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A Survey of Energy Efficient Clustering Algorithms in Wireless Sensor Networks

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Abstract: ***To make the most of network lifetime in Wireless Sensor Networks (WSNs) the paths for data transfer are chosen in a manner that the total energy utilized along the path is minimized. To support high scalability and better data aggregation, sensor nodes are regularly assembled into disjoint, non overlapping subsets called clusters. Clusters create hierarchical WSNs which incorporate efficient utilization of limited resources of sensor nodes and thus extends network lifetime. The goal of this paper is to show a cutting edge review on clustering algorithms reported in the literature of WSNs. This paper presents various energy efficient clustering algorithms in WSNs.***

Keywords: Clustering, Load balancing, Fault Tolerance, Latency, Data Aggregation, LEACH, PEGASIS, TEEN, HEED.

1. Introduction

A wireless sensor network consists of sensor nodes deployed over a geographical area for monitoring physical phenomena like temperature, humidity, vibrations, seismic events and so on. Typically, a sensor node is a minute device that consists of three components such as a sensing subsystem for data attainment from the physical surrounding environment, a processing subsystem for local data processing and storage and a wireless communication subsystem for data transmission. In addition, an energy source supplies the energy needed by the device to perform the planned task. Energy consumption is one of the biggest constraints of the wireless sensor node and this limitation combined with a typical deployment of large number of nodes has added many challenges to the design and management of wireless sensor networks.

Clustering has proven to be an efficient method that increases the network life time by dropping the energy utilization and provides the necessary scalability. To achieve high scalability and increased energy efficiency and to enhance the network life time the researchers have highly adopted the scheme of forming clusters i.e. grouping the sensor nodes in large scale wireless sensor network environments. Basically, a clustering scheme determines a set of nodes that can provide a backbone to connect the network to the base station. The type of nodes discussed here are called cluster heads and the remaining nodes of the network are referred to as member nodes.

In this clustering scheme the member nodes sporadically transmit there data to the heads of the clusters they belong and it becomes the responsibility of the cluster head to aggregate this data and transmit it to the base station. This transmission can either be direct or via other cluster heads. This scheme eventually creates two level structures where higher level constitutes of the cluster head nodes and the member nodes become a part of lower level hierarchy thereby decreasing the number of relayed packets. A cluster head node has an additional load as it must accept messages from its cluster members, aggregate them, broadcast the aggregated message to the next hop towards the sink and relay the aggregated messages originated by other cluster head nodes. Re-clustering the network is often necessary in order to achieve the load balancing.

Ideal implementation of clustering is always energy efficient if the cluster heads are appropriately positioned therefore the position of cluster head becomes a key criteria in clustering for achieving energy efficiency. In clustering scheme the cluster head nodes are elected from one of the deployed sensors in the network where this network is homogenous in nature [1], [2]. Communication vicinity and distance from base station are major concerns that need to consider while implementing clustering in wireless sensor network. Another key aspect of clustering is the communication between the cluster head and the base station, if this is not direct than multihop routing is required which generates the importance of inter-cluster head connectivity. And also the cluster head should not be exhausted unnecessarily which may otherwise lead to unnecessary loss of energy of cluster head nodes [3], [4].

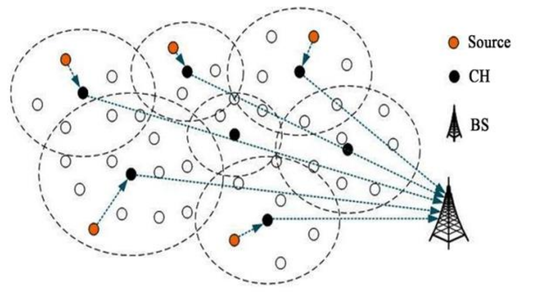

Figure 1: General Sensor Network Architecture

1.1 Clustering Objectives

There are numerous objectives of the clustering which are explained below -

Load Balancing - For improving the life span of the network, the formation of equal sized clusters is essential because it prevents the utilization of the energy of a subset of cluster heads at high rate. Data delay is caused by even distribution of sensor nodes. It is essential to have identical number of sensor nodes in the clusters for the duration of data aggregation so that the full data information is geared up for further processing at the next tier in the network or at the base station almost at the same time.

