Comprehensive Study of Routing Management in Wireless Sensor Networks- Part-2

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Abstract

Wireless sensor networks illustrate enormous potential for increasing the information availability to people in many consumer and industrial applications such as smart buildings, target tracking, data collection, rescue missions, national security, monitoring disaster prone areas, managing inventories, monitoring health care, environmental studies, and home security . Much research effort has been made in the field of wireless sensor networks, in both academia and industry igniting the thrust to realize its unlimited applicability in various application fields. The network topology in a WSN may change drastically since nodes can be added and removed easily. The data from sensor nodes is gathered by the sink. The sink may be connected to the outside world thorough Internet or satellite. Sensor nodes will be scattered over a sensor field, so the locations of sensor nodes in the field cannot be predetermined. This paper continued from the previous part classifies the key routing techniques used in sensor networks. Each routing technique is studied in terms of resource usage, efficiency, applicability and scalability and the most challenging research directions are outlined. We provide a a conclusive study of different routing schemes used in routing characteristic of wireless sensor networks. Each of the routing schemes and algorithms has the common objective of trying to extend the lifetime of the sensor network.

1. Introduction

The precision of the information exchange is greatly enhanced with the alliance of sensor nodes and the reliable routing of the sensed data. The functionality of the routing protocols might vary depending on the sensor network architecture and the application. A daunting challenge in the design of a reliable wireless sensor network is to augment its lifetime in terms of energy and information efficiency. In terms of power expenditure, operation of a sensor node can be categorized in three phases: sensing, processing, and transmission. Among these three phases, it is known that the most power consuming task is data transmission. Approximately, 80% of power consumed in each sensor node is used for data transmission. Energy-aware routing algorithms [1], [2], [3] discuss reducing the consumption of battery-power at different nodes. Another concern is the narrow computing power of the sensor nodes and the limited bandwidth [4] of the connecting nodes, which deter the communication of sensor nodes within the Wireless sensor cloud. Other challenging design requirements are lack of a centralized awareness of the network topology, scalability due to large network size and fault tolerance due to frequent failure of nodes. An optimal objective is to design routing schemes which (a) minimize energy requirements at each node to transfer individual packets and (b) maximize the operational lifetime of scalable networks. It is primarily important to save energy of the sensor nodes while routing query responses back to the sink node. This may either be accomplished by cutting down the number of nodes or incorporating sleep periods, when nodes are not participating in transmitting data on the path ([5], [6]).

2. Hierarchical Routing

Due to the nature of the applications supported by the sensor networks such as a range of estimations measuring temperature, pressure, humidity, seismic, thermal, acoustic, radar, noise levels etc, the sensor nodes need to be densely deployed in a magnitude much greater than conventional ad hoc networks [7]. In hierarchical routing, the nodes with the higher energy can be utilized to process and transmit the information. The low energy nodes can be assigned sensing in the proximity of an event. This routing uses the fact of division of labor, among the sensor nodes. Depending upon the remaining energy, the task to each node can be assigned accordingly. The formation of clusters within the sensor network, allows the sensor nodes to make the decision to choose the cluster leader. This enhances the network lifetime, energy efficiency and scalability of the sensor networks. According to [8], hierarchical routing consists of two layers where one layer is used to select cluster heads and the other layer is used for routing decision. This section explains some of the hierarchical routing schemes

2.1 Low Energy Adaptive Clustering Hierarchy- LEACH

LEACH is an energy conserving communication protocol [9] where all the nodes in the network are uniform and energy constrained. An end user can access the remotely monitored operation, where large numbers of nodes are involved. The nodes organize themselves into local clusters, with one node acting as the randomly selected local cluster-head. If the allocated cluster-heads are always fixed, then they would die quickly, ending the useful lifetime of all nodes belonging to those clusters. LEACH includes random alternation of the high-energy cluster-head nodes to enable the sensors to uniformly sustain the power. Sensors nominate themselves to be local cluster-heads at any given time with some probability. These cluster head nodes relay their status to the other sensors in the network. Each sensor node resolves which cluster to follow by choosing the cluster-head that requires the minimum communication energy. This allows the transceiver of each unassigned node to be turned off at all times except during it's transmit time, thus minimizing the energy dissipated in each sensor. LEACH operates in two phases (a) the initializing or set up phase, where the organization of clusters and selection of cluster heads takes place, and (b) steady state phase, where the actual data transfer takes place. During the set up phase a set of nodes, "p", nominate themselves as cluster heads respectively. A random number "r" between 0 and 1 is selected by the sensor node. If this random number is less than the threshold value, T (n), the respective node becomes the cluster head for the particular event. The calculation of threshold value T (n) is shown below, G is the set of nodes that were not accepted as cluster head in the last "1/p "events

