A STUDY ON ENERGY EFFICIENT ROUTING PROTOCOLS IN WIRELESS SENSOR NETWORKS

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ABSTRACT

A wireless sensor network (WSN) consists of low cost, low power, small in size and multi functional sensor nodes. Routing protocols in WSNs emphasize on data dissemination, limited battery power and bandwidth constraints in order to facilitate efficient working of the network, thereby increasing the lifetime of the network. Routing protocols in WSNs are also application specific which has led to the development of a variety of protocols. Based on the underlying network structure, routing techniques can be classified into three categories: data-centric, hierarchical and location based routing. WSN has a design trade-off between energy and communication overhead which forms the nerve center of the routing techniques. In this paper we present a survey of state-of-the-art routing techniques in WSNs under all the three categories. We epitomize these routing techniques and bring out the advantages and disadvantages followed by their application domain. The paper concludes with issues open for research.

KEYWORDS

Wireless Sensor Networks, Routing Protocols, Energy Efficient Protocols, Data-Centric protocols, Hierarchical Protocols and Location Based Protocols.

1. INTRODUCTION

Recent technological advancements in micro electronics and wireless communication technologies have enabled manufacturing of small, low cost, battery operated and multi-functional sensor nodes[1,2,3,4,5]. These sensor nodes measure ambient condition in the surrounding environment that can be processed to reveal the characteristics of the phenomena occurring at the location where the sensor nodes are deployed. A large number of these sensor nodes are either placed carefully or randomly deployed over a geographical area and networked through wireless links to form a WSN. Each sensor node in WSN is capable of communicating with each other and the base station (BS) for the purpose of data integration and dissemination. WSN are used mainly in military, civilian and for industrial applications. WSNs applications in the military field include battlefield surveillance, intrusion detection, target field and imaging. However, WSN are now being used in many civilian application areas too, including environment and habitat monitoring, health applications, home automation and traffic control.

Traditional wireless communication networks like Mobile Ad hoc Networks (MANET) differs from WSN. WSN have unique characteristics such as denser level of node deployment, higher unreliability of sensor nodes and severe energy, computation and storage constraints which present many challenges in the development and application of WSN. Research has been made to explore and find solutions for various design architecture and application issues and significant advancement has been made in the development and deployment of WSNs. WSN typically contains hundreds or thousands of sensor nodes which allows for sensing over larger

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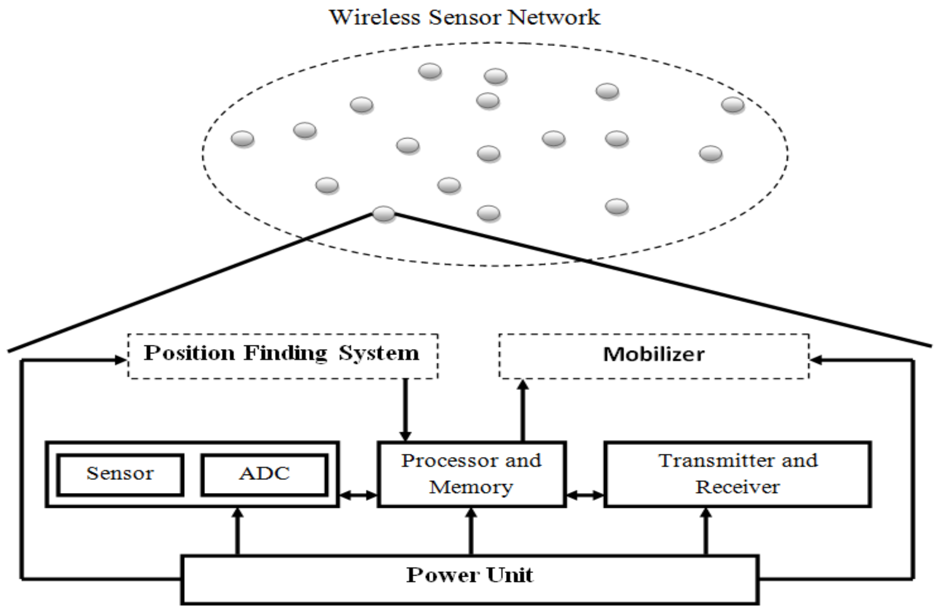


Figure 1. WSN and components of sensor node

geographical regions with greater accuracy. Usually the sensor nodes are deployed randomly over geographical location and these nodes communicate with each other to form a network. Each node has three basic components [6] as shown in figure 1[7]:

1. Sensing unit
2. Processing unit
3. Transmission unit

The node senses the data from the environment processes it and sends it to the base station. These nodes can either route the data to the base station (BS) or to other sensor nodes such that the data eventually reaches the base station. In most applications, sensor nodes suffer from limited energy supply and communication bandwidth. These nodes are powered by irreplaceable batteries and hence network lifetime depends on the battery consumption[8]. Innovative techniques are developed to efficiently use the limited energy and bandwidth resource to maximize the lifetime of the network. These techniques work by careful design and management at all layers of the networking protocol. For example, at the network layer, it is highly desirable to find methods for energy efficient route discovery and relaying of data from the sensor nodes to the base station.

Routing methods in WSNs have to deal with a number of challenges and design issues. Despite advancement in technology, sensor nodes in WSNs still have restrictions such as limited battery power, bandwidth constraint, limited computing power and limited memory. It creates the need for routing protocols to be highly adaptive and resource aware. Some of the challenges of routing protocol are:

1. Node deployment in either random or pre-determined manner.
2. Data reporting method which can be a time-driven, event-driven, query-driven or a hybrid of all of these methods.
3. Trade-off between energy consumption and accuracy of data gathered.
4. Node failure tolerance of the network.

5. Scalability, where routing method should be able to work with large networks.

6. Routing method should be adaptive for mobile sensor nodes.

7. Should support data aggregation to reduce redundant data.

According to the first order radio energy model as shown in figure 2, energy consumed in transmitting a message[9,10] is given by:

$$E_{tx} = K(E_{elec} + \epsilon_{amp}\, d^{\lambda}) \quad 1$$

where, *k* is the length of the message, *d* is the transmission distance between the transmitter and the receiver, E_{elec} is the electronic energy, ϵ_{amp} is the transmitter amplifier and ∂ is the path loss component.

Also, the energy consumed in message reception[9,10] is given by,

$$E_{rx} = K.E_{elec} \quad 2$$

Based on the first order radio energy model, it can be inferred that, with the reduction in size and number of messages being exchanged, energy consumption can be reduced. Routing techniques use this approach to maximize the network lifetime.

