Routing in Wireless Sensor Networks: Protocols and Challenges

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***Abstract*--Energy awareness, power management and data dissemination considerations have made routing in wireless sensor networks a challenging issue. Routing protocols are classified according to the network structure and protocol operation to satisfy the performance requirements of various applications. This paper presents a survey and the importance of routing in wireless sensor networks. We highlight the classification of various routing protocols along with an overview of few routing protocols. This paper also summarizes the various challenges observed in routing in wireless sensor networks and finally we conclude with potential issues for future research.**

***Index Terms*--Wireless sensor networks, Routing, SPIN, Directed Diffusion, LEACH, GEAR.**

I. Introduction

DUE to the recent advances in computer and communication technology, a class of computing device namely, the wireless battery-powered sensor nodes, is finding widespread applications. A Wireless Sensor Network (WSN), containing hundreds of such nodes, can be defined as a network of spatially distributed autonomous devices connected by wireless links using sensors to co-operatively monitor various environmental variables or phenomena like pressure, sound, temperature, motion or pollutants at different locations etc. Dense deployments of nodes (called sensor nodes), that have

Wireless communication capability and some level of intelligence for signal processing and networking of data are placed in close proximity of the monitored event, operate in a co-operative manner to gather data through distributed sensing for phenomena whose exact location is unknown. This gathered data is then routed back to a sink node (BS). Thus wireless sensor networks provide access to those areas that were previously inaccessible due to economic and physical barriers. WSNs fall into the category of infrastructure-less or rapidly-deployable networks [1], where the nodes act as both hosts and routers acting in a self-organizing and adapting manner.

WSNs differ from Mobile Ad-hoc Networks (MANETs) in many ways such as the number of nodes in WSNs is comparatively higher and in most applications sensor nodes need to work unattended where human intervention is not possible. Also, much of the processing in WSNs is data centric, due to the possible absence of global addressing of nodes and use of attribute addressing. WSNs find applications ranging from military to civil such as environment and habitat monitoring, surveillance, wildlife monitoring, remote terrain exploration, health care applications etc.

Routing plays a vital role in the deployment of WSNs. Dense deployments of wireless sensor nodes require the data to be routed over long distances since sensor nodes are not capable of long haul communication due to energy and bandwidth constraints which makes routing extremely important in wireless sensor networks. Routing is also very challenging since the sensor nodes are deployed in an ad-hoc manner making the organization of these nodes difficult to maintain and requiring intelligent resource management. In some cases, where the nodes are mobile, traditional routing protocols do not show a good performance and thus new schemes are required to address the mobility of sensor nodes.

Section 2 presents an overview of the classification of routing protocols, with details on few of them. Various challenges in routing are analyzed in Section 3. Section 4 concludes with a summary of the potential issues for future research to design better routing schemes for wireless sensor networks.

II. Routing Protocol In WSNs

Depending on the network structure, routing protocols in wireless sensor networks can be broadly classified as:-

1) *Data Centric routing or Flat based routing* which uses query based and attribute based routing. Examples include SPIN and Directed Diffusion.
2) *Hierarchical based routing* which enables data aggregation through clustering of data nodes and assigning a cluster head which is responsible for routing local transmissions from the source cluster node to the sink node. Examples include LEACH and Energy Aware routing.
3) *Location based routing* in which location information of the nodes is utilized to relay the data to specific regions instead of the whole network since there is no global addressing scheme for individual identification of the sensor nodes. Most of these protocols consider the mobility of nodes and are energy aware. Examples include GEAR and GAF.

Depending on the protocol operation, routing techniques can be further classified as a) Multi path based routing, b) Negotiation based routing, c) Query based routing, d) QoS based routing, and e) Coherent based routing. Depending on

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the computation of the route from the source or destination, routing protocols can also be classified as f) Proactive protocols (routes are computed before they are actually needed) g) Reactive protocols (routes are computed on demand) h) Hybrid protocols (routes are computed using a combination of proactive and reactive techniques) i) Co-operative routing protocols (aggregation and further processing of data takes place at a central node to which data from various nodes is routed).