$$T(n) = \frac{p}{1 - p(r \bmod (1/p))} \qquad \text{If } n \in G$$

Each nominated cluster head advertises to the rest of the nodes in the network about its status. After receiving the advertisement, the non-cluster head nodes decide as to which cluster they want to fit in. This assessment is based on the signal strength of the advertised message. The signal to noise ratio is compared from various cluster heads surrounding the node/s. The non cluster-head nodes notify the respective cluster-head/s about the decision to join the cluster. This notification takes place using CSMA MAC protocol.

On receiving all the messages from interested nodes, the cluster-head nodes generate a TDMA schedule and announce it to all the nodes within the cluster. In the steady state phase, cluster heads are aware of the schedule of each node transmitting the data during the allocated time slot. The sensor nodes start transmitting data to the cluster-heads. The cluster-head node receives all the data and aggregate the data by performing data fusion algorithms. The resulting information is then sent to the sink node. There exists an uncertainty regarding the strength of this protocol [8]. It is proposed that during the set up phase a set of nodes, "p", nominate themselves as cluster heads respectively. But the idea of uniformly distributing these cluster heads over the entire sensor network cloud is missing. The absence of uniform cluster heads in the sensor network can create the disparity in the rate of energy spending and in some cases may not even complete the communication from source to the sink node. Furthermore, the hypothesis of dynamic clustering can increase the burden of overhead. Secondly, LEACH protocol assumes that all the sensor nodes, irrespective of whether it is a cluster or not, consumes the same amount of energy.

Table 1 compares SPIN, LEACH and the Directed diffusion [8]. These three routing schemes are designed to so that collected data is disseminated efficiently in wireless sensor networks. However, due to in-network processing, directed diffusion shows a promising approach for energy efficient routing.

Table 1 Comparison among SPIN, LEACH and Directed Diffusion

	SPIN	LEACH	Directed Diffusion
Optimal Route	No	No	Yes
Network Lifetime	Good	Very Good	Good
Resource Awareness	Yes	Yes	Yes
Use of Meta-Data	Yes	No	Yes

2.2 Power-Efficient Gathering in Sensor Information Systems-PEGASIS

In PEGASIS [9], each sensor node forms a pattern so that each node will receive from and transmit to a close neighbor. Each node takes turn being the leader for transmission to the base station so that the average energy spent by each node per round is reduced. PEGASIS outdoes LEACH'S performance by (1) purging the overhead of dynamic cluster formation, (2) decreasing the distance non leader-nodes must transmit, (3) reducing the number of transmissions among all nodes, and (4) using only one transmission to the base station per round. Principal goals in the operation PEGASIS are (a) augment the lifetime of each sensor node by using collaborative techniques (b) reducing the bandwidth of communication by allowing the local coordination among neighboring sensor nodes. The performance evaluation in [9] shows that PEGASIS is able to enhance the sensor network lifetime twice as much as the network implementing LEACH protocol. In PEGASIS, this performance gain is attained through the exclusion of the overhead caused by dynamic cluster formation and through reducing the number of transmissions and reception by using data aggregation. Though PEGASIS outweighs the LEACH protocol, there still exists an uncertainty regarding the depth of this protocol [8]. There should be a dynamic topology adjustment in PEGASIS for the nodes to know energy status of its neighbors for routing its data. Secondly, PEGASIS presume that all the sensor nodes maintain a database with the location of all other nodes in the network, which increases the overhead. PEGASIS also assumes the communication of each sensor node with the sink directly, without the multihop routing.