Fault tolerance - Most of the time the sensor nodes needs to works in harsh and unfriendly environment and the danger of physical harm and break down is increased due to exposed nature of sensor nodes. So, with the aim of avoid the loss of data of the sensor nodes the letdown of cluster heads must be permitted. The one way to recover from the cluster head failure is Re-clustering the network and another way to recover from the cluster head failure is assigning backup cluster heads. Rotation of cluster head is also a good way of managing fault tolerance.

Lesser Energy Consumption - In the clustering, data aggregation helps to considerably decrease the data transmission and save energy. Furthermore, clustering with intra-cluster and inter-cluster communications can lessen the number of sensor nodes performing the job of long distance transmissions, thus allowing a lesser amount of energy spending for the entire network. In adding up, only Cluster Head (CH) execute the task of data communication in clustering routing scheme, which can save a large amount of energy consumption.

Improved Connectivity and Lesser delay - In many applications it is beneficial, if the cluster heads have long range communication abilities otherwise inter cluster head connectivity is definitely required. This is mainly true when cluster heads are chosen from the sensors population. To guarantee the possibility of the route from every cluster head to the base station the aim of connectivity can be limited or restricted the length of the route.

Latency Reduction - When we divide the wireless sensor network into clusters, only the cluster head execute the job of data transmissions out of the cluster. As the mode of data transmissions is out of the cluster it helps in avoiding collisions between the nodes. Therefore latency is also reduced. In addition, data broadcast is performed hop by hop generally using the form of flooding in flat routing scheme, but only CHs complete the job of data communication in clustering routing scheme, which can reduce hops from data source to the base station (BS), hence lessening the latency.

Least cluster count - The purpose of least cluster count is mainly common when cluster heads are specified resource rich nodes. The designer of the network often lies to organize the minimum number of such type of nodes because they are more susceptible and precious than other sensor nodes.

Maximizing the Network Lifetime - In the network where sensor nodes are used in harsh environment the key concern is the life span of the network due to energy constrains character of the sensor nodes. It is vital to reduce the energy utilization for the intra cluster communication when cluster heads are specialized resource loaded nodes. The life span of the cluster heads when they are standard nodes can be enlarged by revolving their roles among the cluster members and restricting their load. For increasing network life adaptive clustering is also feasible [5].

Data Aggregation - The method of aggregating the data from many nodes to eradicate the redundant communication and provide the merged data to the BS is known as Data aggregation, which is an efficient practice for WSNs to save energy as mentioned by [6]. The most accepted data aggregation method is clustering data aggregation, in which each Cluster Head (CH) aggregates the collected data and communicates the merged data to the BS as briefly described by [7]. Generally CHs are shaped as a tree structure to broadcast aggregated data by multi hopping through other CHs which results in important energy savings.

More Robustness - Clustering routing scheme makes it handier for the network topology control and it responds to the network changes. It comprises of node mobility and unpredicted failures, etc. A clustering routing scheme required managing up with these changes within the individual clusters only; therefore the full network is stronger and more convenient for the management. For sharing the Cluster Head (CH) duty the CHs are usually rotated among all the sensor nodes to shun the single point of failure in clustering routing algorithms.

Energy Hole Avoidance - Normally, multi-hop routing is used to carry the gathered data to a sink or a base station. In those networks, the traffic transmitted by each node includes both self-generated and relayed traffic. Regardless of MAC protocols, the sensor nodes closer to the base station have to broadcast more packets than those far away from the BS. Resulting in the nodes nearer to the base station tends to drain their energy first, leaving a hole near the BS, partitioning the whole network and preventing the outside nodes by sending the information to the BS, while many remaining nodes still have a plenty of energy. This phenomenon is called as energy hole and it has been stated by [8].

Collision Avoidance - In wireless sensor networks the resources are generally managed by the individual nodes causes less effectiveness in the resource utilization. While in the multi hop clustering model, a wireless sensor network is separated into clusters and the data communications between the sensor nodes includes two modes known as intra-cluster and inter-cluster, respectively for data gathering and for data transmission. Therefore, the resources can be allocated orthogonally to each cluster to lessen the clash among the clusters and it can be reused cluster by cluster as briefed by [9]. Consequently, the multi-hop clustering model is the best model for large-scale WSNs.