There are different routing protocols used in WSN applications which can be classified into three categories. They include: data centric, hierarchical and location based. This paper summarizes the implementation of various routing protocols in WSNs along with their advantages and constraints followed by their application domain. The rest of this paper is organized as follows. Section 2 discusses the routing protocols used in WSNs. Section 3, Section 4 and Section 5 focus on various protocols under data-centric, hierarchical and location based respectively. Section 6 brings forth the future research prospects in WSN routing techniques. Finally, Section 7 concludes the paper and Section 8 provides the references.

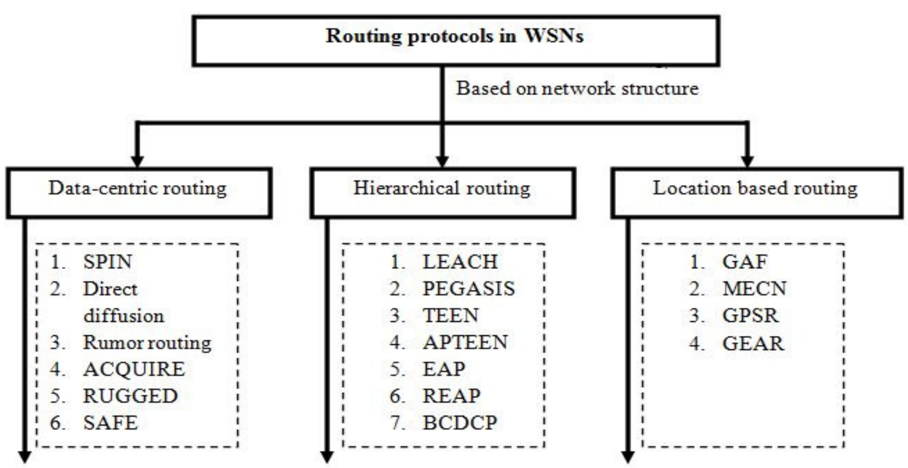


Figure 3. Classification of routing protocols in WSNs

2. Related work

The growing interest in wireless sensor networks and the continual advancements in micro electronics and wireless communication technologies have inspired some previous efforts for surveying the characteristics, applications and communication protocols in this technical area[1,11]. In this subsection we highlight the features that distinguish our survey and hint the difference in scope. The goal is to make a comprehensive survey of working of protocols proposed in the network layer and possible applications of sensor networks are also mentioned. This survey is a good introduction for readers interested in this widespread field. In this paper, we classify sensor networks based on network architecture and dynamics. Such classification is helpful for a designer to select the appropriate infrastructure for his/her application. We study the advantages and disadvantages that are existing in all the wireless sensor networks. Our work is a dedicated study of network layer, describing and categorizing the different approaches for data routing. Moreover, our work reflects the current state of art in routing research by including a comprehensive list of recently proposed routing protocols.

3. ROUTING PROTOCOLS IN WIRELESS SENSOR NETWORK

Routing protocols in WSNs have a common objective of efficiently utilizing the limited resources of sensor nodes in order to extend the lifetime of the network. Different routing techniques can be adopted for different applications based on their requirements. Applications can be time critical or requiring periodic updates, they may require accurate data or long lasting, less precise network, they may require continuous flow of data or event driven output. Routing methods can even be enhanced and adapted for specific application.

Generally, the routing protocols in WSNs can be classified into data-centric, hierarchical, location based routing depending on the network structure as shown in figure 3. In data-centric, all the nodes are functionally equivalent and associate in routing a query received from the base station to the event. In hierarchical approach, some nodes have added responsibilities in order to reduce the load on other nodes in the network. In location based, the knowledge of positions of sensor nodes is exploited to route the query from the base station to the event.

4. DATA-CENTRIC ROUTING TECHNIQUES

A large number of sensor nodes are deployed over a region making it incomprehensible to assign a global identifier for each node. This has led to the development of query based routing techniques known as data-centric routing protocols. In query based, the base station sends a query to a certain region in the network whose data it requires. The query is sent to a random sensor node form the base station, and has to be forwarded to the intended region. The sensor nodes in the region aggregate their sensed data and route back to the base station along the reverse path discovered in the previous step.

4.1. Sensor Protocols for Information via Negotiation (SPIN)

SPIN protocols[12,13] are a family of negotiation based information dissemination protocols used in WSN. In this protocol, the nodes name their data using high level descriptors called metadata. Metadata is used to negotiate and avoid the transmission of the redundant data. The transmission of a node is based on both the application specific knowledge of the data and the knowledge of the resources available to them. This allows the sensors to use their energy and bandwidth efficiently. The classical Flooding has 3 major obstacles as shown in figure 4:

1. *Implosion*: A node receives multiple copies of the same data from its different copies of the neighbours, because the sender node has no way of knowing whether the receiving node has already got the information from a different neighbour.

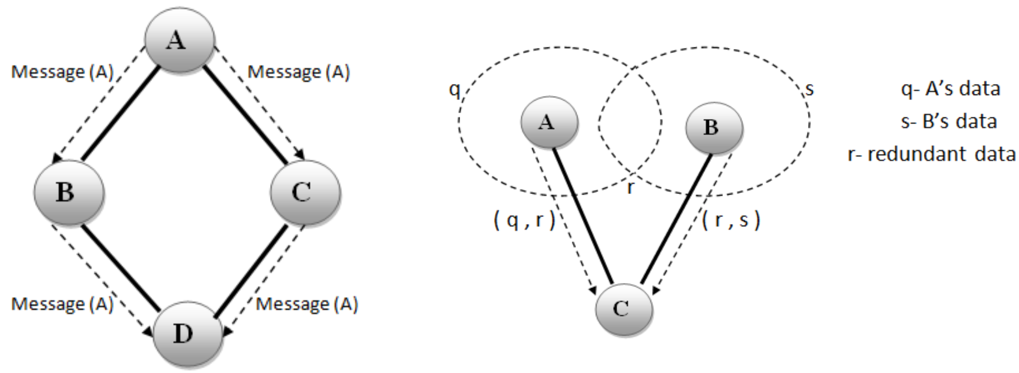


Figure 4. Implosion and Overlap

2. *Overlap*: Sensor nodes often cover same geographical area, and nodes gather overlapping pieces of sensed data. Since the nodes send redundant data to the same destination, bandwidth and energy are used inefficiently. Implosion is a function of only the network topology, whereas overlap is a function of both network and sensor attributes, making overlap a much harder problem than the implosion.

3. *Resource blindness*: The nodes are unaware of the status of its resources which makes them die sooner. It can be rectified by using a local resource manager at each node.

SPIN family of protocols overcome these limitations by negotiation and resource adaption.

