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A Review of Routing Protocols in Wireless Sensor Network

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Abstract

Wireless sensor network (WSN) has emerged as a useful supplement to the modern wireless communication networks. Optimal selection of paths for data transfer results in saving of energy consumption resulting in increase of network lifetime of Wireless Sensor Networks. Many routing, power management, and data dissemination protocols have been specifically designed for WSNs where energy awareness is an essential design issue. Routing protocols in WSNs might differ depending on the application and network architecture as there is still no consensus on a fixed communication stack for WSN. Newer Routing protocols are required to cater to the need of ubiquitous and pervasive computing. In this paper, WSN Routing Protocols has been classified in four ways i.e., routing paths establishment, network structure, protocol operation and initiator of communications. Further, routing protocols have been categorized on the basis of their homogeneity and heterogeneity of sensor nodes followed by the criteria of clustered and non - clustered among both. Data aggregation, support for query and scalability of the network of these routing protocols have also been.

1. Introduction

WSN can be viewed as a network consisting of hundreds or thousands of wireless sensor nodes which collect the information from their surrounding environment and send their sensed data to Base Station or sink node[4]. Routing is a process of determining a path between source and destination for data transmission. In WSNs the network layer is mostly used to implement the routing of the incoming data and Routing protocol is an important factor in design of a communication stack. In multi-hop networks the intermediate sensor nodes have to relay their packets towards Base Station. Routing protocols, designed for sensor networks, must accomplish high reliability. There has to be multiple paths to relay the data from source node to the destination node in order to achieve robustness. Sensor nodes are constrained in energy supply and recharging sensor nodes is normally impractical due to their nature of deployment. Therefore, energy saving is an important design issue in Wireless sensor networks. While the objective of traditional networks is to achieve high quality of service, sensor network protocols must focus additionally on power conservation also to maximize the network lifetime. Flooding the network is a highly expensive operation with respect to energy consumption and should be avoided. Hence, efficient routing is a major challenge in the field of WSN [5].

2. Routing Challenges and Design Issues

In WSN, the routing protocols [6][7]are application specific, data centric, capable of aggregating data and capable of optimizing energy consumption. The important characteristics of a good routing protocol for WSN are simplicity, energy awareness, adaptability and scalability due to limited energy supply, limited computation power,limited memory and limited bandwidth of WSN [8][9][10]. The main design goal of WSNs is to carry out data communication while trying to prolong the lifetime of the network .The design of routing protocol in WSNsis influenced by many challenging factors as summarized below.

- **Node deployment:** Node deployment in WSNs is application dependent and affects the performance of the routing protocol. The deployment is either deterministic (manual) or self-organizing (random). In deterministic situations, the sensors are manually placed and data is routed through pre-determined paths. Whereas in self-organizing systems, the sensor nodes are scattered randomly creating an infrastructure in an ad hoc manner. The position of the sink or the cluster-head is very crucial in terms of energy efficiency and performance. When the distribution of nodes is not uniform, optimal clustering becomes a necessity to enable energy efficient network operation. In some applications like battle field and wildlife monitoring, sensor nodes are randomly deployed like being dropped from an airplane.
- **Network dynamics:** Most of the network architectures assume that sensor nodes are stationary, because there are very few setups that utilize mobile sensors. It is sometimes necessary to support the mobility of sinks or cluster-heads (gateways). Route stability becomes an important optimization factor, in addition to energy, bandwidth etc. as communication from moving nodes is more challenging. Further, the sensed event can also be either dynamic or static depending on the application.
- **Energy Conservation:** During the creation of an infrastructure, the process of setting up the routes is greatly influenced by energy

considerations [11][12][13]. Since the transmission power of a wireless radio is proportional to distance squared or even higher order in the presence of obstacles, multi-hop routing will consume less energy than direct communication. However, multi-hop routing introduces significant overhead for topology management and medium access control. Direct routing would perform well enough if all the nodes were very close to the sink. Most of the time sensors are scattered randomly over an area of interest and multihop routing becomes unavoidable.

- **Fault Tolerance:** If sensor nodes fail, MAC and routing protocols must accommodate formation of new links so that sensor node failure should not affect the overall task of the sensor network.
- **Scalability:** The number of sensor node in the target area may be on the order of hundreds or thousands, or more so protocols should be able to scale to such high degree and take advantage of the high density of such networks.
- **Production Costs:** The cost of a single node must be low.
- **Hardware Constraint:** All Subunits of sensor node (e.g. sensing, processing, communication, power, location finding system and mobilizer) must consume extremely low power [14] and be contained within an extremely small volume.
- **Sensor network topology:** It must be maintained even with very high node density
- **Environment:** Nodes should be operating in inaccessible location because of hostile environment.
- **Transmission Media:** Generally, Transmission Media is wireless (RF or Infrared), which is affected by fading and high error rate and affect the operation of WSNs.
- **Data delivery models:** Data delivery model to the sink can be continuous, event driven, query-driven and hybrid, depending on the application of the sensor network. In the continuous delivery model, each sensor sends data periodically. In event-driven and query-driven models, the transmission of data is triggered when an event occurs or the sink generates a query. Some networks apply a hybrid model using a combination of continuous, event-driven and query-driven data delivery. The routing protocol is highly influenced by the data delivery model, especially with regard to the minimization of energy consumption and route stability.
- **Node capabilities:** In a sensor network, different functionalities can be associated with the sensor nodes. Depending on the application a node can be dedicated to a particular special function such as relaying, sensing and aggregation since engaging the three functionalities at the same time on a node might quickly drain the energy of that node.
- **Data aggregation/fusion:** Data aggregation is the combination of data from different sources by using functions such as suppression (eliminating duplicates), min, max and average. Similar packets from multiple nodes can be aggregated to reduce the transmission.

3. Routing Techniques in WSN

WSN Routing Protocols may be classified in four ways, according to the way of routing paths are established, according to the network structure, according to the protocol operation and according to the initiator of communications. Fig.1 shows the classification of WSN routing protocols.