The following sub-sections presents a detailed analysis of the few routing protocols mentioned above:

A. *SPIN: Sensor Protocol for Information via Negotiation (Data centric protocol)*

This is a data centric routing mechanism [2] that implements attribute based naming of data through the use of high level information descriptors called metadata. In SPIN, each sensor node has its own resource manager that keeps track of the energy for each particular node. Before transmission, each node polls its resource manager to check if they have enough energy or not and cut back on their activities when resources are low thereby increasing the life of the node. Before transmission, metadata is exchanged via data advertisement mechanism. Three messages are defined in SPIN to exchange data: ADV = to allow a sensor node to advertise a particular metadata, REQ = to request a specific metadata, DATA = message that can carry actual data. Each node upon receiving new data advertises it to all its single hop neighbors using the ADV message. Of these nodes that are interested (nodes that do not have the data) retrieve the data by sending a REQ (request) message. Interested nodes then advertise their information to all their single hop neighbors. The SPIN family of protocols consists of different protocols like SPIN - PP, SPIN -EC, SPIN - BC, SPIN - RL.

Advantages of SPIN protocol can be listed as:

1) Metadata negotiation solves the flooding problems of implosion (caused by duplicated messages sent to same node), overlapping of sensor areas (two nodes sensing the same region and sending similar packets to the same neighbor) and resource blindness (excessive consumption of energy without consideration for energy constraints).
2) Topological changes are localized since each node needs to know only its single hop neighbor.
3) It gives a factor of 3.5 less than flooding in terms of energy dissipation and metadata negotiation almost halves redundant data.

Limitations of SPIN protocol are:

1) The data advertisement mechanism employed does not guarantee delivery of the data. If interested nodes are far away from the source node and if nodes between the source and destination are disinterested in the data, then there is no delivery to the far away situated interested node.
2) SPIN is not suitable for applications like intrusion detection that require packet delivery over regular intervals.

B. Directed Diffusion (Data centric protocol)

This routing protocol [3]-[4] implements the data centric routing mechanism by diffusing data through the sensor nodes by using a naming scheme for data and hence eliminates unnecessary operations of the network layer routing thereby saving energy. It implements the use of attribute value pairs and issue interest-defined queries in an on-demand basis by using these pairs which include values like geographical area, name of objects etc. The sink node broadcasts the interest through all its neighbors. The receiving neighbors cache this information for later use which is then compared with the received data. Nodes have the ability to do in-network data aggregation. The sink thus queries the sensor nodes if a specific data is available by flooding some tasks. The interest field also contains information like the data rate of the reply link etc. which constitute the gradient fields. (Gradient is defined as the reply link to a neighbor from which the information is received.) Through optimum utilization of the interests and gradients, several paths are established between the sink and source nodes of which one is selected through reinforcement. Path repair is possible through re-initiating reinforcement by searching among other paths, which are sending data at lower rates, through the employment of multiple paths.

Advantages of Directed Diffusion protocol can be listed as:

1) All nodes can perform sensing, caching and aggregation which provide for improvement in energy efficiency and delay.
2) There is no need for maintaining global network topology since queries are generated on demand.

Limitations of Directed Diffusion protocol are:

1) It is not suitable for applications like environment monitoring that require continuous data delivery since it is a query based data delivery model.
2) Attribute based naming schemes are application dependent and hence naming requires to be done before hand.
3) Matching process for data and queries requires additional overhead at the sensor nodes.

C. LEACH: Low Energy Adaptive Clustering Hierarchy (Hierarchical protocol)

This is a cluster based hierarchical routing protocol mechanism [5] that emphasizes on the concept of distributed cluster formation by creating clusters of sensor nodes on the basis of the received signal strength and then designating a local cluster head that is responsible for routing all local aggregated transmissions to the sink thereby reducing the total number of transmissions and increasing the life of the node by saving energy. Estimation of the total number of cluster heads is about 5% of the total number of nodes. The operation of this protocol consists of 2 phases: setup phase and steady state phase.