Negotiation solves the implosion and overlap problem. It ensures that only relevant information will be transmitted. This uses the metadata approach in order to differentiate between various sensed data and eventually identify the redundant data in the network. Negotiation takes place in a simple 3-stage Handshake protocol. The node wanting to send the data initiates the Handshake by sending (advertisement) ADV messages to all its neighbours. The ADV message contains the metadata. A set of neighbours who need the data responds to the sender with a (response) RES message, requesting the necessary data. The final step of handshaking involves the transfer of actual data with a metadata as identifier. Whenever an intermediate node has its own sensed data along with data received from its neighbour, it aggregates both and forwards it.

In SPIN, nodes poll their resources before data transmission. Each sensor node has its own resource manager that keeps track of resource consumption. Applications probe the manager before transmitting or processing. This allows sensors to cut back on energy consumption and bandwidth usage, by being more prudent in forwarding third party data.

Together, these features overcome the 3 obstacles of classical flooding. SPIN-1 is a 3 stage hand shake protocol for disseminating data, and SPIN-2 is a version of SPIN-1 that backs-off from communication at low energy threshold. Such resource adaptive approach holds the key to the future of routing in WSNs. SPIN keeps up the promise of achieving high performance at low cost in terms of complexity, energy, computation and communication.

4.2. Direct Diffusion

Direct diffusion[14,15] is a data centric query based and application-aware protocol where data aggregation is carried out at each node in the network. The nodes will not advertise the sensed data until a request is made by the BS, and all the data generated by sensor node is named by attribute-value pairs.

The events generated by a single or a group of nodes are the changes in the sensed data. The interest queries are disseminated throughout the sensor network as an interest for named data. This dissemination set up the gradients within the network to draw events. A gradient is a direction state created in each node that receives an interest. The node within the event region sends the data sensed events back to the BS along multiple gradient paths. For each active task the BS broadcasts interest message periodically. The initial message for setting up the gradients for fetching the data will have a much larger interval. Each node in the network maintains an interest cache that contains information about the interest received. The interest cache stores the information about only one-hop neighbour from which it received the interest. When the node receives an interest, it checks the interest cache to see if the interest already exists. If no matching entry exists in the interest cache, then the node creates one interest entry and stores the information about the interest. If the entry already exists then the timestamp and expiresAt fields are updated, and then the node will send the interest to all its neighbours.

The gradient specifies data rate and the direction in which to send the events. The node which receives the events information from the source attempts to find a matching entry in its interest cache. If a match do not exists then the data message is dropped silently. If there exists a match, the received message is added to the data cache and the data message is sent to the nodes neighbours. In this way the data message will eventually reach the BS, the BS reinforces one particular neighbour, and that neighbour reinforces one of its upstream neighbour, the reinforcement continues till the source node.

All sensor nodes in a directed-diffusion-based network are application-aware, which enables diffusion to achieve energy savings by selecting empirically good paths, and by caching and processing data in the network. Caching can increase the efficiency, robustness, and scalability of coordination between sensor nodes, which is the essence of the data diffusion paradigm.

4.3. Rumour Routing

Rumor routing[16] routes the queries to the events in the network and it offers tradeoff between setup overhead and delivery reliability. An event is an abstraction obtained from a set of sensor readings that is assumed to be a localized phenomenon occurring in a fixed region in the network. A query is a request for information, sent by the base station to collect data, and once the query arrives at its destination the data can begin to flow back to the queries originator.

If there is significant amount of data to be sent, it is advisable to invest in discovering the shortest path from source to sink. There are various methods such as directed diffusion, which are energy inefficient as they rely only on query flooding until they reach the event location. But method such as rumor routing uses enhanced flooding approach which makes then more energy efficient. Rumor routing is a logical compromise between flooding queries and flooding event notifications. The goal is to create paths leading to each event; while event flooding creates a network wide gradient field[17].

In methods like direct diffusion, to create path between query source and event location, either event flooding or query flooding can be used. If no localization information is available for use by the network, flooding the entire network with query is the only choice. So, if there are N nodes and Q queries, the number of transmissions in total become $N*Q$. On the other hand, whenever a node witnesses an event, it can flood the network. With the path to the event being established, the query is routed to the event. The total transmissions by the network in the event flooding is $E*N$, where E is the number of events. So when the number of events is low when compared to queries, event flooding can be efficient.

The Rumor Routing algorithm is intended to fill the region between query flooding and event flooding. It is only useful if the number of queries compared to number of events is between the two intersection points. In rumor routing, each node maintains a list of its neighbors, as well as an event table. The event table has paths/ next hop to all the events that the node knows. When a node is in the event location, i.e. when it is able to sense the event, it adds it to its event table, with a distance zero to the event. It also probabilistically generates an agent. An agent is a long lived packet which is forwarded from node to node in the network and thus propagating information about the local events to the far away nodes. Each agent carries a list of all events it has encountered, along with the number of hops to that event. Thus, each agent provides information to the node about the events it has witnessed along its path. The agent has time to live (TTL) assigned to it when it is created. Each time it is forwarded, the TTL is decremented and the forwarding stops once the TTL becomes less than zero. A straightening algorithm is used when determining the agent's next hop which avoids the loops significantly. Usually, the node that witnesses an event generates an agent, whereas other nodes only update their event table and forward the agent accordingly.

A query can be generated any time and virtually by any node, and is targeted to an event. If a node has a route toward the target event, it forwards the query along the route, if it doesn't, it forwards the query to random neighbor, assuming the query hasn't exceeded it TTL. Sometimes, the query doesn't reach the destination and the node that originates the query detects such failure by using methods like timeout and handles it. Failures can be handled in many ways, but the simplest is to flood the query. Though this is expensive, it guarantees delivery.

By setting appropriate values to number of agents, agent TTL and query TTL, Rumor routing can be adopted to various scenarios. Hence it can be employed in a varied range of applications and is also highly scalable. Furthermore, it can handle node failure and consumes far less energy than the direct diffusion.

4.4. ACtive QUery forwarding In sensoR nEtworks (ACQUIRE)

ACQUIRE[18] is based on the basic principle that considers query as an active query that is routed through the network in search of solution. At each node, the query is forwarded using the information from all nodes within *d* hops, which resolves the query partially. At the node where the query gets resolved completely, a response is generated and routed back to the querier.