2.3 Power Concerned Routing

Since a sensor network has limited bandwidth, it is necessary to minimize communication between sensor nodes. In terms of power consumption, operation of a wireless sensor node can be divided into three parts: sensing, processing, and transmission. Among those three operations, it is known that the most power consuming task is data transmission. Approximately, 80% of power consumed in each sensor node is used for data transmission. Energy-aware routing algorithms [1], [2], [3] discuss reducing the consumption of battery-power at the different nodes. Reference [10] explains energy management at the MAC layer using TDMA along with periodic listen and sleep to avoid energy wastage. The authors in [4] discuss about the narrow computing power of the sensor nodes and the limited bandwidth of the connecting nodes, which deter the communication of sensor nodes within the wireless sensor cloud. This section explains some power management techniques. They can be broadly classified as

- Static power management, broadly applied at the (node) design time, aiming at different levels of system's hardware and software components and
- Dynamic power management, applied at runtime. Dynamic power management takes into consideration the runtime events, to reduce power when the sensor nodes are idle or catering to trivial workloads.

2.4 Threshold Sensitive Energy Efficient Sensor Network Protocol

TEEN [12] is a hierarchical protocol using data centric mechanism to route the data to sink. It is designed to be responsive to abrupt variations in the sensed physical attributes such as temperature, pressure etc. In TEEN, physical phenomenon is sensed constantly, but the actual data transmission is done sparingly. Clusters are formed and cluster heads are chosen. The cluster head sends two thresholds to the fellow nodes within the cluster. These two threshold values are (a) Hard Threshold, which is the threshold value of the sensed attribute and (b) Soft Threshold, is a small modification in the value of the sensed attribute that triggers the sensor node to switch on its transmitter and transmits to the respective cluster head. This way the sensor nodes transmit only when the sensed attribute is in the span of interest. The soft threshold lessens the number of transmissions that would have otherwise taken place without any change in the sensed attributes. To organize an effective data transmission, values for both soft and hard threshold can be attuned. TEEN protocol is a trade-offs between energy efficiency and data accuracy. This protocol is appropriate for time critical sensing applications, such as forest fires, sudden temperature increase etc. Downside of TEEN protocol is that if the updated threshold values do not reach the cluster head, the nodes cannot communicate and the information can never reach to the end user.

APTEEN [13], Adaptive Threshold sensitive Energy Efficient sensor Network protocol is an augmentation to TEEN. It is intended to acquire periodic data collections and is more receptive to time-critical events depending on the type of the application. In APTEEN, the cluster-heads broadcasts hard and soft thresholds, and the transmission schedules to all the nodes within the cluster. The node senses the

environment constantly, and the sensor nodes which sense the physical data value beyond the hard threshold are allowed to transmit. The sensor node will transmit data only when the values of that attribute changes by an amount equal to or greater than the soft threshold [8]. In APTEEN, the count time is the maximum time period between two successive reports sent by the sensor node. If the sensor node does not send data beyond the count time, TDMA schedule is used and each node in the cluster is assigned a transmission slot. The performance evaluation of TEEN [12] and APTEEN [13] shows that both of them outperform LEACH. Performance of APTEEN in terms of network lifetime and energy dissipation is better than LEACH. On the negative feature of this scheme, is the added complexity required to execute the threshold functions and the count time. The problem of overhead on forming clusters at multiple levels and the method of implementing threshold-based functions still remains in APTEEN.

2.5 Self-Organizing Protocol

Self Organizing Protocol [14] is a protocol with self-organizing capabilities and taxonomy based on the sensor applications. The self organizing protocol architecture support heterogeneous sensors that can either be mobile or stationary. A subset of the sensor nodes probe the environment and forward the data to a selected set of nodes that acts as routers. Router nodes are stationary and form the backbone for communication. The sink nodes are the robust nodes in terms of energy. The collected data is forwarded through the routers to sink node. The routing architecture is hierarchical where set of nodes are formed and merged when needed. In order to maintain fault tolerance, Local Markov Loops (LML) algorithm, which executes 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. (a) Discovery phase, where each sensor node, discover its respective neighbor/s. (b) Association phase, in this phase based on the grouping of each sensor node a hierarchy is formed. Each sensor node is allocated an address depending upon its position in the hierarchy. A routing table of size O (log N) is created for each sensor node. Broadcast trees that cover all the nodes are created. (c) Maintenance phase, in this phase each node notifies the neighbors about its respective energy level and routing table. Updating of routing tables and the energy levels of sensor nodes are made in the maintenance phase. Local markov loops are used to maintain the broadcast trees. (d) Self-reorganization phase, where the group reorganization is performed in case of node failures. There is a small cost of maintaining the routing tables in this protocol and performance evaluation shows that the energy consumed for broadcasting a message using self organization protocol is less than that consumed in SPIN [4] due to the broadcast trees utilized in the algorithm.

