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A Comprehensive Review of Cluster Based Energy Efficient Routing Protocols for Wireless Sensor Networks

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ABSTRACT

In recent times wireless sensor networks have grown enormously and become progressively attractive in wide variety of applications because of their low cost, low power, small in size, self-organizing behavior in harsh environments. Routing is a vital technology in WSN. There are many routing protocols like: location based, multipath, data centric, mobility based, hierarchical routing, hybrid routing etc. Clustering is used to prolong the lifetime of the wireless sensor networks. Clustering is the process where sensing area is divided in groups to balance the energy level of sensor nodes known as clusters. An Optimal Clustering technique can reduce the energy consumption in WSN and increase the lifetime of the network. Energy is the main consideration when we analyze routing protocols for WSN. In this paper we present the study of different clustering based energy efficient routing protocols of wireless sensor networks and compared them on various parameters.

Keywords: Routing Protocols, Energy Efficient, Network lifetime and Base Station (BS).

1. INTRODUCTION

In these days, wireless sensor network emerging as a promising and interesting area. Homogeneous and Heterogeneous nodes are used in wireless sensor network where a wireless medium is used by the nodes to communicate with each other. A hundred to thousands of nodes can be deployed in the sensing region to sense the environment. These nodes work cooperatively and send sensed information to the sink. Wireless sensor network can be categorized into two types:

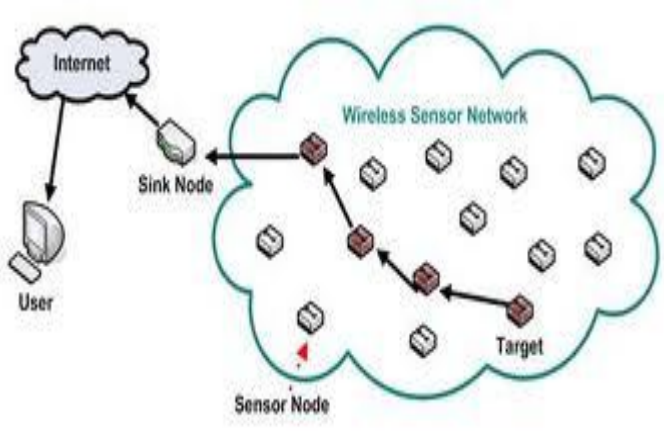

Figure 1 Basic Architecture of Wireless Sensor Network

1 Unstructured WSN- The nodes are densely deployed and also the nodes can be deployed in ad-hoc manner in the sensing area or region. 2 Structured WSN – Sensor node developments of some or all nodes are preplanned. The nodes placement is also planned. So, the maintenance of structured WSN is much easy as compare to Unstructured WSN [1]. Sensor nodes work cooperatively to monitor environment conditions such as temperature, sound, vehicular movement, pressure and pollutants. The sensor nodes are deployed in the sensing area through wireless links which provide opportunities for many civilian and military applications, for example: intrusion detection, battlefield monitoring and availability of equipments, environment observation and home intelligence.

Basically a sensor node is made by four components: a sensing unit, a processing unit, a communication unit, a power unit. A sensing unit is made up of one or many sensors and analog to digital convertor. Where the sensor nodes sense the physical phenomenon and generate the analog signal. Than the ADC convert these analog signal in digital signals which are sensed by the sensors. After the conversion of the signals they are fed into processing unit. The processing unit has limited memory (storage) and processor (microprocessor) provides full control to sensor nodes. A communication unit use radio for data transmission b/w nodes. The most important component or unit of a sensor node is power unit which supply power to the nodes. There can be more components or units can be added to the sensor node, depending on different applications.

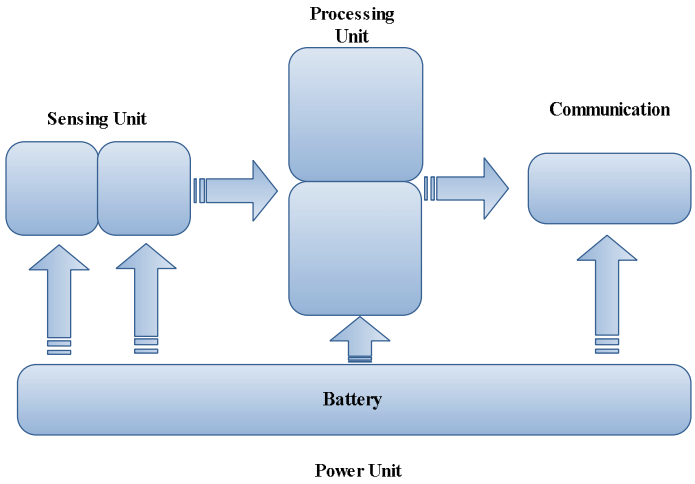

Figure 2 Components of Sensor Node

In some specific application where we need the location information, there we use global positioning system (GPS) in nodes. Some specific applications need to move the sensor nodes, than the motor can be used as a component or unit in a node. These units should be small so that power consumption will be less [5].

