These sensor nodes communicate over short distance via a wireless medium and collaborate to accomplish a common task, for example, environment monitoring, military surveillance, and industrial process control [5].

The wireless sensor node is used to sense and collect data from a certain domain and transmit it to the sink where application lies. Ensuring the direct communication between a sensor and the sink may lead nodes to produce their messages with such a high power that it could result resources to be quickly consumed. Therefore, the collaboration of nodes to ensure that distant nodes communicate with the sink is a requirement. In this way, messages are generated by intermediate nodes so that a route with multiple links or hops to the sink is established.

The communication with the sink could be initially evolved without a routing protocol. Based on this statement, the flooding algorithm comes out as a solution. In this algorithm, the transmitter broadcasts the data which are consecutively retransmitted in order to make them arrive at the intended destination. However, its simplicity brings out significant drawbacks. An implosion is detected because nodes repeatedly receive multiple copies of the same data message.

One optimization relies on the gossiping algorithm [6]. Gossiping avoids implosion as the sensor transmits the message to a selected neighbor instead of informing all its neighbors as in the classical flooding algorithm. However, overlap and resource blindness are still present. Furthermore, these inconveniences are highlighted when the number of nodes in the network increases.

Due to shortcomings of the previous strategies, routing protocols become necessary in wireless sensor networks. Nevertheless, the inclusion of a routing protocol in a wireless sensor network is not a insignificant task. One of the main limitations is the identification of nodes. Since wireless sensor networks are formed by a significant number of nodes, the manual assignation of unique identifiers becomes infeasible [7].

However, this shortcoming is easily overcome in wireless sensor networks since an IP address is not required to identify the destination node of a specific packet. As a matter of fact, attribute-based addressing fits better with the explicitness of wireless sensor networks. In this case, an attribute such as node location and sensor type is used to identify the final destination. Once nodes are identified, routing protocols are in charge of building and maintaining routes between distant nodes. The routing protocols operate in various ways which make them suitable for certain applications.

II. Network Characteristics And Design Objectives

The characteristics of sensor networks and application requirements have a determine impact on the network design objectives in term of network capabilities and network performance [8].

2.1 Network Characteristics

Wireless sensor networks as compared to traditional wireless networks have the following unique characteristics and constraints:

Battery-powered sensor nodes: Sensor nodes are usually powered by battery and are deployed in a harsh environment where it is very difficult to change or recharge the batteries.

Unreliable sensor nodes: Since sensor nodes are prone to physical damages or failures due to its deployment in harsh or hostile environment.

Data redundancy: In most sensor network application, sensor nodes are densely deployed in a region of interest and collaborate to accomplish a common sensing task. Thus, the data sensed by multiple sensor nodes typically have a certain level of correlation or redundancy.

Self-configurable: Sensor nodes are usually randomly deployed and autonomously configure themselves into a communication network.

Frequent topology change: Network topology changes frequently due to the node failures, damage, addition, energy depletion, or channel fading.

Application specific: A sensor network is usually designed and deployed for a specific application. The design requirements of a sensor network change with its application.

Many-to-one traffic pattern: In most sensor network applications, the data sensed by sensor nodes flow from multiple source sensor nodes to a particular sink, exhibiting a many-to-one traffic pattern.

2.2 Network Design Objectives

Most sensor networks are application specific and have different application requirements. Thus, all or part of the following main design objectives is considered in the design of sensor networks:

- **Small node size**
- **Low power consumption**
- **Low node cost**
- **Scalability**
- **Reliability**
- **Adaptability**
- **Self-configurability**
- **Channel utilization**
- **Fault tolerance**
- **QoS support**
- **Security**

III. Design Constraints For Routing In Wireless Sensor Networks

Due to the reduced computing, radio and battery resources of sensors, routing protocols in wireless sensor networks are expected to fulfill the following requirements [9]:

- **Autonomy:** The assumption of a dedicated unit that controls the radio and routing resources does not stand in wireless sensor networks as it could be an easy point of attack. Since there will not be any centralized entity to make the routing decision, the routing procedures are transferred to the network nodes.
- **Energy Efficiency:** Routing protocols should prolong network lifetime while maintaining a good grade of connectivity to allow the communication between nodes. It is important to note that the battery replacement in the sensors is infeasible since most of the sensors are randomly placed. Under some circumstances, the sensors are not even reachable. For instance, in wireless underground sensor networks, some devices are buried to make them able to sense the soil [10].
- **Scalability:** Wireless sensor networks are composed of hundred of nodes so routing protocols should work with this amount of nodes.
- **Resilience:** Sensors may unpredictably stop operating due to environmental reasons or to the battery consumption. Routing protocols should cope with this eventuality so when a current-in-use node fails, an alternative route could be discovered.