Regular data centric protocols work in two stages: query routing and response routing. In contrast, there are no distinct query / response stages in ACQUIRE because it uses an active query. The active query does not just get forwarded to the event, it also gets partially resolved at every intermediate node, as ACQUIRE incorporates a look-ahead parameter *d* at each node. The querier issues an active query, which can be a complex query i.e. can consist of several sub-queries each corresponding to a different variable/ interest. The active query is sent through a sequence of nodes until it is fully resolved. A node carrying the active query, also known as active node, utilizes updates received from all nodes within a look-ahead of *d* hops in order to resolve the query partially. After the active node has resolved the active query partially, it has to forward the active query to the next node. The next node can be selected randomly or selected intelligently based on other information such that the query gets resolved as quickly as possible. Thus, the active query gets smaller and smaller as it is forwarded through the network until eventually it reaches an active node which is able to completely resolve the query. The last active node answers the last remaining piece of the original query. At this point, the active query is transformed into the response and is routed back along either the reverse path or the shortest path to the original querier.

If the intermediate node has stale information about the nodes *d* hops away, an update is done. Update is initiated by a request being sent to all sensor nodes *d* hops away by the intermediate node. The sensor nodes who get the request will then forward their information to the intermediate node. The update frequency is modelled by an average amortization factor, such that an update is likely to occur at any given node only once every 1/C queries.

Depending on the application, different types of queries are used in WSN. The ACQUIRE protocol is well suited for one shot, complex queries for replicated data. The average latency of ACQUIRE in answering a query is far better than a random walk. Also, ACQUIRE saves energy by utilizing a probabilistic flooding approach

4.5. Gradient based routing – RoUting on finGerprint Gradient in sEnsor networks (RUGGED)

Every physical event occurring in the environment results in a natural information gradient in the proximity of the phenomenon. Such information gradient is known as fingerprint of the event caused by the events effect. RUGGED[19] protocol routes the query to the event by effectively utilizing the finger print of the event. Also, most of the physical phenomena follow diffusion law with distance. Unlike other information driven protocols, it eliminates the overload of preparing and maintaining the gradient information.

RUGGED uses an environmental model in which the effect of the event follows a diffusion function with respect to both distance and time. The diffusion function[20][21] of the event is given by,

$$f(d,t) \propto t/d^{\alpha}$$

The effect of the event decreases with time as a liner function. Also, the diffusion can be expressed as a function of distance alone, i.e., $f(d)\ \alpha\ 1/d^{\alpha}$. RUGGED works as a basic information driven routing protocol, where the query is sent to a randomly selected node and forwarded from the node to the event.

Using the information gradient of the event, the network is divided into two regions- 1) Flat region and 2) Gradient region. Gradient region is the space over which the sensor nodes are able to sense the event. The rest of the space in the network forms the flat region. At any instant of time, there could be multiple gradient regions active throughout the network. Depending on the location of the query, it could exist in two modes- Flat region mode and gradient region mode. Initially, the query is in a flat region mode. Once it finds the gradient information about the events effect, it switches to gradient region mode. Thus, the query packet needs fields for query ID and query mode in addition to other information.

A query may be initiated at any arbitrary node. The querier sets the query mode to the flat region mode and forwards the query to its neighbours with its gradient information level about the queried event. Then, each neighbour decides whether to forward the query or not. If the node is in a flat region, it uses flooding to forward the query towards the gradient information region. It sets the query mode to flat region mode. The query doesn't switch to the gradient mode unless gradient information is found. If the node is in gradient information region, it uses a greedy forwarding approach. If the node is able to improve information level, it forwards the query to its neighbours for further improvement. Otherwise, it performs probabilistic forwarding. Due to erroneous sensors readings, sharp drop or rise of information level about the queried event occurs at certain parts thus forming local and isolated maxima or information hole. This creates irregular patterns in the event region. The protocol uses a probabilistic function, which takes the hop count to the gradient information region as a parameter to overcome such uncertainties. Nodes use the reverse path of the resolved query to reply to the queries.

RUGGED proposes a novel method to exploit natural information gradient repository, which is a consequence of the fingerprint gradients of the events effect. It is a reactive and fully distributed routing protocol for WSN. Multiple path exploration and controlling instantiation of paths by simulated makes one protocol well suited for broad range of applications including time gradient based target tracking, event boundary detection.

4.6. An Energy Efficient ANT Based Routing algorithm (EEABR)

This routing protocol is based on ANT colony based routing algorithm[22][23] for MANETs. By introducing energy efficiency parameter to this algorithm, it can be adopted in WSN. It is used for multi-hop ad-hoc networks and is based on swarm intelligence and on the ANT colony based meta-heuristic. These approaches try to map the solution capability of swarms to mathematical and engineering problems. This routing protocol is highly adaptive, efficient and scalable. This feature makes it adaptive to energy constraint WSN.

The EEABR protocol is based on the ANT colony optimization (ACO) heuristic[24] and is focused on the main WSN constrains. EEABR uses a colony of artificial ANTS that travel through the WSN looking for path between sensor nodes and a destination node, that are both short in length and energy efficient, contributing in that way to maximize the lifetime of the WSN.

EEABR protocol finds the shortest path between the source and destination nodes by using forward (FANT) and backward ANTS (BANT). A forward ANT is launched periodically from every node in the network in order to find the path to the destination node, ANT stores the identifiers of all the nodes it visits. The FANT selects the next hop at each node by considering the probabilistic approach proposed in the ACO meta-heuristic given by,

$$P_k\ (r,s) - \frac{[\,T(r,s)]^{\alpha}\,.[E(s)]^{\beta}}{\sum_{n\nexists M_k}[\,T(r,u)]^{\alpha}\,.[E(u)]^{\beta}}$$