The sensor nodes are grouped for local aggregation i.e. called clustering. When the sink is far away from the sensing region then the local aggregation is much better than direct communication. Thus clustering works efficiently in those conditions or environments which aggregates the nodes into clusters. There is only a one cluster head for a cluster. Cluster heads can be chosen by sink or members of the clusters. Cluster heads serve as relays for transmitting the data to the sink. The cluster head of the cluster have the same transmission capacity as the sensor nodes. Data aggregation at cluster head reduces the number of data transmission to the sink and improves energy efficiency and lifetime of the network.

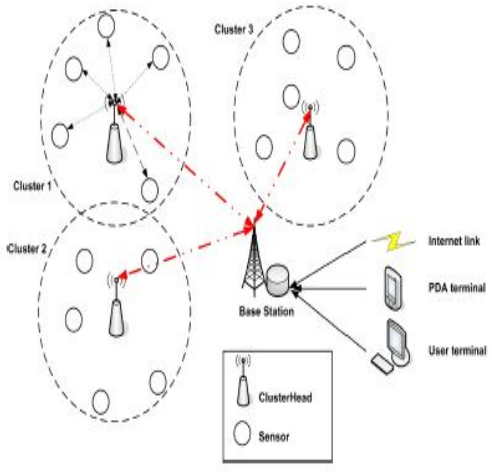

Figure 3 Clustering Process in WSN [7]

Given the importance of clustering for WSNs, The remainder of the paper is organized in follows: Section 2 presents overview of literature review on clustering routing methods in WSNs. Section 3 presents the working of clustering and classification of clustering protocols in WSNs. Section 4 presents some energy efficient clustering protocols. Section 5 presents the comparison of different energy efficient clustering protocols. 6 present the conclusion of the paper and future research.

2. LITERATURE REVIEW

Many research works have been proposed to deal with nodes energy limitation problems. Jiang et al. [33] present a classification of WSN clustering schemes and also analyzed altogether six popular WSN clustering algorithms, such as LEACH, PEGASIS, EEUC and compared these WSN clustering algorithms, including various attributes. Arboleda *et al*. [34] presented a comparison survey between different clustering protocols. The authors of the survey discussed some basic concepts related to the clustering process, such as cluster structure, cluster types, clustering advantages. Maimour et al. [35] discussed clustering routing protocols to achieve energy efficiency in WSNs and presented a review on clustering algorithms from the perspective of data routing. Numbers of routing schemes have been proposed for wireless sensor network. Mainly these are three types of routing schemes.

1. Block Based - UCS[2], EECS[4], CCM[6], HCTE[7].
2. Grid Based - PANEL[8], TTDD[9], SLGC[31].
3. Chain Based – TSC[32].

In this paper, we discuss some energy efficient cluster based routing protocols based on residual energy, average energy, location, density etc.

3. CLUSTERING IN WIRELESS SENSOR NETWORKS

Traditional routing protocols for WSN are not enough optimal in terms of energy efficiency and load balancing. Clustering is introduced to balance the load and increase the lifetime of the network. Clustering is sample of layered protocols where the network is composed of several clusters of sensor nodes. As shown in fig.4, each cluster has a leader node which is also called as cluster head. CH takes data from all the nodes in its cluster. Cluster head aggregate all the data received from cluster members and then send that data to the base station. The transmission between cluster members and cluster head is said to be intra cluster communication, where as the transmission between cluster head and sink is known as inter cluster communication. The local collaboration in clusters, reduce the bandwidth demands. Clustering reduce the routing overhead and make the network more stable [36].

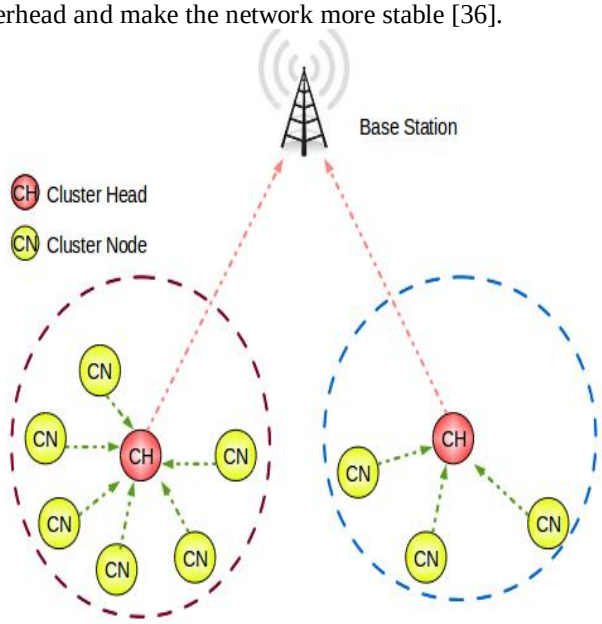

Figure 4 Clustering in WSNs

The set of aspects that are used to differentiate all clustering based protocols are discussed below [3].