1) *Setup phase*: This phase basically involves the organization and selection of cluster heads. In order to balance the load of energy dissipation from all the nodes, the cluster heads are changed randomly over time and are selected on the basis of a decision determined from the following calculation:

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

where p = the desired percentage of cluster heads, r = random value between 0 and 1 and if this value is less than a certain predetermined threshold T(n), the node becomes the cluster head for the current round, G = set of nodes that have not been selected as the cluster head in the last (1/p) rounds. The elected cluster heads then advertises their status to the rest of the nodes in the network, which then determine which cluster they want to be incorporated in. This decision is based on the signal strength of the advertisement of the cluster heads, which are then duly informed by the other non-cluster head nodes of their membership in the cluster. On the basis of the number of nodes in each cluster, the cluster heads then create a TDMA schedule, which is broadcast to all cluster members, and each node is assigned a time slot for their transmission thereby reducing intra-cluster collisions.

2) *Steady state phase*: In this phase, the non- cluster head members sense and transmit data to the cluster head which then performs local aggregation through compression of data from the respective cluster nodes and then sending an aggregated packet to the sink node thereby reducing the total number of transmissions in the network. After a pre-determined time, the network goes back to the setup phase and another round for selecting a new cluster head begins. CDMA codes are used for communication between clusters to avoid inter - cluster collisions. In order to minimize overhead, the steady state phase is longer than the setup phase.

Advantages of LEACH protocol can be listed as:

1) Since LEACH has a distributed nature, it does not require maintaining any global knowledge of the network.
2) It provides a factor of 7 reduction in energy and then dissipation as compared to direct communication and a factor of 4-8compared to minimum transmission energy routing protocol.
3) It increases the network lifetime through cluster formation and local data aggregation thereby reducing the total number of transmissions and excessive energy consumption.

Limitations of LEACH protocol are:

1) It uses single hop routing where each member of the cluster can directly communicate with the cluster head and sink node and it also assumes that each node has enough energy, computational and processing abilities to support different MAC protocols. Hence it is not suitable for networks deployed in large areas.
2) It employs the assumption that cluster heads are uniformly distributed throughout the network but the possibility of the elected cluster head in only one part of the network could result in some nodes not having a cluster head at all.
3) Head changes, cluster head status advertisements, formation of clusters etc. introduce extra overhead since dynamic clustering mechanism is implemented.
4) It also assumes that all members of the cluster have the same energy capacity and that each cluster head has the same amount of energy consumption for each node. To combat this problem, the exchange of data on the basis of negotiation using information descriptors like metadata through the implementation of a scheme that includes the amalgamation of the SPIN and LEACH routing techniques is a possible solution.

D. Energy-Aware routing for cluster-based networks (Hierarchical protocol)

This is a three tier architecture [6] that employs cluster formation before network operation and designation of comparatively lesser energy constrained cluster heads known as gateways. Communication takes place only between these gateways (cluster heads) and the command node (sink node-BS). Gateways maintain the location information of all the nodes and employ a TDMA based MAC mechanism that assigns slots for transmission for a particular node and for listening to the other nodes. This mechanism employs increasing network lifetime and saving energy consumption through programmed and regulated use of power. Since maximum power consumption is encountered in radio transmission and reception, on the basis of the required range it can de duly programmed through independent on and off mechanism. Accordingly, the sensing and processing circuits can also be turned on and off for regulated use. Cluster nodes are generally observed in the following four states:

1) *Sensing state*: The nodes monitor the phenomenon and report accordingly.
2) *Relaying state*: The nodes do not participate in sensing but they relay data from the sensing (active) nodes.
3) *Sensing and relaying state*: The nodes participate in sensing the observed phenomenon as well as relaying data from other nodes.
4) *Inactive state*: The nodes are not involved in any state and shut down their communication circuitry.

Data is then transmitted from the cluster nodes to the gateway through a least cost path, the cost metric of which is defined based on energy consumption and performance metrics. Energy levels of all active nodes are monitored by gateways to ensure efficient performance in data sensing, processing, relaying and appropriate triggering of rerouting.