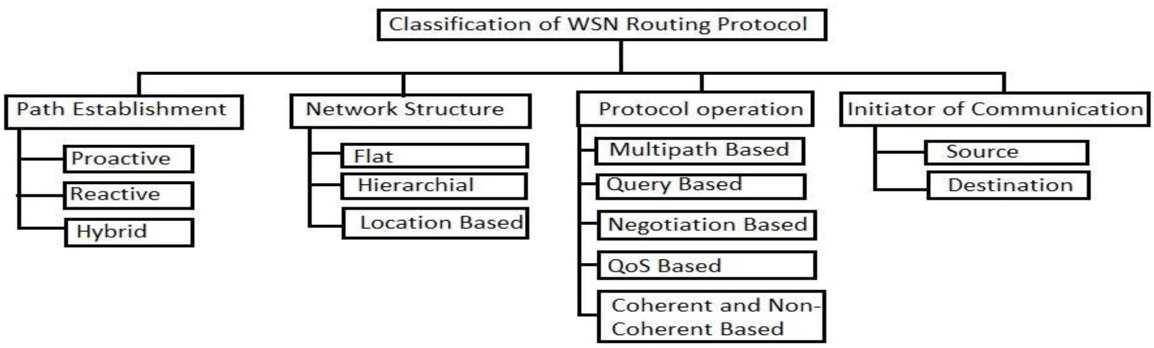

Fig.1: Classification of Routing Protocols in Wireless Sensor Network.

Routing paths can be established in one of three ways, namely proactive, reactive or hybrid. Proactive protocols compute all the routes before they are really needed and then store these routes in a routing table in each node. When a route changes, the change has to be propagated throughout the network. Since a WSN could consist of thousands of nodes, the routing table that each node would have to keep could be huge and therefore proactive protocols are not suited to WSNs. Reactive protocols compute routes only when they are needed. Hybrid protocols use a combination of these two ideas.

According to network flow model, the routing protocols are divided into flat-routing, hierarchical-based and location-based routing. In flat-based routing, all nodes play the same role. In hierarchical-based routing, however, nodes will play different roles in the network. In location-based routing, sensor nodes' positions are exploited to route data in the network.

- **Flat Routing (Data Centric Routing protocols) [15]:** It is not feasible to assign global identifiers to each node due to the sheer number of nodes deployed in many applications of sensor networks. Such lack of global identification along with random deployment of sensor nodes makes it hard to select a specific set of sensor nodes to be queried. Therefore, data is usually transmitted from every sensor node within the deployment region with significant redundancy. This consideration has led to data-centric routing. In data-centric routing, the sink sends queries to certain regions and waits for data from the sensors located in the selected regions.
- **Hierarchical protocols [15]:** One of the major designs attributes of sensor networks are scalability. Since the sensors are not capable of long-haul communication, single gateway architecture is not scalable for a larger set of sensors. Networking clustering has been pursued in some routing approaches to cope with additional load and to be able to cover a large area of interest without degrading the service. Hierarchical routing works in two steps, first step is used to choose cluster heads and the second step is used for routing. To make the WSN more energy efficient, clusters are created and special tasks (data aggregation, fusion) are assigned to them. It increases the overall system scalability, lifetime, and energy efficiency.
- **Location-based protocols:** In most cases location information is needed in order to calculate the distance between two particular nodes so that energy consumption can be estimated. Generally two techniques are used to find location, one is to find the coordinate of the neighboring node and other is to use GPS (Global Positioning System). Since, there is no addressing scheme for sensor networks like IP-addresses and they are spatially deployed on a region, location information can be utilized in routing data in an energy efficient way.

According to protocol operation, routing protocols can also be classified into multipath-based, query-based, negotiation-based, QoS-based, or coherent-based routing techniques.

- **Multipath routing protocols:** Multiple paths are used to enhance the network performance. When the primary path fails between the source and the destination an alternate path exists that measured the fault tolerance (resilience) of a protocol. This can be increased, by maintaining multiple paths between the source and the destination. This increases the cost of energy consumption and traffic generation. The alternate paths are kept alive by sending periodic messages. Due to this, network reliability can be increased. Also the overhead of maintaining the alternate paths increases.
- **Query based routing protocols:** The destination nodes propagate a query for data (sensing task) from a node through the network and a node having this data sends back the data to the node that matches the query to the query that initiates. Usually these queries are described in natural language, or in high-level query languages.
- **Negotiation based routing protocols:** In order to eliminate redundant data transmissions, these use high level data descriptors through negotiation. Based on the resources that are available to them, communication decisions are taken. The motivation is that the use of flooding to disseminate data will produce implosion and overlap between the sent data; hence nodes will receive duplicate copies of the same data. This consumes more energy and more processing by sending the same data to different sensor nodes. So, the main idea of negotiation based routing in WSNs is to suppress duplicate information and prevent redundant data from being sent to the next sensor node or the base-station by conducting a series of negotiation messages before the real data transmission begins.
- **QoS-based routing protocols [16]:** In order to satisfy certain QoS (Quality of Service) metrics, e.g., delay, energy, bandwidth, etc. when delivering data to the Base Station, the network has to balance between energy consumption and data quality.
- **Coherent and non-coherent processing:** Data processing is a major component in the operation of wireless sensor networks. Hence, routing techniques employ different data processing techniques. There are two ways of data processing based routing.
  - **Non-coherent data processing:** In this, nodes will locally process the raw data before being sent to other nodes for further processing. The nodes that perform further processing are called the aggregators.
  - **Coherent data processing:** In coherent routing, the data is forwarded to aggregators after minimum processing. The minimum processing typically includes tasks like time stamping, duplicate suppression, etc. When all nodes are sources and send their data to the central aggregator node, a large amount of energy will be consumed and hence this process has a high cost. One way to lower the energy cost is to limit the number of sources that can send data to the central aggregator node.

In Homogeneous approach, all nodes are of identical types in the sense of size, shape, hardware configuration and the mode of energy supply. All nodes have the same transmission power (range), transmission data rate and processing capability, the same reliability and security. In Heterogeneous approach nodes are of different types in the sense of size, shape, hardware configuration, processing capability and the mode of energy supply. In Clustered protocols different nodes are grouped to form clusters and data from nodes belonging to a single cluster are combined (aggregated).The clustering protocols have several advantages like scalable, energy efficient in finding routes and easy to manage. In the non –clustered approach, there is no need to form a cluster of nodes. Each and every node is free to send data to the Base station on its own.