- **Device Heterogeneity:** Although most of the civil applications of wireless sensor network rely on homogenous nodes, the introduction of different kinds of sensors could report significant benefits. The use of nodes with different processors, transceivers, power units or sensing components may improve the characteristics of the network. Among other, the scalability of the network, the energy drainage or the bandwidth is potential candidates to benefit from the heterogeneity of nodes [11].
- **Mobility Adaptability:** The different applications of wireless sensor networks could demand nodes to cope with their own mobility, the mobility of the sink or the mobility of the event to sense. Routing protocols should render appropriate support for these movements.

IV. Classification Of Routing Protocols In Wireless Sensor Networks

As per the involvement of sensor node in the network, the routing protocols are mainly classified into three categories:

- **Data-centric or negotiation based protocol**
- **Hierarchical or cluster based protocol**
- **location-based protocol**

4.1 DATA-CENTRIC OR NEGOTIATION BASED PROTOCOL

Data-centric or negotiation based protocol [9.12], these protocols are basically query based and depend on the desired data (name of the data), which help us to remove or eliminate the redundancy of the data. Data-centric model assures to combine the applications needed to access data (instead of individual nodes) with a natural framework for in-network processing [13]. Wireless sensor networks have many applications where 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 differentiates data centric routing from traditional address based routing where routes are created between addressable nodes. SPIN [14] 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.

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PIN (Sensor protocol for information exchange): SPIN (sensor protocol for information exchange) is the first category of data centric protocol. The key feature of this routing protocol is to name the data using meta-data which describes the characteristics of data. SPIN is the 3-stage protocol since there are three messages in order to have communication between nodes.

- ADV (Advertisement): To advertise new data.
- REQ (Request): To Request for data.
- DATA: Carry the actual data.

One of the advantages of SPIN is that topological changes are localized since each node needs to know only its single-hop neighbors. SPIN gives a factor of 3.5 less than flooding in terms of energy dissipation and meta-data negotiation almost halves the redundant data.

Directed Diffusion: Directed Diffusion is very significant finding 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. Directed Diffusion avoids unnecessary operation of network layer routing in order to serve its best purpose i.e. to save energy. Directed diffusion has several key elements namely data naming, interests and gradients, data propagation, and reinforcement. A sensing task can be described by a list of attribute-value pairs. At the beginning of the directed diffusion process, the sink specifies a low data rate for incoming events. After that, the sink can reinforce one particular sensor to send events with a higher data rate by resending the original interest message with a smaller interval. Likewise, if a neighboring sensor receives this interest message and finds that the sender's interest has a higher data rate than before, and this data rate is higher than that of any existing gradient, it will reinforce one or more of its neighbors.

4.2 HIERARCHICAL PROTOCOL

Hierarchical or cluster based protocol, as the name suggests in this protocol, the group of some nodes in the network makes one or more clusters (depend on the size of the networks). In a cluster one node works as a cluster head. All nodes in a cluster first send the data to the cluster head; the cluster head perform some aggregation function upon this data then send to the sink or base station. Similar to other communication networks, scalability is one of the major design attributes of sensor networks. A single-tier network can cause the gateway to overload with the increase in sensors density. Such overload might cause latency in communication and inadequate tracking of events. In addition, the single-gateway architecture is not scalable for a larger set of sensors covering a wider area of interest since the sensors are typically not capable of long-haul communication. Clustering is the best approach to increase the scalability of the system and cover a wide area without degrading the performance.

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. LEACH [15] is the first cluster based routing protocol for the sensor network.

LEACH (Low Energy Adaptive Clustering Hierarchy): LEACH [15, 16] is a most popular clustering-based protocol for the sensor network. 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. It utilizes randomized rotation of the cluster-heads to evenly distribute the energy load among the sensor nodes in the network. All nodes in the network are homogeneous and energy-constrained. The main energy saving of LEACH protocol comes from the combination of data compression and routing.

All the data processing such as data fusion and aggregation are local to the cluster. Cluster heads change randomly over time in order to balance the energy dissipation of nodes. 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:

$$T(n) = \begin{cases} p/(1-P*(r \bmod 1/P)) & \text{if } n \text{ belongs to } G \\ 0 & \text{Otherwise} \\ 1 & \end{cases}$$

Where p is the desired percentage of cluster heads (e.g. 0.05), r is the current round, and G is the set of nodes that have not been cluster heads in the last 1=p rounds.

LEACH is completely distributed and requires no global knowledge of network. It reduces energy consumption by (a) minimizing the communication cost between sensors and their cluster heads and (b) turning off non-head nodes as much as possible. 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.