2. Cluster Based Routing Protocols

Among the issues in WSN the utilization of energy is a standout amongst the most essential issues. With respect to energy efficiency, Hierarchical routing protocols are observed to be the best. By the utilization of a clustering strategy they minimize the utilization of energy extraordinarily in gathering and disseminating the data. Hierarchical routing protocols reduce the energy utilization by dividing nodes into clusters. In every cluster, a node having the great processing power is chosen as a cluster head, which totals the data sent by the powered sensor nodes. In this section cluster based routing protocols for remote sensor systems are examined.

1. LEACH [10]

Authors exhibited the LEACH (Low Energy Adaptive Clustering Hierarchy) protocol for WSNs of cluster-based architecture, which is a generally known and elegant clustering algorithm, by selecting the CHs in rounds. LEACH is a mainstream energy efficient adaptive clustering algorithm that structures nodes groups based on the signal quality and utilizes these local cluster heads as routers to the SINK. Since data exchange to the base station devours more energy, all the sensor nodes inside a cluster take turns with the transmission by rotating the group heads. This prompts balanced energy utilization of all nodes and henceforth a more extended lifetime of the system. A predefined value, P (the desired percentage of cluster heads in the network), is set before beginning this algorithm. LEACH works in several rounds where each round has two stages, the setup stage and the steady stage. Amid the setup stage, each node chooses whether to end up a cluster head or not. Each node picks a random number p between 0 and 1, which is the likelihood to elect itself as a cluster head. If the probability p is less than a threshold T (n) for node n, node n will become a cluster head for the current round r. This T (n) is calculated by using the Equation as follows:

$$T(n) = \begin{cases} \frac{p}{1-p*(rmod\frac{1}{p})} & \text{if} n \in G \\ 0 & \text{Otherwise} \end{cases}$$

During the steady phase, the sensor nodes can start sensing and transmitting information to the cluster heads. The cluster heads also aggregate data from the sensor nodes in their cluster and sends data to the base station. After a specific timeframe spent on the steady phase, the network goes into another round of choosing the cluster heads. The length of the steady phase is longer than the span of the setup phase with a specific end goal to minimize the overhead. LEACH provides an optimized behavior for communication in WSNs taking into account self - organization techniques. Mobility is also supported by LEACH, though new nodes must be synchronized to the current round. Node failures may prompt less cluster heads to be chosen than sought in light of the fact that the predefined P is a percentage of the aggregate number of sensor nodes.

Considering a single round of LEACH, a stochastic cluster–head choice won't consequently prompt least energy utilization amid the steady stage for data transfer of a given arrangement of sensor nodes. For instance, a portion of the cluster heads can be situated close to the edges of the network or some adjacent nodes can become cluster heads. In these cases, some sensor nodes are further far from a cluster head. In any case, considering two or more adjusts, a choice of favorable cluster heads at the current round can bring about an unfavorable cluster-heads determination in the later round. With respect to energy utilization, a deterministic cluster-head choice algorithm can play out a stochastic algorithm. The change of the threshold equation by the remaining energy may raise another issue. Since the remaining nodes have a low energy level after a number of rounds, the cluster – head threshold will turn out to be too low. Some cluster heads won't have enough energy to transmit data to the base station.

The network can't function admirably in spite of the fact that there are still nodes accessible with enough energy to perform this task. The threshold equation can be updated further by incorporating a factor that raises the threshold for any node that has not been a cluster head for a certain number of rounds. The possibility of this node turning into a cluster head expands due to the higher threshold.

2. PEGASIS [11]

In this paper authors proposed Power-efficient gathering in sensor information systems (PEGASIS), which is an improvement over the LEACH. It is chain based protocol, in which nodes need to speak with their nearest neighbors and alternate in speaking with BS. Every node in the system utilizes signal quality to find the nearest neighbor. The chain in PEGASIS comprises of nodes nearest to each other that shape a way to the BS. The accumulated type of the data will be sent to the BS by any node in the chain and the nodes in the chain will alternate sending to the BS. This diminishes the power required to transmit information per round on the grounds that the power depleting is spread consistently over all nodes.

Anyhow, the assumptions in PEGASIS may not generally be practical.

a) PEGASIS expect that every sensor node can speak with the BS directly. In practical cases, sensor nodes use multi-hop correspondence to achieve the BS.

b) It considers that all nodes keep up a complete database about the location of every other node in the system; however the strategy by which the node location are gotten is not delineated.

c) It considers that all sensor nodes have the same level of energy and are likely to die at the same time.