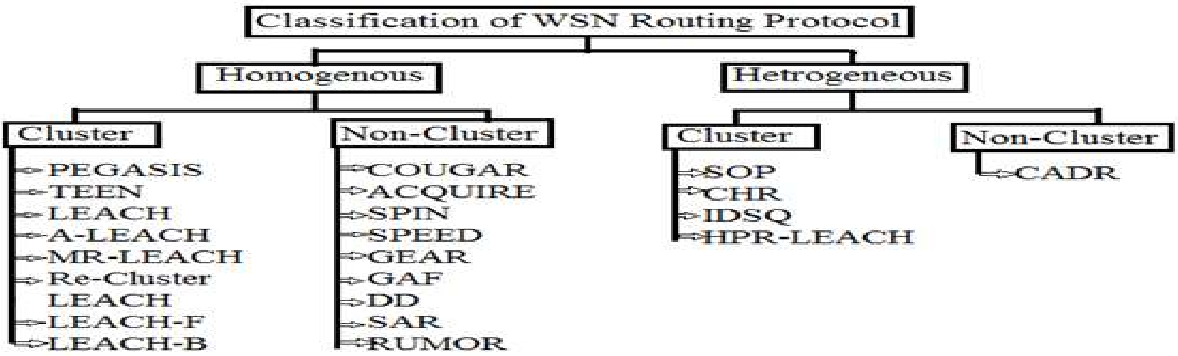

Fig.2: Classification of routing protocol according to types of nodes

4. Descriptions of various Routing Protocols

4.1. Homogenous Clustered Routing Protocol

4.1.1. PEGASIS: PEGASIS (Power-Efficient Gathering in Sensor Information Systems) is considered an optimization of the LEACH algorithm [17]. The key idea in PEGASIS is to form a chain among the sensor nodes so that each node will receive from and transmit to a close neighbour. The chain is constructed with a greedy algorithm. Gathered data moves from node to node, get fused, and eventually a designated node transmits to the BS. Nodes take turns transmitting to the BS so that the average energy spent by each node per round is reduced.

Working of PEGASIS:

For a network running PEGASIS, it is required to form a chain that contains all nodes. The chain construction starts with the farthest node from the base station. By using a greedy algorithm, it chooses the second farthest node as its neighbour. Then the third farthest node is chosen as the second farthest node's other neighbour. This process is repeated until the closest node to the base station is chosen as the other end of the chain.

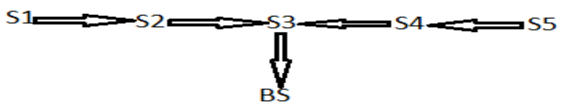

Fig.3: Token passing approach

When some node dies, this chain will be reconstructed. Fig.3 shows one possible PEGASIS chain. To balance the overhead involved in communication between the leader which is responsible for communicating with the base station, and the base station, nodes in the chain take turns to be the leader. PEGASIS gathers data round by round. In each round, the end of one side of the chain starts these round transmissions by sending data to its neighbour on the chain. Then, the neighbour fuses received data with its local data, and sends the result to its other neighbour on the chain. This process is repeated until the data reach the leader. So does the other side to the leader of the chain. After the leader received data from its both sides, it fuses those data with its own data, and sends them to the base station. For instance, as shown in Fig.3 S3 is the current leader. Collected data flow from S1 and S5 to S3 along the chain respectively. S3 is then responsible for sending the fused data to the base station. When a node dies, the chain is reconstructed in the same manner to bypass the dead node.

Features of PEGASIS:

1. It forms chains using greedy approach instead of forming a cluster.
2. In the local gathering, the distances that most of the nodes transmit are much less compared to transmitting to a cluster-head in LEACH.

3. The amount of data for the leader to receive is much less compared to a cluster-head in LEACH.
4. PEGASIS introduces excessive delay for distant node on the chain.
5. Although the PEGASIS approach avoids the clustering overhead of LEACH, it still requires dynamic topology adjustment since sensor's energy is not tracked. For example, every sensor needs to be aware of the status of its neighbor so that it knows where to route that data. Such topology adjustment can introduce significant overhead especially for highly utilized networks.

4.1.2 Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN):

TEEN is a hierarchical clustering protocol [18], which groups different sensor nodes into clusters with each having a cluster-head(CH).The job of the sensors within a cluster is to send their sensed data to their respective CH. The CH now sends the aggregated data to higher level CH until the data reaches the sink. Thus, the sensor network architecture in TEEN is based on a hierarchical grouping where closer nodes form clusters and this process goes on the second level until the BS (sink) is reached.

TEEN is a clustering communication protocol that targets a reactive network and enables CHs to impose a constraint on when the sensor should report their sensed data. After the clusters are formed, the CH broadcasts two thresholds to the nodes namely Hard threshold (HT), and Soft threshold (ST).

Hard threshold is the minimum possible value of an attribute, beyond which a sensor should turn its transmitter ON to report its sensed data to its CH. Thus, the hard threshold allows the nodes to transmit only when the sensed attribute is in the range of interest, thus reducing the number of transmissions significantly. Once a node senses a value at or beyond the hard threshold, it transmits data only when the value of that attribute changes by an amount equal to or greater than the soft threshold, which indicates a small change in the value of the sensed attribute and triggers a sensor to turn ON its transmitter and send its sensed data to the CH. As a consequence, soft threshold will further reduce the number of transmissions for sensed data if there is little or no change in the value of sensed attribute. Thus, the sensors will send only sensed data that are of interest to the end user based on the hard threshold value and the change with respect to the previously reported data, thus yielding more energy savings. One can adjust both hard and soft threshold values in order to control the number of packet transmissions. However, both values of hard and soft thresholds have an impact on TEEN. These values should set very carefully to keep the sensors responsive by reporting sensed data to the sink.

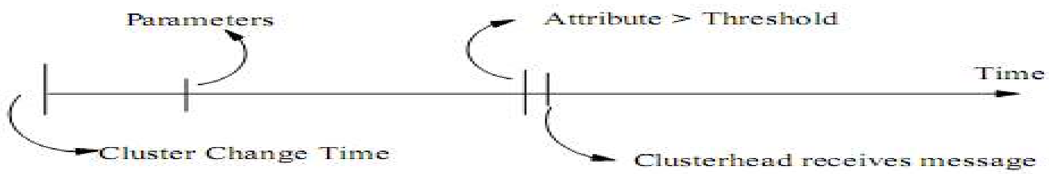

Fig.4: Operation of TEEN

Advantages of TEEN:

a) It is useful for the applications where the users can control a trade-off between energy efficiency, data accuracy, and response time dynamically.
b) TEEN makes use of a data-centric method with hierarchical approach
c) It is suitable for time critical sensing applications.
d) Since message transmission consumes more energy than data sensing, so the energy consumption in this scheme is less in comparison with the proactive networks.

Disadvantages of TEEN:

TEEN is not suitable for sensing applications where periodic reports are needed since the user may not get any data at all if the thresholds are not reached.