$$\text{if} \quad s \nexists M_k$$

$$P_k(\,r,s\,) = 0\text{ , otherwise}$$

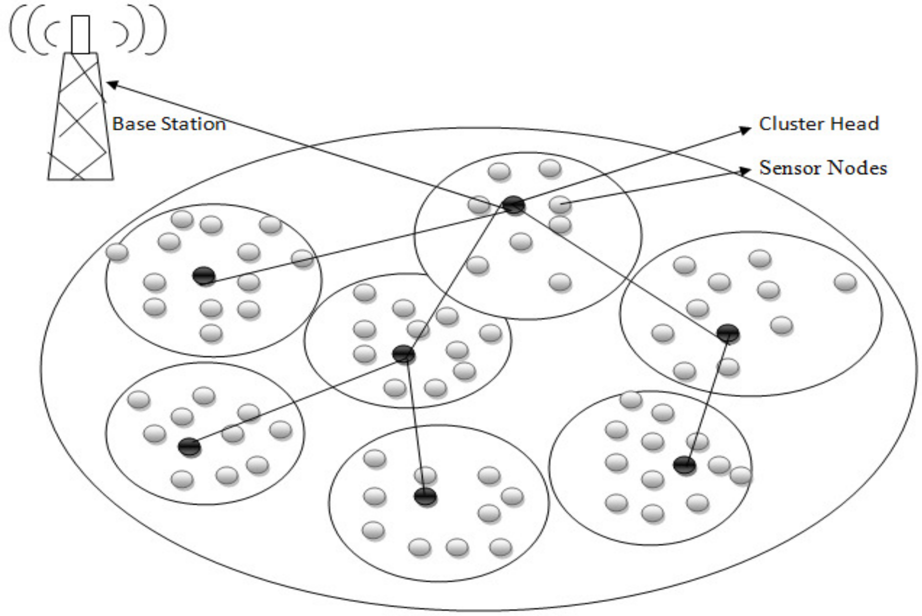
where , P_k is the probability with which ANT, k chooses to move from node r to s, T is routing table at each node that stores the amount of pheromone trail on connection on the initial and current energy level of node s, and α and β are parameter that control the importance of trial versus visibility. The visibility function promotes the nodes with more energy to be chosen with high probability. Whereas, the actual trail intensity promotes the path with higher traffic.

The selection probability is a trade-off between visibility and actual trail intensity. When a FANT reaches the destination node, it is transformed into a BANT and sent back along the path stored in its memory in-order to update the pheromone trail. At destination node, before the BANT leaves, the amount of pheromone trail that the ANT will drop during its journey is computed. Whenever a node receives the BANT coming from a neighboring node, it updates its routing table. Finally, when the BANT reaches the node where it was created, the path has been established and the ANT is destroyed. After several iteration of the above process, each node will know the best path to the destination node/sink.

EEABR can be easily implemented in clustering protocols where there is only one destination node. But if there are multiple destination nodes, the routing table of every node must contain the identification of all nodes. For large network, this can be a problem because of memory and computation constraints of sensor nodes. Enhancements of EEABR considerably reduce the size of routing tables and in consequence, the memory needed by the nodes. By considering the quality of the path between sensor and sink node, not only in terms of distance, but also in terms of energy level of that path, network lifetime can be maximized.

5. HIERARCHICAL ROUTING TECHNIQUES

Hierarchical routing is the procedure of arranging routers in a hierarchical manner. A hierarchical protocol allows an administrator to make best use of his fast powerful routers as backbone routers, and the slower, lower powered routers may be used for access purposes. In this way, the access routers form the first tier of the hierarchy, and the backbone routers form the second tier. Hierarchical protocols make an effort to keep local traffic local, that is, they will not forward traffic to the backbone if it is not necessary to reach a destination.



5.1. Low Energy Adaptive Clustering Hierarchy (LEACH)

Low Energy adaptive clustering hierarchy (LEACH)[25] is a popular energy efficient adaptive clustering algorithm that forms node clusters based on the received signal strength. The cluster head (CH) aggregates the sensed data from all transmits it to the BS as shown in figure 5.

Figure 5. Clusters in WSN

LEACH assumes that the base station is immobile and is located far from the sensors. All nodes are capable of communicating with the BS directly. At any point of time, all the nodes have data to send and nodes located close to each other have co-related data. The cluster head (CH) can perform data aggregation and data dissemination as shown in figure 5.

In LEACH the nodes form local clusters with one of the nodes acting as a local sink or cluster head. If the same node would remain as the cluster head throughout the working of the network, it would die quickly because of the extensive load from the participating sensors in the cluster. Hence the rotation of the cluster head in every round is necessary to distribute the load uniformly. Further energy dissipation can be reduced by aggregating the data from various sensor nodes at the cluster head. The operation of LEACH is broken up into rounds where each round begins with a setup phase, followed by a steady state phase.

The set up phase follows the following sequence

1. *CH selection*: Every round begins with a CH selection each node in the network decides whether to become the CH for the current round or not. Depending on the required percentage of cluster heads for the network and the number of times the node has been a cluster head. For any node *n,* the threshold equation for CH selection is given by,

$$T(n) = \frac{P}{1 - P * (r \ mod \ 1/P)}$$

if n € G

$T(n) - 0$, otherwise

where, P is the desired percentage of CH, r is the current round and G is the set of nodes that have not been CH in the last 1/P rounds. Every node in G chooses a random number between 0 and 1 and if the number is less than the threshold value, it is selected as the CH for the current round.

2. *Cluster Formation*: Once the CHs have been selected, they advertise themselves to the remaining nodes. Based on the signal strength, the nodes decide which cluster to join.

3. *Transmission Schedule Creation*: Based on the number of nodes in the cluster, the CH allots different time slots for each node to transmit by adopting the basic time division multiple access (TDMA) scheduling.

In the steady state phase, the nodes transmit the sensed data to the CH and the CH aggregates the original data to carry only meaningful information. The aggregated data is then transmitted to the BS by CHs.

LEACH enhances the network lifetime by utilizing the resources efficiently, distributing the load uniformly, aggregating data at the CH to contain only the meaningful information, rotating the CH randomly to achieve balanced energy consumption. Also, the sensors do not need to know the location or distance information. Depending on the applications, the different variations of LEACH such as LEACH-C (centralized)[26], E-LEACH (enhanced) and M-LEACH (multi-hop) can be used.

5.2. Power Efficient GAthering in Sensor Information System (PEGASIS)

PEGASIS[27] is a near optimal chain based protocol. The basic idea is for the nodes to communicate their sensed data to their neighbors and the randomly chosen nodes will take turns in communicating to the BS. It assumes that the BS is fixed at a far distance from the sensor nodes. The sensor nodes are homogeneous and energy constraint with uniform energy. The energy cost for transmitting a packet depends on the distance of transmission. All the nodes maintain a complete database about the location of all other nodes.

The objectives of PEGASIS include energy efficient method of communication between the nodes along the chain, load balancing by switching between the nodes that communicate with the BS, allows only local coordination between the nodes that are close to each other so that bandwidth used in the communication is minimized. The nodes are deployed randomly over a geographical location. The nodes are organized to form a chain which can be accomplished either by nodes communicating with each other using a Greedy algorithm or the BS can compute the chain and broadcast it to all the nodes. Because we have assumed that each node has global knowledge of the network, we can employ the greedy approach to construct the chain.

We begin the chain construction with the node farthest from the BS. Using the greedy approach, each node connects to its closest neighbor and the nodes already on the chain cannot be revisited. During every round, each node receives data from its neighbor, fuses it with its own data and transmits to the other neighbor on the chain. (The nodes take turns transmitting the BS). The node 'i' at some random position 'f' on the chain is chosen to transmit to the BS. Thus the leader in each round of communication will be at random position on a chain which is important for nodes to die at random locations. This makes the protocol robust to failures. It uses token passing approach to determine the leaders for communicating with the BS.