Table 2 Hierarchical vs. Flat topologies routing

Flat Routing	Hierarchical routing
Contention-based scheduling	Reservation-based scheduling
Collision overhead present	Collisions avoided
Variable duty cycle by controlling sleep time of nodes	Reduced duty cycle due to periodic sleeping
Node on multi-hop path aggregates incoming data from neighbors	Data aggregation by cluster head
Routing is complex but optimal	Simple but non-optimal routing
Links formed on the fly without synchronization	Requires global and local synchronization
Routes formed only in regions that have data for transmission	Overhead of cluster formation throughout the network
Latency in waking up intermediate nodes and setting up the multipath	Lower latency as multiple hops network formed by cluster heads always available
Energy dissipation depends on traffic patterns	Energy dissipation is uniform
Energy dissipation adapts to traffic pattern	Energy dissipation cannot be controlled
Fairness not guaranteed	Fair channel allocation

This protocol, however, is not an on-demand protocol especially in the organization phase of algorithm, thereby causing an extra overhead. Secondly there is another drawback in forming hierarchy

when there are many cuts in the network [8]. This will be expensive since network-cuts enhance the probability of employing reorganization phase. Table 2 compares the different aspects and issues of hierarchical routing and flat routing.

3. Location Based Routing Protocols

Wireless sensor networks are spatially deployed over a region depending on the application. There is no global addressing scheme for sensor networks like IP-addresses. In location based routing sensor nodes are addressed by means of their physical locations. The distance between neighboring nodes can be calculated on the basis of incoming signal strengths. Comparative coordinates of the neighboring nodes can be acquired by exchanging information between neighbors [15], [16], [17]. In location based scheme, some nodes go to sleep, in order to save the energy. The problem of designing sleep period schedules for each node in a localized manner was explained in [18],[19]. If the location of the sensor nodes and the region to be sensed is known, a query can be diffused only to that specific region which will reduce the number of transmissions significantly. Initially a number of protocols from mobile ad hoc networks were employed on wireless sensor networks [20], [21], [22], [23], [24], [25]. These location-based protocols utilize the location information of ad-hoc nodes to achieve scalability in large-scale networks. However, many of these protocols are not applicable to sensor networks since they are not power aware. This Section discusses some relevant location aware routing protocols.

3.1 Geographic Adaptive Fidelity

GAF [20] is a power-aware location-based routing algorithm designed primarily for ad hoc networks, but can be applicable to wireless sensor networks too. GAF conserves energy by switching off unnecessary sensor nodes in the network without any effect on the level of routing fidelity. The sensor cloud is first divided into fixed zones and forms a virtual grid. Inside each zone, nodes poll resources with each other to play different roles. For example, one sensor node is elected by others 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 sink on behalf of the nodes in the zone [19]. Each sensor node uses its GPS-indicated position to associate itself with a spot in the virtual grid. Nodes related with the same point on the grid are considered equivalent in terms of the cost of packet routing. Such equivalence can be removed by keeping some nodes positioned in a particular grid area in sleeping state in order to save energy.

Figure 1 [20], an example of virtual grid in GAF is depicted. Node 1 can reach 2, 3 and 4 and nodes 2, 3, and 4 can reach 5. This shows that nodes 2, 3 and 4 are equivalent and two of them can sleep. In order to balance the load, each node change state from sleep to active mode. The three stages namely defined in GAF are (a) Discovery stage, this stage decide the neighbors within the grid, (b) active stage, which includes the active routing and (c) sleep stage, when the radio is turned off. The state transitions in GAF are depicted in Figure 2, redrawn from [19], [20]. In order to control the mobility, each sensor node in the grid estimates its respective leaving time from the grid and sends to its neighbor. In order to reliably route the data, the inactive or sleeping neighbors adjust their sleeping time accordingly. Before the departure time of the active node expires, the inactive node wake up and becomes active. GAF is implemented both for non-mobile sensor nodes (GAF-basic) and for mobile sensor nodes (GAF-mobility adaptation).