4.1.3. Adaptive Periodic Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN):

APTEEN has been proposed just as an improvement to TEEN in order to overcome its limitations and shortcomings. It mainly focuses on the capturing periodic data collections (LEACH) as well as reacting to time-critical events (TEEN). Thus, APTEEN is a hybrid clustering-based routing protocol that allows the sensor to send their sensed data periodically and react to any sudden change in the value of the sensed attribute by reporting the corresponding values to their CHs [19]. The architecture of APTEEN is same as in TEEN, which uses the concept hierarchical clustering for energy efficient communication between source sensors and the sink. APTEEN guarantees lower energy dissipation and a helps in ensuring a larger number of sensors alive.

When the base station forms the clusters, the CHs broadcast the attributes, the hard and soft threshold values, and TDMA transmission schedule to all nodes, and a maximum time interval between two successive reports sent to a sensor, called count time (TC). CHs also perform data aggregation in order to save energy. APTEEN supports three different query types namely:

1) Historical query, to analyze past data values,
2) One-time query, to take a snapshot view of the network; and
3) Persistent queries, to monitor an event for a period of time.

APTEEN has following advantages:

1) Guarantees lower energy dissipation,
2) It ensures that a larger number of sensors are alive,
3) Simulation of APTEEN has shown it to outperform LEACH
4) Experiments have demonstrated that APTEEN's performance is between LEACH and TEEN in terms of energy dissipation and network lifetime. While in LEACH sensors transmit their sensed data continuously to the sink, in APTEEN sensors transmit their sensed data based on the threshold values.

Disadvantages of APTEEN are as follows:

a) The overhead and complexity of forming clusters in multiple levels,
b) Implementing threshold-based functions and
c) Dealing with attribute-based naming of queries.

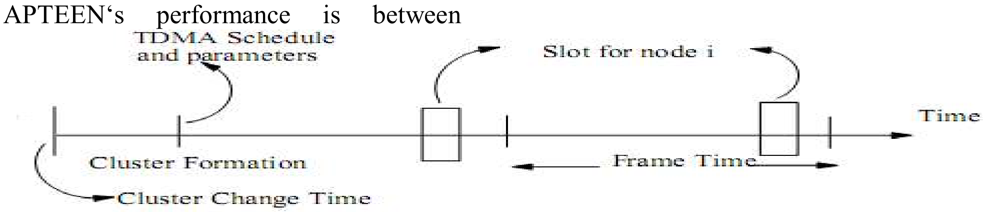

Fig.5: Operation of APTEEN

4.1.4. Low-Energy Adaptive Clustering Hierarchy(LEACH): LEACH is an adaptive clustering-based protocol using randomized rotation of cluster-heads to evenly distribute the energy load among the sensor nodes in the network [20]. The data will be collected by cluster heads from the nodes in the cluster and after processing and data aggregation forwards it to base station. The three important features of LEACH are:

- Localized co-ordination and control for cluster setup.
- Randomized cluster head rotation.
- Local compression to reduce global data communication.

By forming cluster, the energy usage is low within the cluster but drains the energy resource for the cluster head. The cluster heads need to be more powerful than other common nodes of the networks of fixed cluster heads in order to perform maximum long distance communication. LEACH is a fully cluster-base protocol, which includes distributed cluster formation. LEACH randomly selects a few sensor nodes as cluster-heads (CHs) among the different sensor nodes and periodically changes the role of cluster-heads so that the energy load is totally distributed among the different nodes.

In LEACH, the role of the cluster-head (CH) nodes is to compress the data arriving from the different nodes that belong to the respective cluster, and send an aggregated packet to the base station in order to reduce the amount of information that must be transmitted to the base station. However, data collection is centralized and is performed periodically. This protocol proves to be the most appropriate and suitable when constant monitoring is needed by the sensor network. In this situation it may be possible that a user may not need all the data immediately. Hence, periodic data transmissions are unnecessary which may cause the wastage of the limited energy of the sensor nodes. After a given interval of time, the role of the CH is randomly rotated so that uniform energy dissipation in the sensor network is obtained.

Fig.6: LEACH protocol two phases

The operation of LEACH protocol has been divided into two phases, the setup phase and the steady state phase as shown in Fig.6. In the setup phase, the clusters are organized and CHs are selected. In the steady state phase, the actual data transfer to the base station takes place. The duration of the steady state phase is longer than the duration of the setup phase in order to minimize the overhead. During the setup phase, a predetermined fraction of nodes, p, elect themselves as CHs as follows. A sensor node chooses a random number, v, between 0 and 1. If this random number is less than a threshold value, T(n), the node becomes a cluster-head for the current round. The threshold value is calculated based on an equation that incorporates the desired percentage to become a cluster-head in the current round from the set of nodes that have not been selected as a cluster-head in the last (1/P) rounds. The threshold value is given by:

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

Where,

G-It is the set of nodes that are involved in the CH election.
T(n)- a threshold value
p- Predetermined fraction of nodes
r- Current round

Each elected CH broadcasts an advertisement message to the rest of the nodes in the network that they are the new cluster-heads. All the non-cluster head nodes, after receiving this advertisement, decide on the cluster to which they want to belong to. This decision is taken based on the signal strength of the advertisement. The non-cluster-head nodes inform the appropriate cluster-heads that they will be a member of the cluster. After receiving all the messages from the nodes that would like to be included in the cluster and based on the number of nodes in the cluster, the cluster-head node creates a TDMA (i.e., Time Division Multiple Access) schedule and assigns each node a time slot when it can transmit. This schedule is broadcast to all the nodes in the cluster. During the steady state phase, the sensor nodes can begin sensing and transmitting data to the cluster-heads. The cluster-head node, after receiving all the data, aggregates it before sending it to the base-station. After a certain time, which is determined a priori, the network goes back into the setup phase again and enters another round of selecting new CH. Each cluster communicates using different CDMA codes to reduce interference from nodes belonging to other clusters.

4.1.5. Advanced LEACH (A-LEACH)[21]: LEACH protocol suffers with the problem that Cluster Head node spends the more energy in comparison to others. (ALEACH) is a clustering-based protocol architecture where nodes make autonomous decision without any central intervention. ALEACH proposes a new cluster head selection algorithms that enables selecting best suited node for cluster head, algorithms for adaptive clusters and rotating cluster head positions to evenly distribute the energy load among all the nodes. ALEACH improves the threshold equation of LEACH by introducing two terms: General probability (Gp) and Current State probability (CSp).

$$T(n) = G_p + CS_p$$

$$= \frac{k}{N - k(r \bmod \frac{N}{k})} + \frac{E_{current}}{E_{n-max}} \times \frac{k}{N}$$

Where, k= Expected number of cluster heads in a round, N= Total number of nodes in the networks, r=Current round, Ecurrent =Current energy, En−max= Initial energy.