The improvement of PEGASIS, Hierarchical PEGASIS[28], was introduced with the objective of decreasing the delay incurred for packets during transmission to the BS. Energy balancing PEGASIS is the energy efficient chaining algorithm in which a node will consider average distance of formed chain. PEDAP, Power Efficient Data Aggregating Protocol uses spanning tree approach instead of Greedy approach to form the chain resulting in considerable savings og energy.

5.3. Threshold sensitive energy efficient protocols

Threshold sensitive energy efficient protocol (TEEN)[30] and Adaptive threshold sensitive energy efficient protocol (APTEEN)[31] are the two threshold sensitive hierarchical routing protocols based on the clustering approach used in LEACH. LEACH is targeted at pro active network applications where as TEEN and APTEEN are targeted at the reactive network applications. In pro active network, the sensed data is sent periodically to the sink which provides the snap shot of relevant parameters at regular intervals. In reactive networks the nodes react immediately to the sudden change in the sensed data and transmit it to the sink. Since they remain in the sleep mode most of the time, the number of transmissions is reduced, thus reducing the energy consumed.

Both TEEN and APTEEN group the sensor nodes into clusters with each led by a cluster head. Initially, at every cluster change time, in addition to other attributes, the CH broadcasts the threshold values to its member nodes. Hard threshold is the absolute value beyond which, the node sensing the value must switch on its transmitter and report to its CH. The data first transmission of every node depends on the hard threshold. The soft threshold is a small change in the value of the sensed attribute, which triggers the node to switch on its transmitter and transmit.

Thus, the hard threshold tries to reduce the number of transmissions by allowing the nodes to transmit only when the sensed attribute is in the range of interest. The soft threshold further reduces the number of transmissions by eliminating all the transmissions which might have otherwise occurred when there's little or no change in the sensed attribute once the hard threshold is reached.

TEEN mainly focuses on time critical sensing applications. The soft threshold can be varied depending on the criticality of the sensed attribute and the target application. The user can change the threshold values at every cluster change time by broadcasting the new attributes. The message transmission consumes more energy than data sensing. So, even though the node senses continuously, the energy consumption in this scheme can be potentially much less than in the pro active network, cause data transmission is done less frequently. A smaller value of the soft threshold gives a more accurate picture of the network, at the expense of increased energy consumption. One user can control the trade-off between energy efficiency and accuracy.

The main drawback of this scheme is that, if the thresholds are not reached, the nodes will not communicate and the user will not get any data from the network at all. Also the user is not informed even if all the nodes die.

APTEEN is an improvement over TEEN which can transmit data based on the thresholds and also periodically. It is applicable in both pro active and reactive networks and it can adapt itself to the application requirements. Once the CH are decided in each cluster period, the CH first broadcasts a set of parameters, attributes (the set of physical parameters of the environment in which the user is interested), thresholds (this parameter consists of the hard and soft thresholds), schedule (this is a TDMA schedule for assigning a slot to each node), (T_c) Count Time (it is the maximum time period between two successive reports sent by a node. It can be a multiple of the TDMA schedule length and it accounts for the pro active component).

The important features of APTEEN include the combination of both reactive and proactive networks. By sending periodic data, it gives the user a snapshot of the network and thus behaving as a proactive network. It also responds to the drastic changes thus making it responsive to the time critical applications. This hybrid network can be controlled by setting the count time and threshold values according to the relevant application. This offers flexibility for both user and applications. The energy consumption can be controlled by the count time and the threshold.

Although the hybrid protocol is more adaptive, it suffers from the additional complexity required to implement the threshold functions and the count time. However, this is a reasonable trade-off and provides additional flexibility and versatility.

5.4. Energy Aware routing Protocol (EAP)

EAP[32,33] is a hierarchical cluster based protocol which achieves a good performance in terms of lifetime by minimizing energy consumption for in-network communication and balancing energy load among all nodes. It introduces a new clustering parameter for cluster head election which enables better handling of the heterogeneous energy capacities and it also adopts an efficient method known as the intra cluster coverage, which copes with the area coverage problem.

EAP assumes that the sensor nodes are location unaware, for a sensor node there are three kinds of methods to get its location information, i.e., global positioning system (GPS), directional antenna and positional algorithms. The use of GPS and directional antenna methods will lead to an increase in the cost of sensors node and positional algorithms that need to exchange a large quantity of messages to compute the nodes location information will also result in high energy consumption. The last assumption is that the transmission power can be controlled. This can be achieved by using intra cluster and inter cluster communication methods.

EAP is a TDMA based protocol where the operation is divided into rounds. As the CH consumes more energy than member nodes, the CH must be rotated among the nodes in the network. Each round begins with a set-up phase while cluster are organized and the routing tree is constructed, followed by a working phase when the data is sent to the sink node. In EAP protocol, each node needs to maintain a neighborhood table to store information about its neighbors. At the beginning of each round, each node broadcast the E-message within radio range. All nodes within the cluster range of one node can be seen as the neighbors of this node. Each node receives an E-message from all neighbors in its cluster range and updates the neighborhood table. After exchanging E-message, each node computes the broadcast time delay t for competing cluster head,

$$t = k * T * (\frac{E_a}{E_{residual}})$$

where k is the real value uniformly distributed between 0 & 1. T is the time duration for CH election. E_a is the average residual energy.

EAP uses E_a / E residual to solve the heterogeneous energy problem. In EAP, if a node has not received any compete-message from its neighbor nodes in the time (0 , t) then this node will broadcast the compete-message to all the neighbor nodes, otherwise, it will give up competition. After the node broadcasts compete-message, it will wait for $2*\partial t$, where ∂t denotes the time interval which can guarantee that all the neighbor nodes will receive the compete-message. If the node has not received any compete-message from its neighbor over ∂t, it will set it as head or else, it will compare its weight with other broadcasting neighbors. If the weight is the largest, it will be set state as head and other broadcasting neighbors give up the competition or else, it will set its state as plain.

EAP uses the intra cluster coverage method, which selects some active nodes within cluster while maintaining the coverage expectation. The use of intra cluster coverage has two advantages, reduces power consumption in each round by turning redundant nodes off and reduces TDMA schedule overhead. After network is constructed, the cluster method is used for construction of routing tree.