Advantages of Energy-aware protocol can be listed as:

1) This routing technique involves the use of TDMA based medium access control which reduces the possibility of collisions and further increases network lifetime.
2) Through proper regulation of the minimum transmission range, it further enhances the metrics of efficient throughput and minimizing end to end delay.

Limitations of Energy-aware protocol are:

1) Large deployment of gateways may be required for greater coverage. A possible solution would be the use of agents that report the status of unreachable nodes to the gateways and communicate from the gateways to the unreachable sensors.

E. GEAR: Geographic and Energy Aware Routing (Location based protocol)

Instead of flooding the interests to the whole network which results in redundancy and greater energy consumption, this routing technique[7] routes the interests towards the concerned target region only instead of broadcasting it to the whole network. This is done through the use of location attributes and employment of energy aware and geographically informed neighbor selection heuristics thus saving energy and increasing network lifetime. This routing protocol maintains the cost metric over the network through the use of *estimated costs* and *learning costs*. Estimated cost is a combination of the residual energy and distance to the destination. Learning cost is used for the adjustment of the route setup to the destination for each next incoming packet and is a refinement of the estimated cost that determines routing through regions called *holes* where there is no neighbor node closer to the target region than the transmitting node itself. In the absence of holes, the estimated cost is equal to the learning cost.

It consists of 2 phases described below:

- *Phase 1*: Forwarding packets towards the target region. This depends on two sub-cases as follows. a) Absence of holes: When there are one or more neighbor nodes that are closer to the target region than the transmitting node itself, next hop is determined through the selection of the neighbor that is the closest to the target region. b) Presence of holes: When there are no neighbor nodes closer to the target region than the transmitting node itself, next hop is determined by randomly selecting any of the next hop is determined by randomly selecting any of the convergence of which during the delivery of packets can further help in updating the choice of the next hop neighbor.
- *Phase 2*: Forwarding packets within the target region. After the packets reach the target region, further diffusion can be accomplished through either one of the two mechanisms: Restricted flooding which is effective in sparse deployments and Recursive geographic flooding which is effective in dense deployments due to its greater energy efficiency achieved through the process of splitting and forwarding.

Advantages of GEAR protocol can be listed as:

1) This routing technique reduces the energy consumption for route setup by reducing the total number of transmissions.
2) It also shows better performance in terms of packet delivery for both even as well as uneven traffic distribution scenarios.
3) It eliminates the need for route discovery and improves caching behavior for applications where requests can be location dependent.

Limitations of GEAR protocol are:

1) Since it uses location information for routing, there is a possibility for the occurrence of localization errors.
2) Global knowledge of the network may be required.

III. Challenges For Routing In WSNs

Several characteristics that distinguish wireless sensor networks form contemporary communication and wireless ad-hoc networks make routing in sensor networks very challenging. These challenges can be outlined as follows:

1) Node deployment in wireless sensor networks can be deterministic (nodes are manually placed and data is routed through predetermined paths) or randomized (nodes are scattered randomly and creating an infrastructure in an ad-hoc manner). Thus node deployment in wireless sensor networks is application dependent and affects the performance of routing protocols. Optimal clustering for effective connectivity and energy efficient network operation are prime factors to be considered by routing protocols in a case of resultant distribution that is not uniform. LEACH accounts for this by clustering.
2) Energy awareness in routing protocols is very important since power conservation and power management are primary design factors. Sensor node lifetime shows a strong dependence on the battery lifetime. In multi-hop WSN, each node plays the dual role of both the data sender and data router and malfunctioning of some nodes due to power failure can cause significant topological changes and might require rerouting of packets and reorganization of network. Data centric protocols through attribute based routing, hierarchical protocols like LEACH through changing cluster heads and location based protocols like GEAR through energy aware and geographically informed neighbor selection heuristics achieve optimal energy saving. Routing protocols should be proficient to deal with energy consumption without losing accuracy.
3) In the event of failure of nodes, the routing protocol should still guarantee safe delivery of packets by using redundant transmissions, or by reducing energy consumption to adjust transmitted power, or by rerouting the packets through area where more energy is available. Since individual nodes are more prone to failure as compared to other types of networks, the network should sustain information dissemination despite these failures. Directed diffusion implements efficient path repairs through employment of multiple paths in advance where one path is selected without additional cost for searching for another path instead of re-initiating reinforcement by searching for a new path which is comparatively costlier. LEACH also balances the energy load among the different nodes and rotates the selection of cluster heads for efficient network operation.
4) Routing schemes should be able to scale the immense dense deployments and take advantage of the high density of the networks. Routing protocols should be scalable enough to respond to events in the environment. These nodes could be in a sleep state, until an event occurs, with

