CLUSTERING ALGORITHMS BASED ON ENERGY EFFICIENCY IN WIRELESS SENSOR NETWORKS: SURVEY

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ABSTRACT

This technological development of micro-electronics and wireless networks have created a new generation of large scale sensor suitable for a varied range of applications, it is the wireless sensor networks (WSN). In spite of the remarkable advances in WSN, there are still many problems to solve. However, the control of the energy consumption by sensor networks and maximizing their lifetime are the most fundamental issues. The use of wireless sensor networks is often correlated with an absence of infrastructure this raises the problem of activation of the network topology and maintaining this connectivity. Therefore the network needs to perform an initialization phase to self-organize. Actually most of self-organization protocols used in wireless sensor networks is mainly based on clustering. In this paper, we present a survey of clustering algorithms based on energy efficiency in WSNs highlighting their objectives, features, complexity, etc.

Keywords: wireless sensor networks, clustering algorithms, self-organization, energy efficiency.

INTRODUCTION

Wireless sensor network (WSN) is a network designed to extract the information in disaster environments. It plays a vital role in our daily lives and it meets the requirements of several application areas (industrial, cultural, environmental):

- Collection of information relating to the environment (temperature, light, carbon dioxide levels, the presence of toxic, radio activity, etc.).
- Monitoring structure of infrastructure,
- Optimizing treatment for patients, etc.

The battery is an important component of a sensor. In general, it is not replaceable or rechargeable; so it limits the lifetime of the sensor and affects the overall operation of network. In the other side, once they are deployed the sensors are considered independent. Therefore, no human intervention may be required to ensure their organization. Self-configuration of these networks is necessary for their efficiency. Today, the challenge is how to create an organizational structure amongst these nodes and to preserve the energy [1].

Self-organization is a mechanism that allows having an organized system without centralized entity and without external control. It could distribute roles on all nodes and provides local interaction and coordination nodes; it could assign roles on all nodes and ensures their local interaction and coordination. Thereby it maintains the structure of the network over a long period and minimizes energy consumption.

Most of self-organization algorithms take into account the structure of sensors: each sensor consists of three units: A unit of event detection, calculation and communication. All these components are powered by a battery; therefore it is necessary that the proposed protocols limit the exchange of control packet for a minimum expenditure of energy. The two main classes of self-organization protocols used today in wireless sensor networks are mainly based on clustering, and multi-hop routing (see hybridization of two) [2].

Various approaches are suggested to determine the optimal route in multi-hop routing protocols. Some propose to take the shortest route in terms of the distance to the station base [3]. Others are based on the energy level of the nodes by favoring those with maximum amounts of energy [4, 5]. The major drawback of multi-hop routing in wireless networks is the periodic exchange of messages to maintain the end of valid channels, which overloads the network and increases thereafter the energy consumption. By cons clustering leads to more scalability, energy efficiency and prolong network lifetime in large-scale WSNs. So clustering gives the best results than the multi-hop routing, why most self-organization protocols are based on clustering.

The rest of the paper is organized in following structure; Section 2 presents the basic concepts of clustering. Section 3 presents taxonomy of energy efficient clustering algorithms in WSNs. Section 4 presents the conclusion of the paper.

OVERVIEW OF CLUSTERING SCHEMES

Basic concepts

Clustering means grouping sensor nodes geographically close into sets called "clusters". The nodes belonging in a group can execute different functions from other nodes [6, 7, and 8]. Each cluster is represented by a particular node called cluster-head (CH). The CH is elected by a specific metric or combination of metrics. It is responsible for coordination between the different members of the cluster, and it can forward the aggregated data to the sink through other CHs or directly.

In a cluster, each node can communicate with their CH directly or multi-hop and stores all information of

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its cluster and some of information of other clusters. So the clustering minimizes considerably the size of routing tables and the number of messages exchanged in the network.

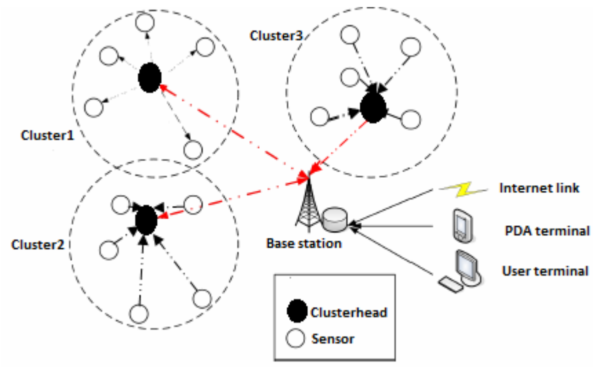

Figure-1. Clustering overview.

Others cluster members have different status and serve as several functions and responsibilities according to different usages and topologies. The two other status involved in most clustering algorithms are the gateway and ordinary node.

- **Ordinary node:** This is a node that never sends the received packets. It is always listening the channel to read / captured packets that are destined.
- **Gateway:** This is a node that provides communication between the cluster heads. Several heuristics exist to elect and to minimize the number of Gateways.

Clustering schemes have some significant advantages except for delay reduction, as listed in the following:

- Data aggregation and summarization: reducing volume of transmitted data.
- Scalability in large-scale WSNs.
- Communication overhead reduction (for both single and multihop communications): data transferring reduction.
- Stability of network topology [9, 10]: clusters establishing, more regular, more stable, better and more distance communications.
- Load balanced distribution [11, 12].
- Easy maintenance: network easier management.
- Network lifetime prolonged.
- Energy efficiency and distributed: reducing the consumed energy and redundancy reduction.