3.1 Clustering Method

The three approaches are used for clustering process are centralized, distributed and hybrid. In centralized clustering, the clusters and cluster heads are made by an authority (centralized authority). In distributed clustering, all the nodes in the clusters can took the decision of becoming cluster head for the current round. Hybrid clustering is the mixture of both of above.

3.2 Cluster Properties

In clustering process, following properties are used in the structure of the cluster.

3.2.1 Cluster Count

Cluster heads can be pre assigned for fixed clusters or cluster heads can be elected by its cluster members for variable number of clusters. Cluster count can be defined as no. of clusters formed in a round. Small size cluster distribution can be better to conserve energy in wireless sensor network.

3.2.2 Cluster Size

Cluster size is the maximum distance between the sensor (member) nodes and cluster head. Cluster size can be fixed for fixed clusters or it can be variable for each cluster. Large sized clusters are not good in term of energy consumption because it maximizes transmission distance.

3.2.3 Cluster density

Cluster density is proportion of number of cluster member in cluster and cluster area. In fixed clustering approach, there is sparse density of cluster where as in dynamic clustering the cluster density is variable. So it is a big challenge to conserve energy of cluster heads in dense clusters.

3.2.4 Message count

The number of message transmissions is required for a cluster head selection is called as message count. The cluster heads are chosen using message transmission in many non probabilistic algorithms. If message transmission number is more for a cluster head than the energy consumption also increases.

3.2.5 Stability

During the clustering process if cluster counts are not varied than it is called fixed. But if the cluster counts varied during clustering process than that is called as adaptive. Fixed cluster count gives more stability to the WSN's.

3.2.6 Intra-cluster Topology

The communication between the cluster head and the sensor (member) nodes can be direct or multi-hop. This depends upon the sensor node's range of transmission. If the communication range of sensor node is very high than the node can direct communicate with cluster head (CH). But if the transmissions range of the node is low than the node can communicate with CH using multi-hop.

3.2.7 Inter-cluster head connectivity

The procedure indicates the communication between the CH and the base station (BS). CH has some range or capability to connect to the BS. But if Ch have not that capability than clustering scheme has to ensure some intermediate provision of routing to base station.

3.3 Cluster-head Capabilities

The capabilities of cluster heads during clustering process play very important role. The capabilities of CH's can influence the clustering process in terms of stability and life time of sensor network. Following are some aspects for differentiating the clustering process.

3.3.1 Node Type

Some nodes are pre chosen as cluster heads at the time of sensor nodes deployment for that round only depends upon their energy and computation resources.

3.3.2 Mobility

Mobile CH can be used for balancing the cluster which gives the better network performance. Mobility of CH's in the network cane assigned on the basis of objectives defined in clustering scheme. If there is any need in the network than mobile cluster heads can be re-locatable easily.

3.3.3 Role

The role of CH's in the network is to collect the information from sensor nodes, aggregate that information and send to the base station.

3.4 Cluster-head Selection

Cluster heads can be pre assigned or chosen randomly from deployed sensor network. Following are the two ways to select the cluster head.

3.4.1 Probability Based CH Selection

In probability based clustering algorithm, each sensor node in the network uses pre assigned probability to determine the initial cluster heads. Probability can be the maximum energy of the sensor nodes.

3.4.2 Non Probability Based CH Selection

In non probability based clustering algorithm, the cluster heads selection is based on sensor nodes proximity, connectivity and degree.