Hence ALEACH improves system life time and energy efficiency in terms of different simulation performance metrics.

4.1.6 Multi-hop hop routing- Low energy adaptive clustering hierarchy (MR-LEACH) [22]: MR-LEACH partitions the network into different layers of clusters. Cluster heads in each layer collaborates with the adjacent layers to transmit sensor's data to the base station. Ordinary sensor nodes join cluster heads based on the Received Signal Strength Indicator (RSSI). The transmission of nodes is controlled by a Base Station (BS) that defines the Time Division Multiple Access (TDMA) schedule for each cluster-head. BS selects the upper layers cluster heads to act as super cluster heads for lower layer cluster heads.

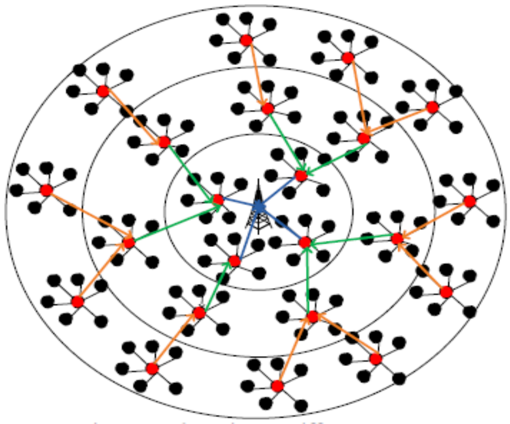

Fig.7: Clustering at Different Layers

Thus, MR-LEACH follows multi-hop routing from cluster-heads to a base station to conserve energy, unlike the LEACH protocol to achieve significant improvement in the LEACH protocol and provides energy efficient routing for WSN.

4.1.7. Re-Cluster-LEACH [23]: Re-cluster-LEACH protocol based on nodes density, which considers the density of nodes inside the cluster[24] and adopts the mechanisms like the cluster-based data fusion, the second selection of cluster head and appropriate multi-hop algorithm to optimize the protocol. It makes relatively big improvements to the LEACH protocol in terms of cluster head selection and cluster structure. The stable data transmission still uses TDMA and CDMA in LEACH protocol.

4.1.8. Fixed number of Cluster- Low energy adaptive clustering hierarchy (LEACH-F) [25]: It is an algorithm in which the number of clusters will be fixed throughout the network lifetime and the cluster heads rotated within its clusters. Steady state phase of LEACH-F is identical to that of LEACH. LEACH-F may or may not be provided energy saving and this protocol does not provide the flexibility to sensor nodes mobility or sensor nodes being removed or added from the sensor networks.

4.1.9. Balanced- Low energy adaptive clustering hierarchy (LEACH-B) [26]: It is a decentralized algorithms of cluster formation in which sensor node only knows about own position and position of final receiver and not the position of all sensor nodes. LEACH-B operates in following phases: Cluster head selection algorithm, Cluster formation and data transmission with multiple accesses. Each sensor node chooses its cluster head by evaluating the energy dissipated in the path between final receiver and itself. It provides better energy efficiency than LEACH.

4.1.10.Energy–LEACH [27]: E- LEACH provides improvement in selection of cluster heads of LEACH protocol. It makes residual energy of the node as the main factor which decides whether these sensor nodes turn into the cluster head or not in the next round. This protocol provides longer network life time and energy saving compared to LEACH protocol.

4.1.11. Hybrid Energy-Efficient Distributed Clustering (HEED): HEED extends the basic scheme of LEACH by using residual energy and node degree or density as a metrics for cluster selection to achieve power balancing [28]. It operates in multi-hop networks, using an adaptive transmission power in the inter-clustering communication. HEED was proposed with four primary goals namely.

1) Prolonging network lifetime by distributing energy consumption,
2) Terminating the clustering process within a constant number of iterations,
3) Minimizing control overhead, and
4) Producing well-distributed CHs and compact clusters.

In HEED, the proposed algorithm periodically selects CHs according to a combination of two clustering parameters. The primary parameter is their residual energy of each sensor node (used in calculating probability of becoming a CH) and the secondary parameter is the intra-cluster communication cost as a function of cluster density or node degree (i.e. number of neighbours). The primary parameter is used to select an initial set of CHs while the secondary parameter is used for breaking ties requires several rounds. Every round is long enough to receive messages from any neighbour within the cluster range. As in LEACH, an initial percentage of CHs in the network (Cprob) is predefined but in HEED the parameter Cprob is only used to limit the initial CH announcements and has no direct impact on the final cluster structure. Hence each sensor node sets the probability CH probof becoming a CH as CH prob= Cprob * Eresidual / Emax .Where Eresidualis the estimated current residual energy in this sensor node and Emax is the maximum energy corresponding to a fully charged battery, which is typically identical for homogeneous sensor nodes. A CH is either a tentative CH, if its CH prob is<1, or a final CH, if its CH prob has reached. During each round of HEED, every sensor node that never heard from a CH elects itself to become a CH with probability CH prob. The newly selected CHs are added to the current set of CHs. If a sensor node is selected to become a CH, it broadcasts an announcement message as a tentative CH or a final CH. A sensor node hearing the CH list selects the CH with the lowest cost from this set of CHs. Every node then doubles its CH proband goes to the next step. If a node completes the HEED execution without electing itself to become a CH or joining a cluster, it announces itself as a final CH. A tentative CH node can become a regular node at a later iteration if it hears from lower cost CH. Here, a node can be selected as a CH at consecutive clustering intervals if it has higher residual energy with lower cost.

In HEED, the distribution of energy consumption extends the lifetime of all the nodes in the network, thus sustaining stability of the neighbour set. Nodes also automatically update their neighbour sets in multi-hop networks by periodically sending and receiving messages. The HEED clustering improves network lifetime over LEACH clustering because LEACH randomly selects CHs (and hence cluster size)., which may result in faster death of some nodes. The final CHs selected in HEED are well distributed across the network and the communication costs minimized. However, the cluster selection deals with only subset of parameters, which can possibly impose constraints on the system. These methods are suitable for prolonging the network lifetime rather than for the entire needs of WSN.