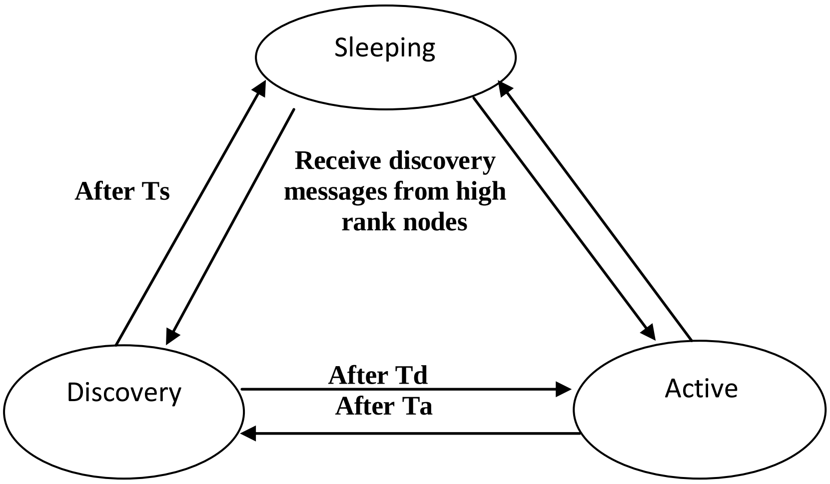
PEGASIS (Power-Efficient Gathering in Sensor Information Systems): PEGASIS [17] is an extension of the LEACH protocol, which forms chains from sensor nodes so that each node transmits and receives from a neighbor and only one node is selected from that chain to transmit to the base station (sink). The data is gathered and moves from node to node, aggregated and eventually sent to the base station. The chain construction is performed in a greedy way. Simulation results showed that PEGASIS is able to increase the lifetime of the network twice as much the lifetime of the network under the LEACH protocol. Such performance gain is achieved through the elimination of the overhead caused by dynamic cluster formation in LEACH and through decreasing the number of transmissions and reception by using data aggregation. PEGASIS is a chain-based power efficient protocol based on LEACH.

4.3 LOCATION-BASED PROTOCOL

location-based protocol, these protocol utilize the position information of the desired data in the desired region than rather considering the whole network [9, 12].Most of the routing protocols for sensor networks require location information for sensor nodes. In most cases location information is needed in order to calculate the distance between two particular nodes so that energy consumption can be estimated. Since, there is no addressing scheme for sensor networks like IP-addresses and they are spatially deployed on a region, location information can be utilized in routing data in an energy efficient way. For instance, if the region to be sensed is known, using the location of sensors, the query can be diffused only to that particular region which will eliminate the number of transmission significantly. The location-based routing protocols take into account the mobility of sensor nodes and perform very well when the density of network increases. But, the performance is very poor when the network deployment is sparse, and there is no data aggregation and further processing by the header node. In this section, we present a sample of location-aware routing protocols proposed for WSNs.

Geographic Adaptive Fidelity (GAF): Geographic adaptive fidelity (GAF) [18] 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 is based on mechanism of turning off unnecessary sensors while keeping a constant level of routing fidelity (or uninterrupted connectivity between communicating sensors). In GAF, sensor field is divided into grid squares and every sensor uses its location information, which can be provided by GPS or other location systems, to associate itself with a particular grid in which it resides. This kind of association is exploited by GAF to identify the sensors that are equivalent from the perspective of packet forwarding.



As shown in Figure 1, the state transition diagram of GAF has three states, namely, discovery, active, and sleeping. When a sensor enters the sleeping state, it turns off its radio for energy savings. In the discovery state, a sensor exchanges discovery messages to learn about other sensors in the same grid. Even in the active state, a sensor periodically broadcasts its discovery message to inform equivalent sensors about its state. The time spent in each of these states can be tuned by the application depending on several factors, such as its needs and sensor mobility. GAF aims to maximize the network lifetime by reaching a state where each grid has only one active sensor based on sensor ranking rules. The ranking of sensors is based on their residual energy levels. Thus, a sensor with a higher rank will be able to handle routing within their corresponding grids.

Geographic and Energy-Aware Routing (GEAR): GEAR [19] is an energy-efficient routing protocol proposed for routing queries to target regions in a sensor field, In GEAR, the sensors are supposed to have localization hardware equipped, for example, a GPS unit or a localization system [20] so that they know their current positions. Furthermore, the sensors are aware of their residual energy as well as the locations and residual energy of each of their neighbors. GEAR uses energy aware heuristics that are based on geographical information to select sensors to route a packet toward its destination region. Then, GEAR uses a recursive geographic forwarding algorithm to disseminate the packet inside the target region.

V. Conclusion

Routing emerges as a challenge in wireless sensor network as compared to traditional wireless networking. In this paper, we reviewed routing protocols in wireless sensor networks based on the various performance characteristics (like scalability, efficient use of resources, Energy saving). Overall, depending upon the network structure, routing techniques are divided into three categories. Data centric or flat routing, hierarchical or cluster routing and location based routing. All these routing techniques have common goal to increase the life of the network.

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