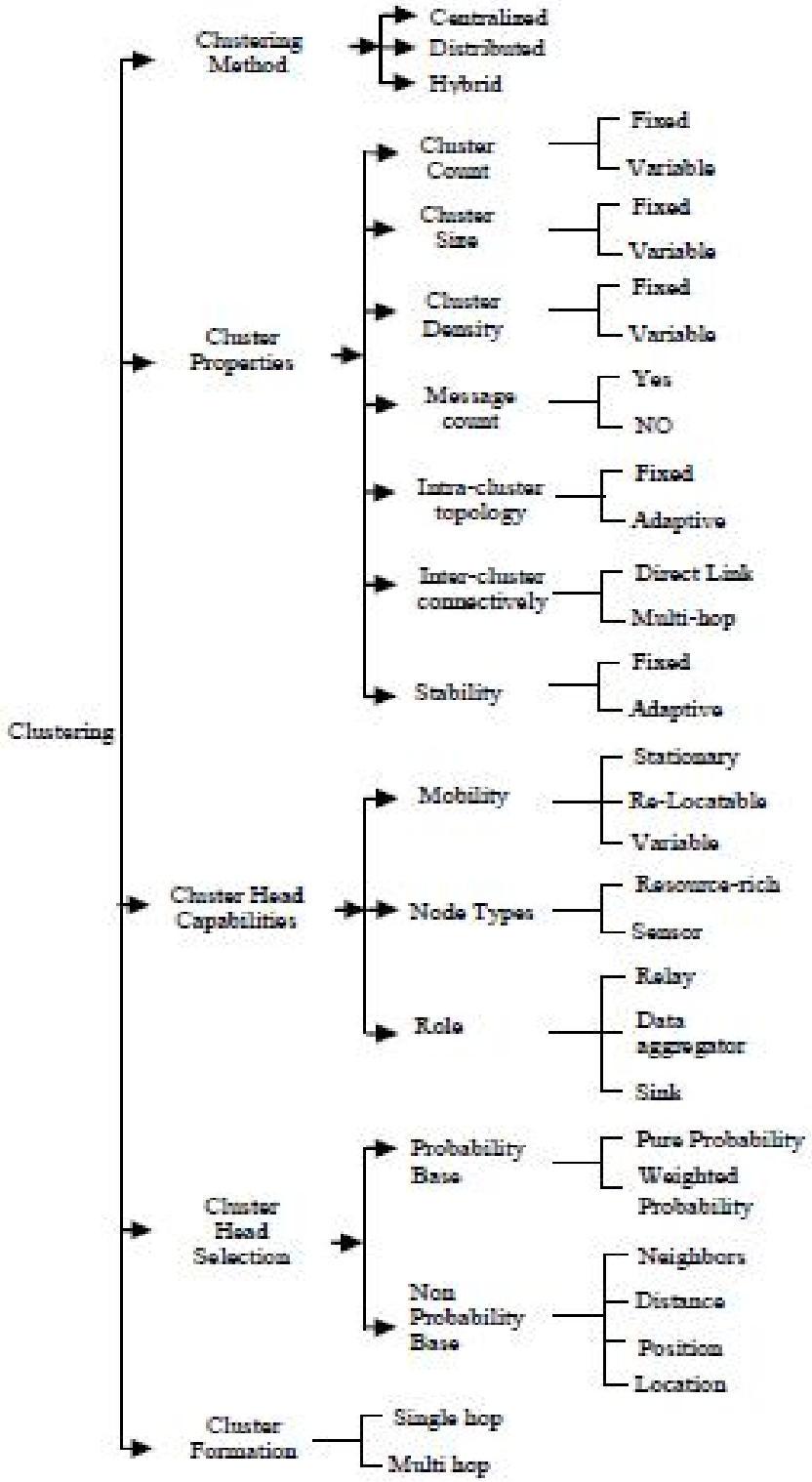

Figure 5 Categorization of the different aspects of clustering in WSN's [3]

3.5 Cluster Formation

In this phase the cluster heads will send the request to all the nodes in its range to form the cluster. After getting request from cluster head, the nodes will send join message to cluster heads. Following is the categorization of different aspects of clustering in sensor network.

3.6 Characteristics desired in Clusters

1. Every node should be in one cluster.

2. Guarantee the total coverage of network.
3. Number of cluster head should be less so that there will be less overlapping of clusters and which will improve energy efficiency.
4. Clustering should be uniform and balanced.

4. ENERGY-EFFICIENT CLUSTERING PROTOCOLS

Sending data from source node to destination node is called routing. In routing process intermediate nodes can also collaboratively participate. The routing can be done hop by hop or end to end. In hop by hop routing the intermediate nodes are used to route the data.

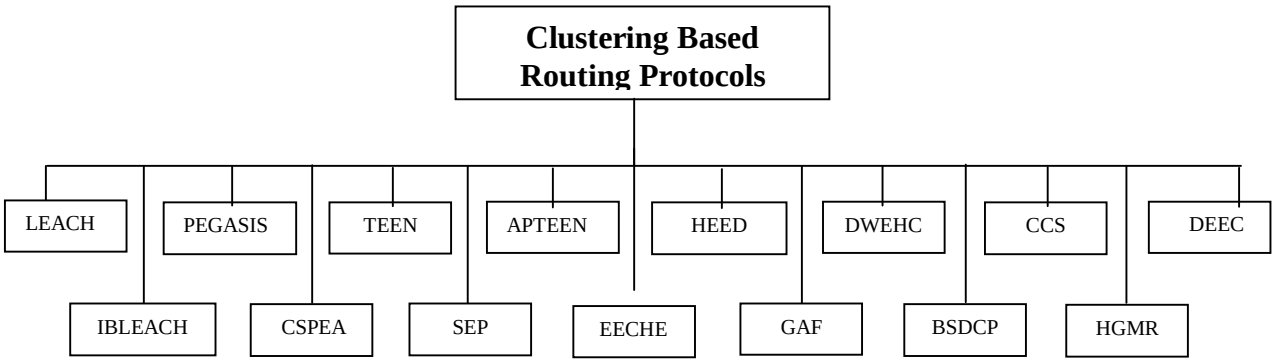

Figure 6 Clustering Based Energy Efficient Routing Protocols

Hop by hop routing is more efficient because in this technique the transmission or retransmission distance is shorter. There are mainly three types of routing: flat based routing, hierarchical based routing, adaptive routing. In flat based routing the entire sensors in the network has same role. In hierarchical based routing all nodes has different role. In adaptive routing, the role of the sensor change according to application.