4.2. Homogeneous Non-Clustered Routing Protocol

4.2.1. COUGAR: COUGAR is an example of a data-centric approach which treats the whole network as a huge distributed database system and use declarative queries in order to abstract query processing from the network layer functions such as selection of relevant sensors [29]COUGAR makes use of in-network data aggregation to obtain more energy savings. The abstraction is supported through an additional query layer that lies between the network and application layers. COUGAR includes architecture for the sensor database system where sensor nodes select a leader node among themselves to perform aggregation and transmit the data to the BS. The BS is responsible for generating a query plan, which specifies the necessary information about the data flow and in-network computation for the incoming query and send it to the relevant nodes. The query plan also describes how to select a leader for the query. The architecture provides in-network computation ability that can provide energy efficiency in situations when the generated data is huge independent methods for data query. However, COUGAR has some drawbacks. First, the addition of query layer on each sensor node may add an extra overhead in terms of energy consumption and memory storage. Second, to obtain successful in-network data computation, synchronization among nodes is required (not all data are received at the same time from incoming sources) before sending the data to the leader node. Third, the leader nodes should be dynamically maintained to prevent them from being hot-spots (failure prone).

4.2.2 ACQUIRE (Active Query Forwarding in Sensor Networks): This algorithm [30] also considers the wireless sensor network as a distributed database. In this scheme, a node injects an active query packet into the network. Neighbouring nodes that detects that the packet contains obsolete information, emits an update message to the node. Then, the node randomly selects a neighbour to propagate the query which needs to resolve it. As the active query progress through network, it is progressively resolved into smaller and smaller components until it is completely solved. Then, the query is returned back to the querying node as a completed response.

4.2.3. Sensor Protocols for Information via Negotiation (SPIN): The SPIN family of protocols uses data negotiation and resource-adaptive algorithms[31]. SPIN efficiently disseminates information among sensors in an energy-constrained wireless sensor network. This enables a user to query any node and get the required information immediately. Nodes running a SPIN communication protocol name their data using high-level data descriptors, called meta-data. They use meta-data negotiations to eliminate the transmission of redundant data throughout the network. These protocols work in a time-driven approach and distribute the information all over the network, even if a user does not request any data. There are three messages defined in SPIN to exchange data between nodes. These are:

a) ADV message to allow a sensor to advertise a particular meta-data,

b) REQ message to request the specific data and

c) DATA message that carry the actual data.

There are two protocols in the SPIN family: SPIN-l (or SPIN-PP) and SPIN-2 (or SPIN-EC) .While SPIN-l uses a negotiation mechanism to reduce the consumption of the sensors, SPIN-2 uses a resource-aware mechanism for energy savings. Both protocols allow the sensors to exchange information about their sensed data, thus helping them to obtain the data they are interested in. SPIN-l is a three-stage handshake protocol by which the sensors can disseminate their data. This protocol applies for those networks using point-to-point transmission media (or point-to-point networks), in which two sensors can communicate exclusively with each other without interfering with other sensors. SPIN-BC improves SPIN-PP by using one-to-many communication instead of many one-to-one communications. It is a three-stage handshake protocol for broadcast transmission media, where the sensors in a network communicate with each other using a single shared channel. SPIN-2 differs from SPIN-l in that it takes into account the residual energy of sensors. If the sensors have plenty of energy, SPIN-2 is identical to SPIN-l, and hence has the same three stages. However, when a sensor has low residual energy, it controls its participation in a data dissemination process. While the family of SPIN protocols applies to lossless networks, it can be slightly updated to apply to lousy or mobile networks.

Advantages of SPIN:

a) In SPIN, topological changes are localized since each node needs to know only its single-hop neighbours.

b)SPIN gives a factor of 3.5 less than flooding in terms of energy dissipation

c) Meta-data negotiation almost halves the redundant data.

Disadvantages of SPIN:

a)SPIN's data advertisement mechanism cannot ensure permanently the delivery of data. For instance, if the nodes that are interested in the data are far away from the source node and the nodes between source and destination are not interested in that data, such data will not be delivered to the destination at all.

b) SPIN is not a good choice for applications such as intrusion detection, which require reliable delivery of data packets over regular intervals.

4.2.4. SPEED(Stateless Protocol for End-to-End Delay): It is an example of QoS routing protocol for sensor networks that provides soft real-time end-to-end guarantees[32]. This protocol requires each node to maintain information about its neighbours and uses geographic forwarding technique to find the paths. In addition, SPEED tries to ensure a certain speed for each packet in the network so that each application can roughly calculate the end-to-end delay for the packets by dividing the distance to the Base station by the speed of the packet. Moreover, SPEED can provide congestion avoidance when the network is congested. SPEED maintains a desired delivery speed across sensor networks by both diverting traffic at the networking layer and locally regulating packets sent to the MAC layer. SPEED aims at providing a uniform packet delivery speed across the sensor network, so that the end-to-end delay of a packet is proportional to the distance between the source and destination. With this service, real-time applications can estimate end-to-end delay before making admission decisions.

The routing module in SPEED is called Stateless Non-Deterministic Geographic forwarding (SNGF) and works with four other modules at the network layer. The beacon exchange mechanism collects information about the nodes and their location. Delay estimation at each node is basically made by calculating the elapsed time when an ACK is received from a neighbour as a response to a transmitted data packet. By looking at the delay values, SNGF selects the node that meets the speed requirement. If it fails, the relay ratio of the node is checked, which is calculated by looking at the miss ratios of the neighbours of a node (the nodes which could not provide the desired speed) and is entered into the SNGF module. SPEED does not consider any further energy metric in its routing protocol. Therefore, for more realistic understanding of SPEED's energy consumption, there is a need for comparing it to a routing protocol, which is energy-aware.