5.5. Ring based Energy Adaptive Protocol (REAP)

In REAP[34], the nodes self organize in virtual ring bands centred at the BS. Packets are delivered to the BS along a path with decreasing ring band number. Also, with a probabilistic forwarding approach, the workload among neighbouring nodes within the same ring band, is balanced. REAP limits its use of flooding, thereby leading to significant energy savings. Finally, REAP is robust against node failures as it does not require creating and maintaining routing tables. These features of REAP help to effectively prolong the network lifetime

The ring band consists of a set of sensor nodes which are located within same number of hops from the BS. The initial ring band is initiated by the BS and consists of a set of sensor nodes, which are within the transmission range of the BS. These nodes are considered to be one hop away from the BS, and as such they belong to ring band 1. To form multiple ring bands, the process continues recursively until every node in the network belongs to a ring band. During the construction of i^{th} ring band, each node in the $i\text{-}1^{th}$ ring band discovers the other nodes in its transmission range such that the discovered nodes do not belong to any of the ring bands $<=i-1$. The set of newly discovered sensor nodes forms the i^{th} ring band.

To distinguish between the various functionalities of REAP, it uses different packet types. The different packet types are Ring band initialization, data packet, Ring status inquiry, Re-initialization request, Routing request (RR), Response to RR and Dummy packet. Furthermore, each node maintains a local variable L to record its own ring band number. During the network initialization phase, the BS broadcasts a ring band initialization packet with the ring band field set to 1. Upon receiving the type ring band initialization packet, the node checks the value of the ring band field of the packet i.e., V and if $L=O$, then the node copies the received ring band number (V) into its own variable L, thus joining that particular ring band. If L is greater than V, the node overwrites L with the value V. Then the node increments the value V of the packet and re-broadcasts it. At the completion of initialization phase, all nodes would have correctly associated themselves with the proper ring band.

Once the initialization phase has completed, the data is forwarded from the outer to inner ring bands. REAP also uses a power aware strategy to decide whether to forward the received packet or not by taking into consideration their current residual energy and the number of attempts to forward the packet. When a node receives a packet, it adds it to the received queue, Q_r, it stays there until it either successfully forwards the packet to a lower ring band or it determines that a neighbouring node within its ring band has assumed responsibility to transmit the packet .In latter case, the node drops the packet. By doing so the load is distributed among neighbouring nodes and the redundancy of packets is reduced.

If a node forwards a packet to the lower ring band, it keeps the packet in a sent queue, Q_s, until it gets a confirmation of successful delivery or a time out occurs. The confirmation is provided, if the node overhears that packet being forwarded by a lower ring band node towards the BS. Hence, extra packet is not sent for the acknowledgement (ACK), which reduces energy spent and reduces the risk of collision of packets.

In REAP, nodes only maintain the ring band number of the ring to which they belong, instead of a routing table. Updates are less frequent and only involve one-hop neighbours. Also, the protocol is scalable and self adaptive during failure of nodes.

6. LOCATION BASED ROUTING TECHNIQUES

Routing algorithms based on geographical location is an important research subject in the WSN. They use location information to guide routing discovery and maintenance as well as packet forwarding, thus enabling the best routing to be selected, reducing energy consumption and optimizing the whole network. Through three aspects involving the flooding restriction scheme, the virtual area partition scheme and the best routing choice scheme, the importance of location information is seen in the routing algorithm.

6.1. Geographic Adaptive Fidelity (GAF)

GAF[35] is a location based routing protocol for WSN. It is also an energy aware routing protocol. GAF works in such a way that, it turns off unnecessary nodes in the network without affecting the level of routing fidelity, this conserves energy. A virtual grid for the area that is to be covered is formed. The cost of packet routing is considered equivalent for nodes associated with the same point on the virtual grid. Such equivalence is exploited in keeping some nodes located in a particular grid area in sleeping state in order to save energy. By doing this the network lifetime is increased as the number of nodes increases. There are three states in this protocol and they are *discovery*, for determining the neighbors in the grid, *active* tells that the nodes are participating in routing and *sleep* when the radio is turned off. The load is balanced when nodes change states from sleeping to active in turns.

GAF keeps the network connected, by keeping a representative node always in active node for each region on its virtual grid. Although GAF is a location based protocol, it can be considered as a hierarchical protocol, where the clusters are based on geographic location.

6.2. Minimum Energy Communication Network (MECN)

MECN[35] is a location based routing protocol. It maintains a minimum energy network for wireless networks by utilizing low power GPS. This protocol can be used for mobile networks but it is best suited for sensor networks. This is because sensor networks are not mobile[36]. A master node is included to a minimum power topology for stationary nodes. MECN assumes a master-site as the information sink, which is always the case for sensor networks.

MECN identifies a relay region. This region consists of nodes in a surrounding area where transmission through those nodes is more energy efficient than direct transmission. The main idea of MECN is to find a sub-network which will have less number of nodes and require less power for transmission between two nodes . MECN consists of two phases, firstly, it constructs a sparse graph or an enclosure graph, by taking positions of a two dimensional plane. This construction requires local computations in the nodes. The enclosure graph contains globally optimal links in terms of energy consumption. Secondly, it finds optimal links on the graph using the Belmann Ford shortest path algorithm.

MECN is self organizing and dynamically adapts to nodes failure or the deployment of new sensor nodes. Small Minimum Energy Communication Network (SMECN)[37] is an extension of MECN. In SMECN, possible obstacles between any pair of nodes are considered.

6.3. Greedy Perimeter Stateless Routing (GPSR)

The Greedy Perimeter Stateless Routing (GPSR)[38,39], is a routing protocol based on the position of routers and packets destination to make a forwarding decision for WSN. GPSR makes the forwarding decision which is actually transferring the packet from one node to another destination node using the minimum shortest path possible. Hence the routing protocol is associated with the term “greedy”. The greedy forwarding decision for a packet is made using the information about a router’s immediate neighbors in the network topology. If a packet reaches a region where greedy forwarding is not possible, then an alternative step is taken by routing around the perimeter of the region. Even though there are frequent changes made to the topology due to mobility, the GPSR protocol uses the local topology information to find correct new routes quickly. The scalability of GPSR routing protocol depends on two major factors like the rate of change of topology and the number of routers existing in the routing domain. Scalability is aimed at increasing number of nodes in the network and increasing the mobility rate.

Coming to the way the GPRS protocol works, it consists of two methods for forwarding packets greedy forwarding, which is used as much as possible and perimeter forwarding which is used when greedy forwarding is not possible.

Packets in the GPSR protocol are marked by their originator with their destinations location. By this, a forwarding node can make a locally optimal, greedy choice in choosing a packets next hop. The locally optimal choice or next hop is the neighbor geographically closest to the packets destination, this happen only if a node knows its radio neighbors positions. Forwarding in this way, the destination is reached in successively close geographic hops.