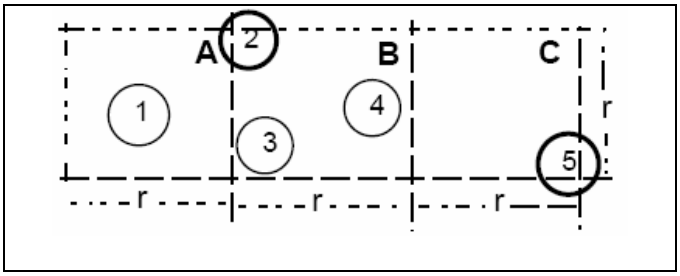

Figure 1 Example of virtual grid in GAF

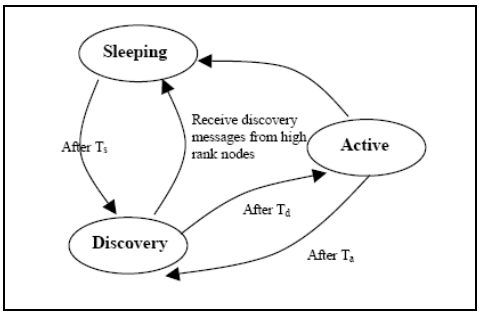

Figure 2 State transitions in GAF

GAF [21] assume that sensor nodes can identify their locations using GPS cards, which is inconceivable with the current technology. Performance evaluation of GAF shows that it performs reasonably well as a normal ad hoc routing protocol in terms of latency and packet loss. Besides it increases the lifetime of the network by saving energy. GAF may also be considered as a hierarchical protocol, where the clusters are based on geographic location [8]. For each particular grid area, a master node acts as the leader to transmit the data to subsequent nodes. It is worth mentioning that in GAF, the leader node does not do any data aggregation like other hierarchical protocols discussed earlier in this article.

3.2 Minimum Energy Communication Network

Minimum Energy Communication Network (MECN) [26] sets up and maintains a minimum energy network for wireless networks by utilizing low power GPS. The initial assumption of this protocol is for a mobile network, but it is applicable to the wireless sensor networks. MECN identifies a relay region for each sensor node. This relay region is a collection of the sensor nodes in a surrounding area, through which transmission is more energy efficient than the direct transmission. Figure 3 shows the relay region for a node pair (i, r) [26], [19]. The enclosure of a node "i" is then formed by taking the union of all the relay regions that node "i" can reach. The key proposal of MECN is to find a sub-network, which will have less number of nodes and require less power for transmission between any two particular source and destination pair. A localized search for each sensor node is performed considering its respective relay regions. This way the minimum power paths are found without taking into account all the nodes in the network. MECN protocol is self-reconfiguring and can dynamically adjust to node's failure or the deployment of new nodes.

SMECN [27], Small minimum energy communication network is a realistic modification over the MECN. SMECN assumes possible obstacles between any pair of nodes unlike the assumption in MECN that each node can transmit to every other node. The sub-network constructed by SMECN for minimum energy relaying is smaller in terms of number of edges. As a result, the number of hops for transmissions will decrease. Simulation results show that SMECN uses less energy than MECN and maintenance cost of the links is less. However, finding a sub-network with smaller number of edges introduces more overhead in the algorithm.

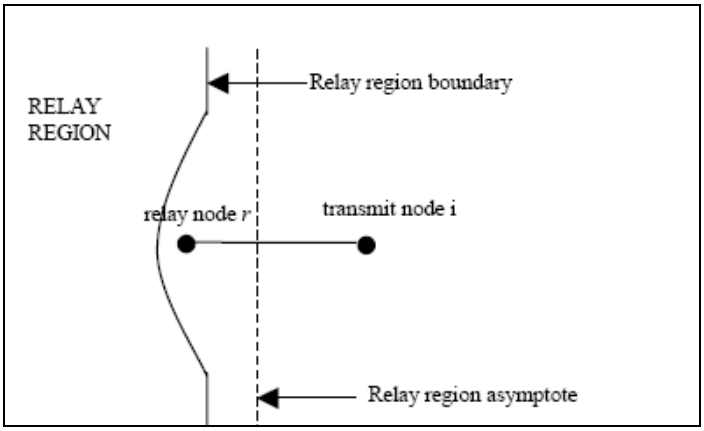

Figure 3 Relay region of transmit-relay node pair (i, r)