In spite of the fact that in many situations sensors will be fixed or immobile as assumed in PEGASIS, a few sensors might be permitted to move and in this way influence the protocol functions.

3. TEEN [12]

Authors proposed a hierarchical clustering based protocol produced for responsive systems in which nodes respond instantly to sudden and extreme changes in environment known as TEEN. Cluster formation and data transfer are done as in the LEACH threshold values alongside different traits - Hard Threshold (HT) and Soft Threshold (ST). These values as well as the environment are sensed by the nodes continuously. At the point when the node finds that the detected trait has achieved HT, the node switches on its transmitter and sends the sensed data.

The sensed value is put away in an inner variable SV in the node. In the present cluster period, the node will next transmit data just when the present estimation of the sensed attribute is higher than HT and the present estimation of the sensed attribute varies from SV by a sum equivalent to or higher than the ST. The utilization of HT and ST will decrease the number of transmissions in the network and consequently it diminishes the general energy dissipation in the network. This plan is suited for time critical data sensing applications.

4. APTEEN [13]

Adaptive Periodic Threshold-Sensitive Energy Efficient Sensor Network scheme (APTEEN) is an augmentation to TEEN and goes for both sending occasional periodic and respond to critical times. Then again, APTEEN consolidates the component of proactive and reactive systems and transmits information in customizable time interims while regardless it reacts to sudden changes in trait values. APTEEN depends on a query framework which permits three sorts of inquiries: recorded on-time and constant which can be utilized as a part of a hybrid system. The CH choice system depends on the technique utilized as a part of LEACH-C. In APTEEN, CHs telecast the four parameters: Attributes, Thresholds, Schedule and Count Time.

All nodes in APTEEN sense the environment consistently, yet the information transmission happens just when detected information quality is at or more prominent than HT. For a node, if an information transmission does not occur in day and age equivalent to the number time, it must sense and transmit the information once more. In APTEEN, each CH totals the information from the part nodes inside its cluster and transmits the amassed information to the BS. The protocol accept that the information got from member nodes are adequately correlated, along these lines it decreases a lot of excess of the information to be sent to the BS. Besides, an adjusted TDMA plan actualizes the hybrid system by allocating transmission slot to all nodes in a cluster. What's more, APTEEN offers a great deal of flexibility by permitting the users to set the CT interim and the threshold values for energy utilization can be controlled by changing the CT and in addition the limit values.

5. EEHC [14]

Authors proposed a distributed, randomized clustering algorithm for WSNs. This method is partitioned into two stages in particular single-level clustering and multi-level clustering. In the single-level clustering, every sensor node declares itself as a CH with probability p to the neighboring node inside its communication range. These CHs are named as the volunteer CHs. All nodes that are inside k hops range of a CH get this announcement either by direct correspondence or by forwarding. Forced CHs are nodes that are neither CH nor belong to a cluster. On the off chance that the announcement does not achieve a node inside a pre-set time interval t that is computed in light of the duration for a packet to reach a node that is k hops away, the node will turn into a forced CH expecting that it is not inside k hops of all volunteer CHs. The second phase, called multi-level clustering builds h levels of cluster hierarchy. The algorithm guarantees h-jump network amongst CHs and the base station. The CHs nearest to the base station have disadvantage since they go about as relays for different CHs.

6. HEED [15]

Another prominent energy-proficient node clustering algorithm is the **H**ybrid, **E**nergy - **E**fficient and **D**istributed (HEED) clustering approach for ad hoc sensor networks. HEED created by [201] is a distributed clustering protocol which was proposed with four essential objectives as follows: (1) increasing network lifespan by distributing energy utilization, (2) ending the clustering procedure inside a steady number of iterations, (3) reducing control overhead (to be linear in the number of nodes), and (4) generating well - distributed cluster heads and compact clusters. HEED periodically chooses cluster heads based on a hybrid of two clustering parameters: The essential parameter is the leftover energy of every sensor node and the secondary parameter is the intra-cluster correspondence cost as a component of neighbor vicinity or cluster density. The primary parameter is utilized to probabilistically choose an initial set of cluster heads while the secondary parameter is used for breaking ties.