the data from the remaining few nodes providing a coarse quality. Energy aware routing for cluster based sensor networks use time arbitration for access control and hence achieve better network operation. Also the location based protocol, GEAR, implements routing on the basis of geographical attributes thereby reducing transmissions and increasing operation efficiency.

5) Problems of fading, high error rate, low bandwidth(typically 1-100 kbps for sensor networks) etc that are associated with wireless media affect the operation of the sensor network. In order to overcome the problems associated with the transmission media, appropriate MAC design of sensor networks through the use of energy conservative TDMA based protocols over contention based protocols like CSMA like those in energy aware routing techniques, implementation of Bluetooth technology etc. is preferred.
6) Area coverage is an important design parameter in WSNs since each sensor node can cover a limited physical area of the environment and provides accurate data for this limited range.
7) IP based protocols cannot be applied to sensor networks as it is not possible to implement a global addressing scheme due to the extensive deployment of sensor nodes.
8) Significant redundancy may be observed in the generated data traffic as multiple nodes within the vicinity of a particular phenomenon may generate the same data and hence energy and bandwidth utilization considerations need to be handled by routing protocols for example, hierarchical protocols which achieve this through data aggregation.
9) Sensor nodes are tightly constrained in terms of transmission power, storage, processing capacity and on-board energy and thus careful resource management is important. Data centric protocols like SPIN provides for polling the resource manager of the nodes prior to transmission and also provides for data exchange using information descriptors like meta data to achieve this objective.
10) Certain applications require data delivery within a specific time limit, after sensing in order to maintain effectiveness of data. Such time constrained applications have a bounded latency requirements while some other applications may compromise on the quality of data to reduce energy dissipation. Thus routing protocols should be able to meet these different QoS requirements. Energy aware routing protocols achieve this through route setup using cost metrics defined on the basis of energy awareness and delay optimization.
11) Route stability as well as energy and bandwidth considerations are important criteria in applications where mobility of both the source and sink nodes is involved. This is important since most network architectures assume the nodes to be stationary and routing protocols are not very proficient in handling scenarios involved with mobility.

IV. Conclusion And Open Issues

The numerous advantages of WSNs have made them indispensable for numerous applications bounded by different constraints. This paper presented a brief summary about the importance of routing in wireless sensor networks and the classification of different routing protocols.

In order to avoid the overhead in cluster formation, designation of cluster heads, attribute based naming etc is employed in data centric protocols. Development of efficient naming schemes is an issue, open to further research in this field. Hierarchical protocols further address the problems of energy constraints, bounded latency and redundancy in transmissions through cluster formation, designation of less energy constrained and powerful nodes as cluster heads and data aggregation and fusion techniques. Further research to improvise on these existing schemes is an interesting problem to explore. Utilization of location based information and topological deployment of sensor nodes for energy efficient routing is implemented through the use of location based protocols. Open issues for further research in this area are intelligent utilization of geographical attributes and communication between the distributed sensors and these routing protocols.

There are several other challenges that can be observed. Human supervision or intervention is not possible in certain areas of employment of WSNs and hence their proficiency in operation, self organization and recovery abilities are crucial. Energy constraints further affect the coverage while QoS constraints influence the bandwidth and delay in WSNs and are major challenges in this field. Greater research is needed to address the issue of node mobility in applications that require both the source and sink nodes to be mobile and hence in this case management of the overhead of mobility and topology changes in an energy constrained environment is important. We have tried to summarize the various existing research challenges and also potential research in different directions in this domain.

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VI. BIOGRAPHIES

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