3.3 Geographic and Energy Aware Routing (GEAR)

GEAR, [28] discusses the utilization of geographic information while disseminating queries to suitable regions since data queries often include geographic attributes. GEAR uses an energy aware and geographically-informed neighbor select heuristics to route a data packet towards the sink region. This routing algorithm limits the number of interests in directed diffusion by only taking into account, a certain region instead of sending the interests to the entire network. Each sensor node in GEAR maintains an estimated cost and a learned cost of reaching the destination. The estimated cost is calculated by the combination of distance to the sink and the residual energy. The learned cost is the supplement of the estimated cost that accounts for routing around holes in the network. Formation of hole occurs when a node does not have any neighbor in the target region other than itself. In absence of the holes, the estimated cost is equal to the learned cost. The learned cost is transmitted one hop back every time a data packet reaches the sink so that route setup for next packet can be adjusted. There are two phases in the algorithm

- Forwarding packets towards the target region: On receiving the packet, sensor node make sure that there is at least one neighbor, which is closer to the target region than itself. If there is one neighbor, it is selected. If it's more than one, the nearest neighbor to the target region is selected as the next hop. If no neighbor is found, it is accounted as a hole. Then one of the neighbors is chosen to forward the packet based on the learning cost function.
- Forwarding the packets within the region: After the packet has reached the region, it can be disseminated by restricting flooding or recursive geographic forwarding. In high-density networks, recursive geographic flooding is more energy efficient than restricted flooding.

4. Negotiation Based Protocols

In negotiation based protocols, high level data descriptors or labels are incorporated within the sensor network. With the help of these data descriptors, sensor nodes negotiate with the neighboring nodes to eliminate redundant data transmissions. Exchange of communication between the sensor nodes depends on the resources available to each senor node within the network. SPIN [4] family of protocol is based on the continuous collaborative negotiation of sensor nodes. The SPIN protocols are designed to disseminate the data of one sensor to all other sensors assuming these sensors are potential base-stations. The key idea of negotiation based routing in WSNs is to hold back the superfluous information and avert redundant data from being sent to neighboring sensor node. This is accomplished by performing a series of negotiation messages before the real data transmission begins.

5. Coherent and Non Coherent Routing

In wireless sensor networks the processing of the data is required at the node level. The sensor nodes make a collaborative effort to process the data within the sensor network. The routing mechanism which initiates the data processing module is proposed in [29]. This mechanism is divided into two categories;

- Coherent Data Processing Based Routing: This category is an energy efficient mechanism where only the minimum processing is done by the sensor node. Time stamping, duplicate suppression etc are the tasks accomplished in minimum processing. After the minimum processing, the data is forwarded to the aggregators.
- Non Coherent Data processing based routing: In this category the, the sensor nodes locally process the actual data and then send to the other nodes for further processing. The nodes that perform further processing are called the aggregators. There are three phases of data processing in non-coherent routing. (a) Target detection, data collection, and preprocessing (b) Membership declaration, and (c) Central node election [8]. In target detection stage, an event is detected, its information collected and preprocessed. In the membership declaration phase, sensor node chooses to participate in a cooperative function and declare this intention to all neighbors. In the central node election stage, a central node is chosen to perform more refined information processing.

Additionally, single and multiple winner algorithms were proposed for non-coherent and coherent processing, respectively [29]. A single aggregator node is chosen for complex processing in the single winner algorithm (SWE). The selection of this node is established on the robustness of the sensor nodes in

terms of energy and computational ability. By the end of the SWE process, a minimum-hop spanning tree completely covers the network. In multiple winner algorithm (MWE), when all the nodes send the data to the central aggregator node, this expends more energy. In this algorithm, limit the number of nodes that can send data to the central aggregator node. Each node maintains a record of up to “n” nodes, instead of only the best candidate node. This way each sensor node in the network has a set of minimum-energy paths to each source node (SN). Single winner algorithm is employed to find that node which yields the minimum energy consumption. This node can then operate as the central node for the coherent processing.