The grouping procedure at every sensor node requires a few rounds. Each round is sufficiently long to get messages from any neighbor inside the cluster range. As in LEACH, an underlying rate of cluster heads in the system, C_{prob}, is predefined. The parameter C_{prob} is just used to constrain the underlying cluster head announcements and has no direct effect on the final cluster structure. In HEED, each sensor node sets the probability CH_{prob} of becoming a cluster head as follows

$$CH_{prob} = C_{prob} * \frac{E_{residual}}{E_{max}}$$

Where $E_{residual}$ is the estimated current residual energy in this sensor node and E_{max} is the maximum energy (corresponding to a fully charged battery), which is typically identical for homogeneous sensor nodes. The CH_{prob} value must be greater than a minimum threshold p min. A cluster head is either a tentative cluster - head, if its CH_{prob} is < 1, or a final cluster - head, if its CH_{prob} has reached 1.

Amid each round of HEED, each sensor node that never got notification from a cluster head chooses itself to become a cluster head with probability CH_{prob}. The recently chose cluster heads are added to the present arrangement of cluster heads. If a sensor node is chosen to end up a group head, it telecasts an announcement message as a tentative cluster - head or a last cluster head. A sensor node listening to the cluster - head list chooses the cluster head with the most minimal expense from this arrangement of cluster heads. Every node then doubles its CH_{prob} and goes to the next step. If a node finishes the HEED execution without choosing itself to become a cluster head or joining a cluster, it declares itself as a final cluster-head. A tentative cluster - head node can become a regular node at a later iteration if it hears from a lower cost cluster head. Note that a node can be chosen as a cluster head at back to back clustering intervals if it has higher remaining energy with lower cost. Since a WSN is thought to be a stationary network, where node don't die suddenly, the neighbor set of each node does not change every now and again.

Here HEED does not have to do neighbor revelation regularly. What's more, distribution of energy utilization of HEED increase the lifetime of all the nodes in the network, thus supporting steadiness of the neighbor set. Nodes also automatically update their neighbor sets in multi-hop networks by periodically sending and receiving messages. The HEED clustering enhances system lifetime over LEACH clustering since LEACH haphazardly chooses cluster heads (and hence cluster sizes), which may bring about speedier demise of a few nodes. The final cluster heads chose in HEED are very much circulated over the network and the correspondence expense is minimized.

7. UCS [16]

Authors proposed first unequal clustering model, called Unequal Clustering Size (UCS) to adjust energy utilization. The sensor field is separated into two concentric circles called layers and every layer has some number of clusters of same size. The size and shapes of the clusters of two layers are distinctive. The protocol assumes that the BS is situated in the center point of the system and CHs areas are determined "priori" which are situated symmetrically in concentric circles around the BS. To minimize the energy utilization inside the cluster, each CH ought to be set at the center point of the cluster. CHs are deterministically planted in the system and are thought to be super nodes which are much more costly than member nodes. The coverage of the clusters can be shifted by differing the first of the primary layer around the BS, so the number of nodes in a specific cluster also changed. Each CH transmits data to BS by picking the nearest CH toward BS.

The UCS has two preferences contrasted with LEACH. To begin with, the UCS can keep up uniform energy utilization among CHs. This can be accomplished by differing the number of nodes in each cluster as for the normal communication load. Also, protocol makes two layered network model and two-hop inter-cluster communication method, this outcome in a shorter average transmission distance contrasted and LEACH, in this way successfully lessens the complete energy utilization.

8. FBR [17]

Authors proposed the flow-balanced routing (FBR) protocol for multi-hop clustered WSNs. The protocol endeavors to accomplish both power efficiency and coverage safeguarding. The protocol comprises of four stages: network clustering, multi-hop backbone construction, flow balanced transmission and rerouting. The several nodes are gathered into one cluster on the basis of overlapping degrees of sensors. In backbone development stage, a novel multi-level back- bone is built utilizing the CHs and the BS. The flow-balanced routing allots the transferred data over multiple paths from the sensors to the BS so as to even out the power utilization of sensors. At the point when the CH came up short on energy, the CH drops out from the backbone and in such places the network topology is reconfigured in rerouting stage. The two measurements called the network lifetime and the coverage lifetime are considered to assess the achievement of FBR protocol. The simulation results demonstrate that FBR yields both longer lifetime and better coverage safeguarding.