4.1 Low energy adaptive clustering hierarchical (LEACH)

LEACH is a clustering based protocol. In which the network is divided into clusters. Each cluster has some number of nodes where each cluster has a cluster head. CH is chosen from the nodes in the network based on their receiving signal strength. After each round the cluster head is changes which collects the data from other nodes in the cluster and send the data to the sink. 5 percentage of total number of nodes are chosen as cluster head.

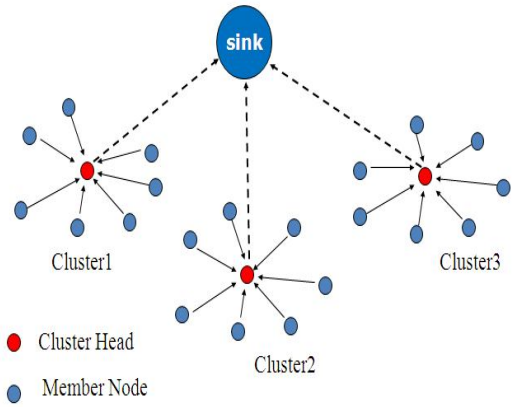

Figure 7 Basic Topology of LEACH

$$T(n) = \begin{cases} \frac{P}{1-P(r \bmod \frac{1}{P})} & \text{if } n \in G \\ 0 \end{cases} \quad (1)$$

The aggregation is performed in each cluster. Each node selects a random value 0 and 1. The nodes whose random value is less than the threshold those nodes are chosen as cluster head for current round only where P=desired percentage of cluster heads, r=current round and G is the set of nodes that have not been cluster heads in the last 1/P rounds. The nodes that are cluster head in round 0 cannot be cluster head for the next 1/P rounds [10]. Various modifications have been

made to the LEACH protocol such as TL-LEACH [11], E-LEACH [12], M-LEACH [13], LEACH-C [14], V-LEACH [15], LEACH-FL [16], W-LEACH [17], T-LEACH [18].

4.2 Threshold-sensitive energy-efficient sensor network protocol (TEEN)

TEEN protocol is used for precipitous changes in the sensed attributes in the network. It uses a data centric mechanism and makes clusters in a hierarchical fashion. Two threshold values are broadcast to the nodes: hard threshold and soft threshold etc. The hard threshold is the minimum possible value of an attribute. Sensor nodes send data to the cluster head only if they found the sensed value is greater than the hard threshold.

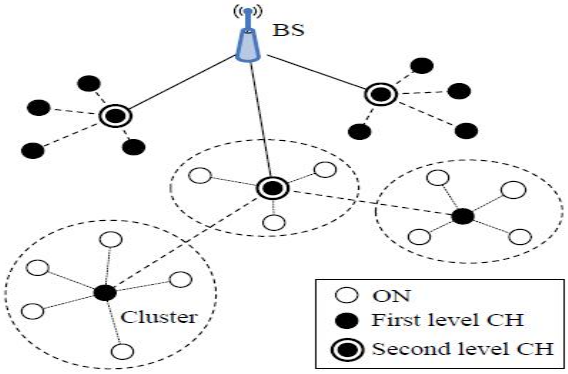

Figure 8 Clustering Topology in TEEN

If sensor nodes found that the sensed value is less than the attribute value of threshold than they do not send the data to the cluster head. By this way only relative data is send by the sensor nodes. Next time when sensor node again sense value greater than the hard threshold value than they check the difference between current and earlier value with soft threshold. If the difference is again greater than the soft threshold than the sensor nodes will send recent sensed data to the cluster head. This process will remove burden from the cluster head [19].

4.3 Adaptive TEEN

This protocol is used to capture the data periodically. Three types of data query are made: historical, one time, persistent etc. In historical, the previous recorded values are analyzed and further decisions are also being taken based on their value (previous value). In one time, the snapshot of current network is taken and also envisioned (visualized). In persistent, when a event takes place than it monitors the network [20].

4.4 Geographic adaptive fidelity (GAF)

It locates nodes in the network and makes the best use of them to have a better fidelity. All the nodes use a location-identification technique to locate itself with its nearest neighbors by using location-information systems like GPS. In GAF, all the nodes arrange themselves according to grids also. All the nodes divide themselves in grids and all nodes which are under a same grid coordinate among themselves to see who will go into sleep state and for how long. Nodes in grid A can communicate with all the nodes in grid B that are adjacent. The time for sleeping is decided or depends on the application. GAF has three state states, discovery, active and sleeping. Every node starts with the discovery state. In this state the node turns on its radio and starts sending discovery messages. A node can fall into sleep state if there are other nodes in the grid which are equivalent in handling the fidelity before falling into the active state. In the active state the node sets a timeout value Ta which shows the remaining amount of time for which a node is intended to stay in active state. A node enters into sleeping state either from the discovery state or from the active state where Td is discovery time, Ta is active time and Ts is sleep time [26].