6. QOS Based Routing

Quality of Service enables the sensor network to provide better service to information flows. The performance of sensor network should be the balance between energy consumption and data quality. The network while delivering data to sink has to assure certain QoS metrics like latency, power, bandwidth etc. Sequential Assignment Routing (SAR) [29] takes into account the quality of service requirements in the sensor networks. It takes into account three factors (a) energy resources, (b) QoS on each path, and the (c) priority level of each data packet. SAR includes the multipath approach and localized path restoration. To create multiple paths from a source node, a tree is formed from the source node to the sink. The paths of the tree are formed in accordance to QoS metrics. At the end of this process, each sensor node will be part of multi-path tree. SAR algorithm takes into account the weighted QoS metric, which is the product of the (a) additive QoS metric and (b) weight coefficient associated with the priority level of the packet. Throughout the network lifetime, the objective of SAR algorithm is to minimize the average weighted QoS metric. A path re-computation is needed in case of node failure. SAR is a multipath routing scheme, which ensures fault-tolerance and easy recovery. But at the same time the protocol suffers from the overhead cost of maintaining the tables at each sensor node.

7. Conclusions

Sensor nodes are not assigned any global identifications like an IP address for the computers; instead, sensor nodes and the data are acknowledged through their respective contents, location and constraints. The data centric routing is generally followed in order to avoid the overhead of forming clusters. The naming schemes such as attribute-value pairs might not be adequate for complex queries and they are usually dependent on the application. Efficient standard naming scheme is one of the most appealing future research direction related to this category. Another interesting research issue regarding the formation of cluster heads is to optimize the latency and the energy consumption. According to [19], cluster formation and cluster-head communication are open issues for future research. The fusion among different clusters is also an interesting problem to explore. Protocols that employ the physical information and topological establishment of sensor nodes are classified as location-based. An optimized energy efficient solution to utilize the location information needs to be studied further. Quality of Service is another issue for the concentration of research. Real time applications such as signal processing, broadcasting video etc. demand an optimal balance between QoS requirements and energy efficiency. Another interesting issue for routing protocols is the consideration of node mobility. Most of the current protocols assume that the sensor nodes and the sink are stationary. However, there might be situations such as battle environments where the sink and possibly the sensors need to be mobile. In such cases, the frequent update of the position of the command node and the sensor nodes and the propagation of that information through the network may excessively drain the energy of nodes. New routing algorithms are needed in order to handle the overhead of mobility and topology changes in such energy constrained environment. Other possible 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. There are some hybrid protocols that can be placed under more than one category. The summarize research results is shown in Table 3 [8]. The Table compares different routing techniques according to many metrics.Since the routing requirements of each environment are different, further research is necessary for handling these kinds of situations. Each routing technique is studied in terms of resource usage, efficiency, applicability and scalability and the most

challenging research directions are outlined. Each of the routing schemes and algorithms has the common objective of trying to extend the lifetime of the sensor network.

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Table 3: Categorization and Assessment of Routing protocols in Wireless Sensor Networks

	Classification	Mobility	Position Aware	Power Usage	Negotiation Based	Data Aggre-gation	Local-ization	QoS	State Complexity	Scalability	Multi path	Query Based
SPIN	Flat	Possible	No	Limited	Yes	Yes	No	No	Low	Limited	Yes	Yes
Directed Diffusion	Flat	Limited	No	Limited	Yes	Yes	Yes	No	Low	Limited	Yes	Yes
Rumor Routing	Flat	Very Limited	No	N/A	No	Yes	No	No	Low	Good	No	Yes
COUGAR	Flat	No	No	Limited	No	Yes	No	No	Low	Limited	No	Yes
ACQUIRE	Flat	Limited	No	N/A	No	Yes	No	No	Low	Limited	No	Yes
LEACH	Hierarchical	Fixed BS	No	Maximum	No	Yes	Yes	No	CH's	Good	No	No
TEEN & APTEEN	Hierarchical	Fixed BS	No	Maximum	No	Yes	Yes	No	CH's	Good	No	No
PEGASIS	Hierarchical	Fixed BS	No	Maximum	No	No	Yes	No	Low	Good	No	No
MECN & SMECN	Hierarchical	No	No	Maximum	No	No	No	No	Low	Low	No	No
SOP	Hierarchical	No	No	N/A	No	No	No	No	Low	Low	No	No
GAF	Location	Limited	No	Limited	No	No	No	No	Low	Good	No	No
GEAR	Location	Limited	No	Limited	No	No	No	No	Low	Limited	No	No
SAR	QoS	No	No	N/A	Yes	Yes	No	Yes	Moderate	Limited	No	Yes