9. CBRP [18]

Authors proposed CBRP scheme in which the system is clustered by utilizing a few parameters and after that developing a spanning tree for sending amassed information to the base station. The operation of CBRP is partitioned into two stages, for example, Cluster head choice stage and routing tree era stage. In the CH choice stage the CH selection depends on the Cluster Head Selection Value (CHSV), the biggest CHSV value node will turn into the cluster head. In routing tree era stage every cluster head will choose their parent sensor node in light of the Parent Selection Value (PSV). Next, the routing tree is built and the transmission happens. CBRP considers the distance and residual energy of nodes and chooses ideal CHs that can spare more energy in nodes. Trial results demonstrate that CBRP parities the energy utilization among CHs and therefore more energy is spared in the system.

10. EECS [19]

Authors proposed an Energy Efficient Clustering Scheme (EECS) for the periodical information gathering applications. In EECS, the system is apportioned into different clusters and uses single-hop communications between the CH and the BS. In EECS, CH applicants compete for the capacity to elevate CH for a given round. Each CH hopefuls show their left energy to neighboring applicants. In the event that a given node does not discover a node with more leftover energy, it turns into a CH. EECS broadens LEACH by dynamic measuring of groups in view of cluster distance from the BS. The intra-cluster correspondence expense is diminished by picking the nearest CH.

11. PEACH [20]

Power-Efficient and Adaptive Clustering Hierarchy (PEACH) convention is proposed for WSNs to broaden system lifetime by lessening the energy utilization. The nodes in the system can perceive the source and destination of the information packets by overhearing attributes of wireless correspondence. In PEACH, the clusters are framed without extra transmission overhead, for example, notice, declaration, joining and scheduling messages. PEACH is probabilistic directing algorithm and give a versatile multi-level clustering. PEACH is extremely proficient and scalable under different circumstances than the current clustering protocols.

PEACH might be appropriate to both aware and unaware WSNs with respect to location. In specific applications, the location information data of the node is not known. In such applications, location unaware PEACH convention can be utilized. The location aware PEACH works when the confinement mechanism, for example, a GPS-like equipment is accessible on sensor nodes.

12. TTCRP [21]

In this, two routing schemes were proposed by the authors to upgrade the system lifetime: Two Tier Cluster Based Routing Protocol (TTCRP) and power control algorithm (PCA). TTCRP arranges the nodes as clusters at two levels. At the primary level sensor nodes join pre assigned asset rich CHs. These CHs structure the second level of bunches to convey information to the BS. The CHs are outfitted with double channels in which distinctive channels are utilized for correspondence at both levels. The CHs get information from their individuals at one channel and utilize second channel to send it to the BS through different CHs. The proposed plan executes a power control algorithm to permit the disengaged sensor nodes and also group heads to progressively change their transmission power for interfacing sensor nodes with inaccessible clusters and subsequently gives system robustness.

13. DAIC [22]

Distance Aware Intelligent Clustering (DAIC) is a progressive routing convention proposed to minimize the energy utilization and expand the system lifetime. The scheme isolates the system into two levels: primary and secondary. The CHs of the primary level are chosen by considering the distance between the CH and BS. The protocol decides the quantity of CHs powerfully in view of the quantity of alive nodes in the system, which keeps away from the determination of superfluously huge number of CHs. The non-CH nodes transmit the information to the essential CHs and the CH nodes at the secondary level transmit the information to the BS. For uniform distribution of energy load, DAIC utilizes rotation of CHs as a part of each round of communication and chooses CHs on the premise of residual energy.

3. Conclusions

Researchers have been enticed towards wireless sensor networks in recent past both in academic and industrial domains. The design of effective, robust, and scalable routing protocols for WSNs is a challenging task. On the other hand, clustering routing algorithms, generally, can well match the constraints and the challenges of WSNs. As a result, it is clearly seen so far that, significant efforts have been made in addressing the techniques to design effective and efficient clustering routing protocols for WSNs in the past few years.

This paper have surveyed the state-of-art of different clustering algorithms in wireless sensor networks along with LEACH and other important protocols reported in the literature of WSNs till today. Every effort has been made to provide complete and accurate state of the art survey on energy efficient clustering algorithms as applicable to WSNs.

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