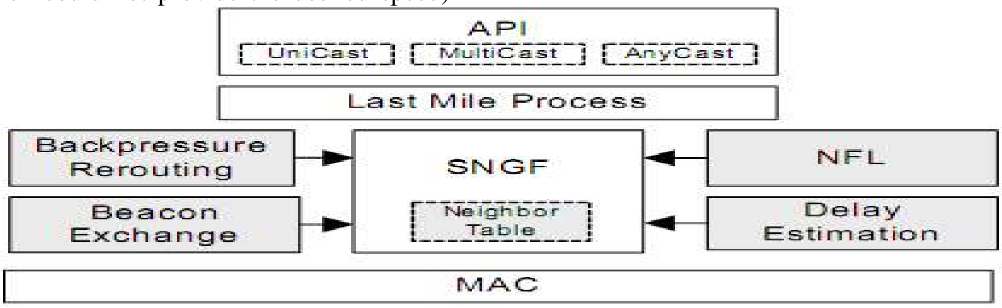

Fig.8: SPEED Protocol

4.2.5. Geographic and Energy-Aware Routing (GEAR): GEAR is an energy-efficient routing protocol which has been proposed for routing queries to target regions in a sensor field. In GEAR, the sensors are supposed to have localization hardware equipped with it, for example, a GPS unit or a localization system so that they can know their current positions [33]. Furthermore, the sensors are aware of their residual energy as well as the locations and residual energy of each of their neighbours. GEAR uses energy aware mechanism that is based on geographical information to select sensors to forward a packet towards its destination region. Then, GEAR uses a recursive geographic forwarding algorithm to spread widely the packet inside the target region. There are two phases in the algorithm designed for GEAR:

1) Forwarding packets towards the target region: As soon as a node receives a packet, it checks its neighbours to see if there is any neighbour, which is closer to the target region than itself. If there is more than one, the nearest neighbour to the target region is selected as the next hop. If they are all further than the node itself, this means there is a hole. In this case, one of the neighbours is picked to forward the packet based on the learning cost function.

2) Forwarding the packets within the region: If the packet has reached the region, it can be diffused in that region by either recursive geographic forwarding or restricted flooding. Restricted flooding is good when the sensors are not densely deployed. In case of high density of sensors, recursive geographic flooding is used which is more energy efficient than restricted flooding. In that case, the region is divided into four sub regions and four copies of the packets are created. This splitting and forwarding process continues until the regions are left where there is only one node.

4.2.6. Geographic Adaptive Fidelity (GAF): GAF is an energy-aware routing protocol which has been mainly proposed for MANETs, but can also be used for WSNs because it deals with energy conservation [34]. The design of GAF is based on an energy model that considers energy consumption due to the reception and transmission of packets as well as idle (or listening) time, when the radio of a sensor is to detect the presence of incoming packets. GAF is based on mechanism of turning off unnecessary sensors while keeping a constant level of routing fidelity (or uninterrupted connectivity between communicating sensors).It has three types of states in GAF a)Discovery state, b) Active state and c) Sleeping state

GAF uses discovery messages to learn about other sensors in the same grid. Even in the active state, a sensor periodically broadcasts its discovery message to inform equivalent sensors about its state. The time spent in each of these states can be tuned by the application depending on several factors, such as its needs and sensor mobility. GAF aims to maximize the network lifetime by reaching a state where each grid has only one active sensor based on sensor ranking rules. The ranking of sensors is based on their residual energy levels. Thus, a sensor with a higher rank will be able to handle routing within their corresponding grids. For example, a sensor in the active state has a higher rank than a sensor in the discovery state. A sensor with longer expected lifetime has a higher rank. In GAF, sensor field is divided into grid squares and every sensor uses its location information, which can be provided by GPS or other location systems to relate itself with a particular grid in which it resides. This kind of association is exploited by GAF to identify the sensors that are equivalent from the perspective of packet forwarding As shown in Fig.9 below, the state transition diagram of GAF has three states, namely, discovery, active, and sleeping. When a sensor enters the sleeping state, it turns off its radio for energy savings. In the discovery state, a sensor exchanges discovery

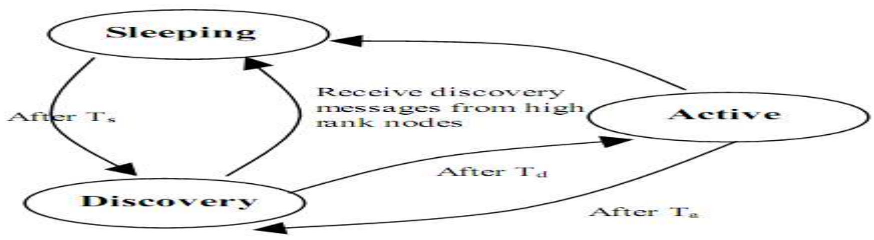

Fig.9: State transition in GAF

4.2.7. Directed Diffusion:
Directed Diffusion is a data-centric paradigm. Data generated by sensor nodes is named by attribute-value pairs. A node that demands the data generates a request where an interest is specified according to the attribute-value based scheme defined by the application. The sink usually injects an interest in the network for each application task [35]. The nodes update an internal interest cache with the interest messages received. The nodes also keep a data cache where the recent data messages are stored. This structure helps on determining the data rate. On receiving this message, the nodes establish a reply link to the originator of the interest. This link is called gradient and it is characterized by the data rate, duration and expiration time. Additionally, the node activates its sensors to collect the intended data. The reception of an interest message makes the node establish multiple gradients (or first hop in a route) to the sink. In order to identify the optimum gradient, positive and negative reinforcements are used. This algorithm works with two types of gradients: exploratory and data gradients. Exploratory gradients are intended for route set-up and repair whereas data gradients are used for sending real data.

4.2.8. SAR: SAR [36] is the first protocols for wireless sensor networks that provide the notion of QoS routing criteria. It is based on the association of a priority level to each packet. Additionally, the links and the routes are related to a metric that characterizes their potential provision of quality of service. This metric is based on the delay and the energy cost. Then, the algorithm creates trees rooted at the one-hop neighbours of the sink. To do so, several parameters such as the packet priority, the energy resources and the QoS metrics are taken into account. The protocol must periodically recalculate the routes to be prepared in case of failure of one of the active nodes. Although, this ensures fault-tolerance and easy recovery, the protocol suffers from the overhead of maintaining the tables and states at each sensor node especially when the number of nodes is huge.

4.2.9. Rumor routing: Rumor routing [37] is a variation of directed diffusion which attempts to combine characteristics of event flooding (classic flooding) and query flooding (directed diffusion).The key idea is to route the queries to the nodes that have observed a particular event rather than flooding the entire network to get the information about the occurring events. In order to flood events through the network, the rumor routing algorithm employs long-lived packets, called agents. In this scheme, each node maintains a list of neighbours and an event table. When a node detects an event, it adds such event to its event table, and generates an agent. Agent travels the network in order to propagate information about local events to distant nodes. When a sink generates a query for an event, the nodes that know the route, may respond to the query by inspecting its event table. Hence, there is no need to flood the whole network, which reduces the communication cost. Rumor routing maintains only one path between source and destination as opposed to directed diffusion where data can be routed through multiple paths at low rates.