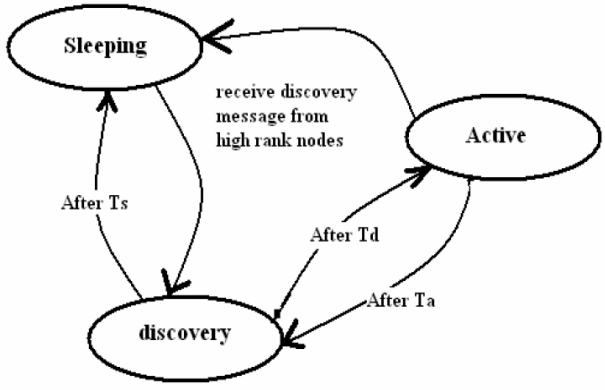

Figure 9 Three State Transitions in GAF

4.5 Constrained shortest path energy aware routing (CSPEA)

Network is divided into clusters where each cluster has a cluster head and a gateway node is used to connect them. Estimation of energy consumption can be made by calculating distance from source to destination. Energy efficiency can be achieved by choosing best path for data routing. It is the best approach because it entails less control packet overhead. In data cycles, the nodes send data to gateway nodes. In routing cycle, the routing state of all sensor nodes is maintained by its cluster head. The transmission power to send data from one node to another node is calculated by distance between sender and receiver nodes. A constraint can be added in this technique i.e. rerouting. This is carried only when; 1.sensor nodes reorganized in the cluster, 2.Battery level of sensor nodes decreases.

4.6 Power-efficient gathering in sensor information system (PEGASIS)

A chain of sensor nodes is made instead of clusters. All the nodes in the chain can transmit and receive data from its neighbor nodes. The node that starts transmitting data is called as an end node. Than the other nodes in the chain starts receiving data and send the data to its next neighbor after aggregating data. This process continues till the last node in the chain which is elected as leader node

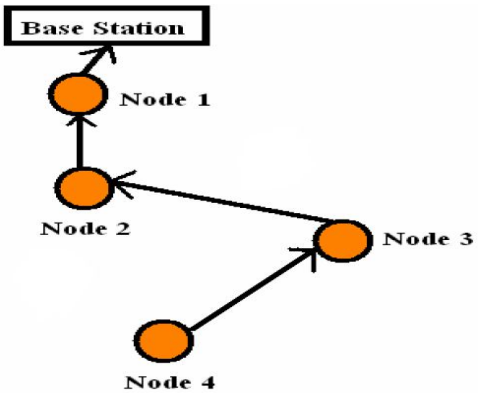

Figure 10 Flows of Data in Chain to BS

Leader node sends data to the sink. Multi-hop routing is done in PEGASIS. There is delay for the nodes which are far away from the leader node in the chain. The bottleneck problem occurs at the leader node. When numbers of transmissions among the non-leader nodes are less than that leads to overall energy efficiency [27].

4.7 Stable election protocol (SEP)

It is improved version of LEACH. It operates like LEACH but the difference in SEP that there are two types of nodes; 1.Normal nodes, 2.Advance nodes which has different level of energy. In SEP, weighted election probabilities are used to select the cluster head from all the sensor nodes according to their energy [29].

4.8 Hierarchical Geographic Multicast Routing (HGMR)

This is location-based multicast protocol. This protocol incorporates the key design concepts of the Geographic Multicast Routing (GMR) and Hierarchical Rendezvous Point Multicast (HRPM) protocols. HGMR decompose the multicast group into subgroup. HGMR apply the local multicast scheme of GMR to forward data packets along multiple branches of the multicast tree in one transmission. In HGMR, the multicast group is divided into subgroups using the mobile geographic hashing: the deployment area is partitioned into a number of equal-sized square sub-domains called cells and each cell comprises a manageably-sized subgroup of members. In each cell there is an Access Point (AP) responsible for all members in that cell, and all APs are managed by a Rendezvous Point (RP) [21].

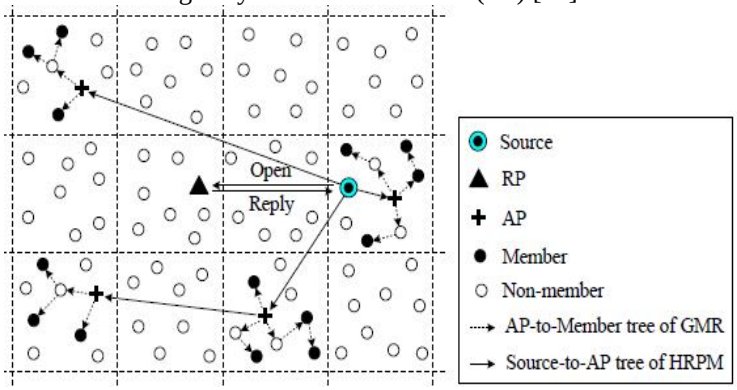

Figure 11 Data Delivery in HGMR

4.9 Distributed energy-efficient clustering (DEEC)

It is also based on LEACH protocol and used for heterogeneous WSN. The network is divided into clusters and each cluster head is chosen by a probability of ratio between residual energy of each node and average energy of the network. DEEC is better than LEACH, SEP because it has longer lifetime [30].