Through a beaconing algorithm, all nodes know their neighbors positions. If a beacon from a neighbor is not received for some time interval T, then the GPSR router assumes that the neighbor has failed or gone out of range and deletes the neighbor from its table.

An advantage of this method of forwarding is its reliance only an knowledge of the forwarding nodes immediate neighbors. The state required is negligible and dependent on the density of the nodes in the wireless network, not the total number of destinations in the network. The beacons time interval is important because a nodes neighbor might be moving in and out of the range of a node and the table has to be updated for some time interval. Another way of forwarding other than the greedy forwarding is the perimeter forwarding. The perimeter forwarding uses a rule known as the Right Hand rule for traversing graph. Basically the perimeter forwarding is used when there exists a void between the current node where the packet is available and the destination. Here void means no other node exists in the path between two nodes. When there is a void, the routing has to be in such a way that the destination is reached using the perimeter of the void or in other words to route around the void. It is known that the right hand rule traverses the interior of a closed polygonal region in clockwise edge order. The same rule traverses an exterior region, i.e. the outside region on counter clockwise edge order.

GPSR routing algorithm makes use of geography to achieve small per node routing state. This routing protocol is an extremely robust packet delivery on densely deployed wireless networks. GPSR generates routing protocol traffic in a quantity independent of the length of the routes through the network, and therefore generates a constant, low volume of routing protocol messages as mobility increases, yet doesn't suffer from decreased robustness in finding routes. GPSR benefits all stem from geographic routings use of only immediate-neighbor information in forwarding decisions.

6.4. Geographic and Energy Aware Routing (GEAR)

Geographic and Energy Aware Routing algorithm or simply known as GEAR[40] is a location based routing protocol for WSN. GEAR is an energy efficient protocol which uses the energy aware neighbour selection to route a packet towards a particular geographical region and then use either the recursive geographic forwarding or restricted flooding algorithms to disseminate the packet inside the destination region. GEAR shows considerably longer network lifetime than most non-energy aware geographic routing algorithms especially for non-uniform traffic distribution when compared to uniform traffic distribution.

GEAR protocol follows the query based method where in a query is routed to regions in proposed sensor-net applications. The process of forwarding a packet to all the nodes in the target region mainly consists of two phases. In first phase, the packets are forwarded towards the target region. This protocol uses a geographical and energy aware neighbour selection heuristic to find the minimum cost to route the packet towards the target region. This again has two cases for consideration, if a neighbour which is closer to the destination exists the GEAR chooses a next-hop node among other nodes, if all the neighbours are further away then there exists a hole to which GEAR chooses a next-hop node that minimizes the cost value of this neighbour. Second phase involves dissemination of packets within the region. For this to happen, Recursive Geographic Forwarding algorithm is used in general. But if the network is of low density then using a recursive forwarding algorithm is a drawback , this is because the algorithm does not terminate, routing uselessly around an empty target region till the packet's hop-count exceeds some bound. Therefore, restricted flooding is used for low density networks, but flooding requires a lot of energy if used for high density networks.

To compute the energy-aware neighbour computation, the protocol assumes that the node *N* is forwarding a packet *P* to a target region *R*. The target region consists of many nodes and a particular node is taken as the centroid of the target region as *D*. While routing the packet, to balance the energy consumption across its neighbours, node *N*, minimizes the learned cost *h(N,R)* value of its neighbour *N*. Each node maintains state *h(N,R)* which is known as the learned cost to region *R* . If the *h(N,R)* or learned cost of node is not known then the estimated cost *c(N,R)* is computed as default value for *h(N,R)* . Estimated cost is defined as,

$$c(N,R) = \alpha * d(N,R) + (1-\alpha) * e(N)$$

where, α is a tunable weight , *d(N,R)* is the distance from *N* to centroid *D* and *e(N)* is the consumed energy at node *N* . Consider a case where node *N* knows that there is a hole, then the learned cost *h(N,R)* and its update rule are combined to circumvent holes. While routing towards the region *R*, if no holes are found then the node's learned cost *h(N,R)* is equal to the estimated cost *c(N,R)* . If there is a hole, the node's learned cost represents a "resistance" to following the path towards that hole.

Recursive geographic forwarding is applied to disseminate the packet inside the target region. However, a simple flooding with duplicate suppression scheme can be used to flood the packet inside region *R*. But flooding is very expensive in terms of energy consumption when applied to highly dense networks. Therefore, Recursive forwarding method is used mostly.

GEAR protocol is very sensitive to location error which is caused due to imprecise measurement from the GPS system. GEAR achieves energy balancing by taking a different path or an alternative path , therefore the energy balancing strategy increases the path length by 25% to 45% overall packets delivered.

7. OPEN RESEARCH ISSUES

Throughout this paper we have discussed energy efficient routing protocols in WSNs. Quality of service (QoS) is as important as energy efficiency in real time applications. Real time applications require guaranteed bandwidth and throughput throughout the working of the WSN. Also most of the current routing protocols assume that the BS and sensor nodes are immobile. Some of the real world applications like battlefield surveillance require the sensor nodes to be mobile (and sometimes even the BS to be mobile). New routing protocols must be dynamic and be able to adapt to the mobile nodes network. When the sensors are deployed randomly, depending on the sensor's range, more than one sensor can be sensing the same region. By identifying such redundancy in the network, the sensors can be periodically made to sleep in order to conserve energy. Tiered architectures are highly scalable, thus introducing the need for more efficient methods to organize the sensor nodes. With increasing demand and usage of WSNs in varied fields, the security of the information collected has been a primary goal lately. Along with energy efficiency and QoS, routing in WSNs need to be secure. The above mentioned aspects of routing protocols in WSNs are open for future research. Since the routing methods in WSNs are application specific, there is always scope for improvements.

8. CONCLUSION

WSNs have discovered a wide range of applications in the recent era. Growing demand for WSN has accelerated the research and development of routing protocols used in WSNs. In this paper we classify the routing protocols in WSNs into data-centric, hierarchical and location based depending on the network structure. Data-centric protocols use the metadata structure to transmit the sensed information to the BS. Naming the data helps to construct a query which requests for only certain attributes of the data, thus known as data-centric routing techniques. Regardless, the sensor nodes can also be grouped for efficient data dissemination to the sink. Hierarchical routing protocols adopt the clustering approach by grouping sensor nodes. This approach is highly scalable and thus used in a number of applications. Location based protocols use the information of position of sensor nodes intelligently to route data. We epitomize the logic behind these protocols followed by the advantages and constraints. We also mention the possible application domain of these protocols and scope for improvement in the future.

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