4.3. Heterogeneous Clustered Routing Protocol

4.3.1. Self Organizing Protocol (SOP): Self-organizing protocol (SOP)[38] is heterogeneity based routing protocol. In this approach, some sensors sense the environment and forward the data to a designated set of nodes that act as routers. Router nodes are stationary and form a backbone for communication. Collected data are forwarded through the routers tithe more powerful BS nodes. Sensing nodes can be identified through the address of the router node they are connected to. The routing architecture is hierarchical where groups of nodes are formed and merged when needed. Local Markov Loops (LML) algorithm, which performs a random walk on spanning trees of a graph, is used to support fault tolerance and as a medium for broadcasting. Here sensor nodes can be addressed individually, and hence it is suitable for applications where communication to a particular node is required. The algorithm for self organizing the router nodes and creating the routing tables consists of four phases:

• Discovery phase: The nodes in the neighbourhood of each sensor are discovered.

• Organization phase: Groups are formed and merged by forming a hierarchy. Each node is allocated an address based on its position in the hierarchy. Routing tables of size O(log N) are created for each node. Broadcast trees that span all the nodes are constructed.

• Maintenance phase: Updating of routing tables and energy levels of nodes is made in this phase. Each node informs the neighbours about its routing table and energy level. LML are used to maintain broadcast trees.

• Self-reorganization phase: In case of partition or node failures, group reorganizations are performed.

The proposed algorithm utilizes the router nodes to keep all the sensors connected by forming a dominating set. The major advantage of using the algorithm is the small cost of maintaining routing tables and keeping routing balanced. The disadvantage is in the organization phase of algorithm, which is not on-demand. Furthermore, this algorithm incurs a small cost for maintaining routing tables and maintaining a balanced routing hierarchy. Therefore, it may cause extra overhead.

4.3.2. Cluster-Head Relay Routing (CHR)

CHR routing protocol [39] uses two types of sensors to form a heterogeneous network with a single sink: a large number of low-end sensors, denoted by L-sensors, and a small number of powerful high-end sensors, denoted by H-sensors. Both types of sensors are static and aware of their locations using some location service. Moreover, those L- and H-sensors are uniformly and randomly distributed in the sensor field. Within a cluster, the L-sensors are in charge of sensing the underlying environment and forwarding data packets originated by other L-sensors towards their cluster head in a multichip fashion. The H-sensors, on the other hand, are responsible for data fusion within their own clusters and forwarding aggregated data packets originated from other cluster heads toward the sink in a multichip fashion using only cluster heads. While L-sensors use short-range data transmission to their neighbouring H-sensors within the same cluster, H-sensors perform long-range data communication to other neighbouring H-sensors and the sink.

4.3.3. Information-driven sensor querying (IDSQ) Information Driven Sensor Query (IDSQ) [39] [40] is heterogeneity based routing protocol which is used in real world application with positive result. It addresses the problem of heterogeneous WSNs of maximizing information gain and minimizing detection latency and energy consumption for target localization and tracking through dynamic sensor querying and data routing. To improve tracking accuracy and reduce detection latency, communication between sensors is necessary and consumes significant energy. In order to conserve power, only a subset of sensors need to be active when there are interesting events to report in some parts of the network. The choice of a subset of active sensors that have the most useful information is balanced by the communication cost needed between those sensors. In IDSQ protocol, first step is to select a sensor as leader from the cluster of sensors. This leader will be responsible for selecting optimal sensors to make "belief system" based on some information utility measure. From this it determines which node might be the next best one to investigate (say a node it believes is closer to the measurement to be made), and then passes its information to that node and declares it to be the new leader.

The algorithm is as follows:

1. The nodes sit in idle mode but wake up to sense any change in the environment.
2. If a change is detected then a leader node is elected (the one with the best sense of the change detected).
3. The leader node creates a "belief state" which contains the best known information at the time.
4. The leader node creates a group of nodes to collaborate with and disables other nodes from becoming leader.
5. The leader node propagates the belief state to the next best node and passes "leadership" status to it.

Since most nodes sit in an idle state making occasional detections, this state must be energy-efficient for the nodes. Some networks may elect multiple leader nodes as the information propagates throughout the system. Through a series of messages, a leader node can try and suppress other groups from forming. This technique works well with object tracking because the nature of the application focuses on a subset of the nodes in a group. As the object moves through the network, the "leader" node can pass its information along to other nodes without having to rely on a centralized repository of information. The key idea is to introduce an information utility measure to select which sensors to query and to dynamically guide data routing. This maximizes information gain while minimizes detection latency and bandwidth consumption for tasks such as localization and tracking.

4.3.4. Heterogeneous- Low energy adaptive clustering hierarchy(LEACH-HPR)[41]: LEACH-HPR is a energy efficient cluster head election method and using the improved Prim algorithm to construct an inter-cluster routing in the heterogeneous WSN. It considered three types of sensor nodes having different energy resources. It uses the minimum spanning tree algorithm to construct an inter-cluster routing. LEACH-HPR is more efficient to reduce and balance energy consumption and hence enhance the lifetime of WSN

4.4. Heterogeneous Non-Clustered Routing Protocol

4.4.1. CADR:

Constrained Anisotropic diffusion routing (CADR)[39] is a general form of Directed Diffusion which deploys two types of nodes, namely line-powered sensors which have no energy constraint, and the battery-powered sensors having limited lifetime. CADR diffuses queries by using a set of information criteria to select which sensors can get the data. This is achieved by activating only the sensors that are close to a particular event and dynamically adjusting data routes. In CADR, each node evaluates an information/cost objective and routes data based on the local information/cost gradient and end-user requirements. Since CADR diffuses queries by using a set of information criteria to select which sensors to get the data, simulation results confirmed that it is more energy efficient than Directed Diffusion where queries are diffused in an isotropic fashion, reaching nearest neighbours first.

5. Conclusion

Routing protocols in WSNs is still an area of research as sensor nodes are finding newer and newer applications with time. The growth in the fields of pervasive and ubiquitous computing coupled with the advances in the field of Nano technology have raised new routing challenges which the researcher community has to overcome[2],[42],[43]. In this paper, we have classified routing protocols on the basis of homogeneity and heterogeneity of sensor nodes in the area of deployment. This gives an opportunity for researchers to further explore these algorithms in those domains where work has not been done. Also we presented an overview of various routing protocols with emphasis on Data aggregation, support for query and scalability of the network all of which are important area of research.

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