4.10 Distributed Weight-based Energy-efficient Hierarchical Clustering protocol (DWEHC)

DWEHC is very much similar to HEED. DWEHC improves HEED by making balanced cluster sizes and optimize the intra-cluster topology using location awareness of the nodes. Both DWEHC also consider residual energy in the process of CH election. It creates a multi-level structure for intra-cluster communication and limits a parent node's number of children. Each node calculates its weight according to:

$$W_{\text{weight}}(s) = \frac{E_{\text{residual}}(s)}{E_{\text{initial}}(s)} \times \sum_{u} \frac{R-d}{6R} \quad (2)$$

where *E*residual (*s*) and *E*initial (*s*) are respectively residual and initial energy at node *s*, *R* is the cluster range that indicate how far a node is from the CH inside a cluster, and *d* is the distance between node *s* and the neighboring node *u*. The node with largest weight would be elected a CH and the other nodes become members. Mobile Nodes are considered as 1-level nodes and communicate directly with the CH. Energy consumption for communicate in a cluster can be computed according to node's knowledge of the distance to its neighbors. To limit the number of levels, every cluster is assigned a cluster range within which Mobile Nodes should lay. Intra-cluster communication is performed by TDMA. Each children node forwards the data to its parent node until the data reaches the CH. The parent node may aggregates several data packets from its children together with its own data into one packet. For inter-cluster communication, the Cluster heads poll their first-level children, including their own data and transmit to the sink [22].

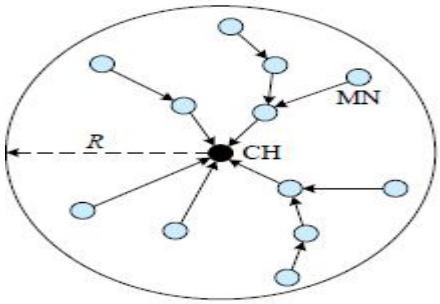

Figure 12 Multilevel Clustering in DWEHC

4.11 Improved and balanced LEACH (IBLEACH)

It is improved version of LEACH. Some high energy nodes declare themselves to be gateway nodes and send ADV (advertisement) messages to other non-gateway nodes. The other non-gateway nodes with maximum energy declare themselves to be cluster head and send ADV messages to non-cluster nodes. The non-cluster nodes can receive two or more ADV requests. A node sends Join-Request to that cluster head which require minimum communication energy. Each node starts their task after the construction of clusters [28].

4.12 Concentric Clustering Scheme (CCS)

Concentric Clustering Scheme reduces the energy consumption loopholes in PEGASIS. CCS considers the location of the BS to enhance the lifetime of the network. In CCS, the network is divided into a variety of concentric circular tracks. Each circular track is assigned with a level. The track nearest to the BS is assigned with level-1 and the level number increases with the increase of the distance to the BS. Each node in the network is assigned with its own level.

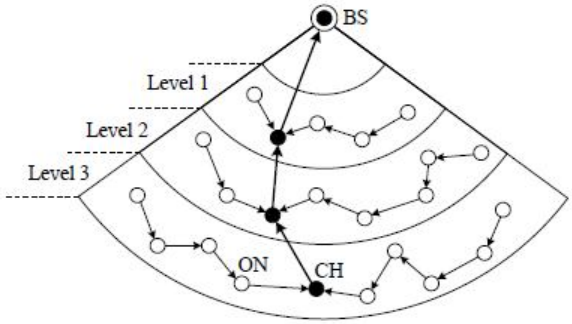

Figure 13 Data Transmission in CCS

Chains are constructed within the track as in PEGASIS. One of the nodes on the chain at each level area is selected as a CH. After CH selection, each CH transmits the data of its own location to both the upper and lower level CH in one grade. In the phase of the data transmission, all nodes transmit the data to the nearest node from themselves along the chain. The node receives the data and aggregates its own data and transmits these data to the next node. CH receives at most two data messages. CH in each level transmits the data to the lower CH and at last, level 1 CH transmits these data to the BS [23].

4.13Energy-efficient cluster head election protocol (EECHE)

It is the improved version of Prim's algorithm. Some sensor nodes use additional energy resources. The cluster head broadcast the TDMA schedule to all sensor nodes and based on that TDMA schedule the sensor nodes participate in the network operations. Otherwise they will turn off their radio when they are not participating. This process minimizes the energy consumption. This protocol reduces energy consumption of those nodes which are far away from the sink and balance the energy consumption which are near to the sink. Routing is done based on the residual energy of the cluster heads.

4.14Hybrid Energy-Efficient Distributed Clustering (HEED)

Hybrid Energy-Efficient Distributed clustering is different from LEACH in the manner of CH election; HEED does not select nodes as CHs randomly. Cluster formation is performed based on the hybrid combination of two parameters. One parameter depends on the node's residual energy and the other parameter is the intra-cluster communication cost. In HEED, elected CHs have relatively high average residual energy compared to member nodes. In HEED, a percentage of CHs among all nodes, *C*prob is set to assume that an optimal percentage cannot be computed a priori. The probability that a node becomes a CH is:

$$CH_{\text{prob}} = C_{\text{prob}} \frac{E_{\text{residual}}}{E_{\max}} \quad (3)$$

where *Eresidual is* the estimated current energy of the node, and *E*max is a reference maximum energy, The value of *CH*prob is not allowed to fall below a certain threshold that is selected to be inversely proportional to *E*max. Afterwards, each node goes through several iterations until it finds the CH. If it hears from no CH, the node elects itself to be a CH and sends an announcement message to its neighbors. There are two types of status that a sensor node could announce to its neighbors: tentative status and final status. If its *CH*prob is less than 1, the node becomes a tentative CH and can change its status to a regular node. If it's *CH*prob has reached 1, the node permanently becomes a CH. In HEED, every node elects the least communication cost CH in order to join it [24].

4.15 Base-Station Controlled Dynamic Clustering Protocol (BCDCP)

This is a centralized clustering routing protocol. In BCDCP the cluster formation is done where each CH serves an almost equal number of mobile nodes to balance cluster head overload. At the beginning of cluster setup, the BS receives information on the residual energy from all the nodes in the network.

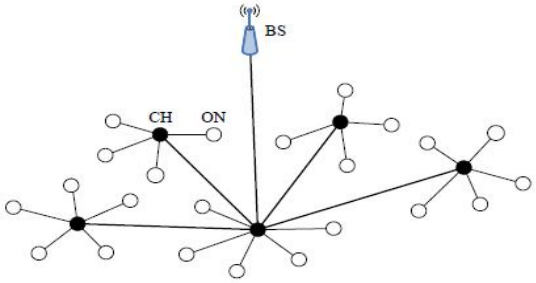

Figure 14 Clustering Topology in BCDCP

Based on the information, the BS computes the average energy level of all the nodes in the network and then chooses a set of nodes whose energy levels are above the average value. Only the nodes from the chosen set can be elected CHs for the current round. Based on the picked set, the BS computes the performs the task of clustering where the network is split into two sub-clusters and proceeds further by splitting the sub-clusters into smaller clusters. This process will be repeated until the desired number of clusters is achieved. BCDCP uses a multi-hop routing scheme to transfer the sensed data to the BS [25].

5. COMPARISON OF CLUSTERING BASED ROUTING PROTOCOLS

Clustering reduce interferences and collision in the network and gives better throughput. In this section, we compare several clustering based routing protocols by different parameters:

Table 1 Comparison of the Clustering Based Routing Protocols for WSN

Protocol Name	Cluster Stability	Delivery Delay	Scalability	Load Balancing	Clustering Method	Algorithm Complexity	Energy Efficiency
LEACH	Medium	Very Small	Very Low	Medium	D	Low	Very Poor
TEEN	High	Small	Low	Good	D	High	Very High
APTEEN	Very Low	Small	Low	Medium	D	Very High	Medium
GAF	Medium	Poor	High	Medium	D	Medium	Medium
CSPEA	Medium	Medium	Very Low	Medium	D	High	High
PEGASIS	Low	Very Large	Very Low	Medium	D	High	Poor
SEP	Medium	Very Small	Medium	Good	D	Very Low	Medium
HGMR	High	Medium	Very High	Poor	D	Low	Poor
DEEC	High	Very Small	High	Good	D	Very Low	High
DWEHC	High	Medium	Medium	Very Good	D	Medium	Very High
IBLEACH	High	Very Small	High	Very Good	D	Medium	Very High
CCS	Low	Large	Poor	Very Poor	D	Medium	Poor
EECHE	Medium	Small	Medium	Very Good	D	Low	Very Good
HEED	High	Medium	Medium	Medium	D	Medium	Medium
BCDCP	High	Small	Very Poor	Good	C	Very High	Very Poor

6. CONCLUSION AND FUTURE RESEARCH

In last few years, energy conservation in wireless sensor networks has become one of the most important research areas. The main objective behind the routing protocol design is to keep sensors alive as much as possible, thus prolonging the lifetime of network. For heterogeneous wireless sensor networks, many energy efficient clustering protocols are proposed which are based on residual energy, density etc. In this paper we have surveyed the past research works which mainly focuses on energy efficient clustering based routing protocols for wireless sensor networks and we have systematically analyzed a few classical WSN clustering routing protocols in deep, and compared these different approaches based some primary metrics. WSN is a broad area so this paper covered only some clustering based routing protocols. Although these routing protocols shows the improvements but still there is possibility of improvements in Wireless sensor networks. Further research would be needed to address issues related to Cluster formation, cluster head communication and data fusion etc.

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