Taxonomy of clustering methods in WSNs

In the literature, clustering attributes in WSNs, generally, can be grossly classified into cluster characteristics, cluster-head characteristics and clustering process. In this section, we discuss most of the attributes of clustering for sensor networks.

Cluster characteristics

Such characteristics can be related to properties of the generated clusters, their internal structure or how it relates to others. The following are important attributes:

- **Cluster count**: Based on the number of clusters, clustering schemes can be classified into two types: fixed and variable ones. In some approaches the set of CHs are predetermined and the number of clusters are preset. However in other approaches the number of clusters is variable, in which CHs are selected, randomly or based on some rules, from the deployed sensor nodes.
- **Cluster size**: Taking into account the uniformity of the cluster sizes, clustering protocols in WSNs can be classified into two classes: uniform, no uniform ones, respectively with the same size clusters and different size clusters in the network.
- **Intra-Cluster schemes**: Intra-Cluster schemes in WSNs include two classes: single-hop intra-cluster methods and multiple-hop ones. For the intra-cluster single-hop scheme, all nodes in the cluster transmit data to its designated CH directly. Instead, multiple-hop methods the communication between a sensor and its corresponding CH is provided by data relaying. This connectivity is sometimes required; especially when the node's communication range is limited.
- **Inter-Cluster communication**: in the single-hop topology, all CHs communicate with the BS directly. In contrast to it, data relaying is used by CHs in the inter-cluster multiple-hop scheme.

Cluster-head capabilities

As previously mentioned, CH has an important role in the formation and inter-cluster communication; thereafter its characteristics can differentiate the clustering approaches. The following capabilities of the CH node represent the different factors among clustering schemes:

- **Mobility:** the CH can have two states, mobile and stationary. In mobile clustering approaches membership dynamically change, Therefore a cluster should be permanently maintained. Contrary to it, in stationary approaches the CH can keep a stable cluster and facilitate network management. Sometimes, a CH can travel for limited distances to reposition itself for better network performance [13].
- **Functionality:** CH can have four functionalities: transmission, aggregation, management and maintaining structure. It transmits the traffic generated by the sensor nodes in its cluster as a relay but before it aggregates the collected information from sensor nodes in its cluster. At time a cluster-head manages the communication inter-cluster. thereby it can maintain the structure of cluster for long-standing
- **Uniformity of energy:** Based on uniformity of energy assignment for sensor nodes, clustering manners in WSNs include two classes homogeneous or heterogeneous ones. In homogeneous schemes, CHs are elected based in a random way or other criteria

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because all the sensor nodes are assigned with equal energy. By cons, CHs are equipped with significantly more energy in heterogeneous schemes, in which all the sensor nodes are assigned with unequal energy.

Clustering proceeding

The different stages of the construction cluster, cluster-head election and maintenance cluster vary significantly among published clustering schemes. The following attributes are considered relevant:

- **Construction cluster:** In distributed approaches each node in the network takes part in the cluster formation process. By cons in centralized methods CHs takes charge of forming its own cluster and inter-CHs coordination. Hybrid schemes can also be found. In the later case, the clusters are formed by CHs and inter-CHs coordination is performed in a distributed manner.
- **Cluster-head selection:** CHs can be pre-assigned in a round-robin fashion to achieve load balancing, energy balancing, and topology reconfiguration [14]. Clustering approaches can be categorized as pre-assigned and random ones. In pre-assigned manners, CHs are elected from the deployed sensor nodes based on specific attributes of the sensor nodes such as the identifier (ID), number of neighbors, residual energy, communication cost, and etc. In random schemes CHs are elected randomly without any metrics.
- **Clustering mechanisms:** clustering methods can be grouped into active, passive, and hybrid ones. In active scheme, the synchronization between sensor nodes is necessary to construct and maintain the clusters. Contrariwise passive mechanism does not use any specific protocol control packets or signals. It exploits the data packets to transmit neighbor's information. Hybrid approaches use a combination of the above two methods.
- **Objectives:** as already mentioned in the previous section, several objectives have been determined. Such as data aggregation/fusion, fault-tolerance, network connectivity, lifetime extension, load balancing, quality of service, etc.

Algorithm characteristics

- **Convergence Rate:** Time clustering algorithms in WSNs can be grouped into variable and constant convergence time ones. In variable convergence algorithms, the convergence rate depends on the number of nodes in the network. By cons in constant convergence rate, in spite of the scale of the networks, the constant convergence time algorithms certainly converge after a fixed number of iterations.
- **Distribution estimation:** Considering the distribution estimation of sensor nodes, clustering modes in WSNs can be classified into two classes: probabilistic or iterative ones. In probabilistic clustering, each sensor node can determinate its own role based on the probability assigned to all sensor nodes. Whereas, in iterative clustering manner. Every node decides its role after a certain number of iterations.

We would like to underline that some of these attributes are mutually exclusive, e.g. mobile or stationary mobility, and some are not. For example, a clustering processing may have multiple objectives. It is also important to note that network clustering can impact or be impacted by the planned network and link layer protocols. Figure-2 summarizes the taxonomy of the different attributes of clustering in WSNs. We use this set of attributes in categorizing the clustering algorithms summarized in the next section.

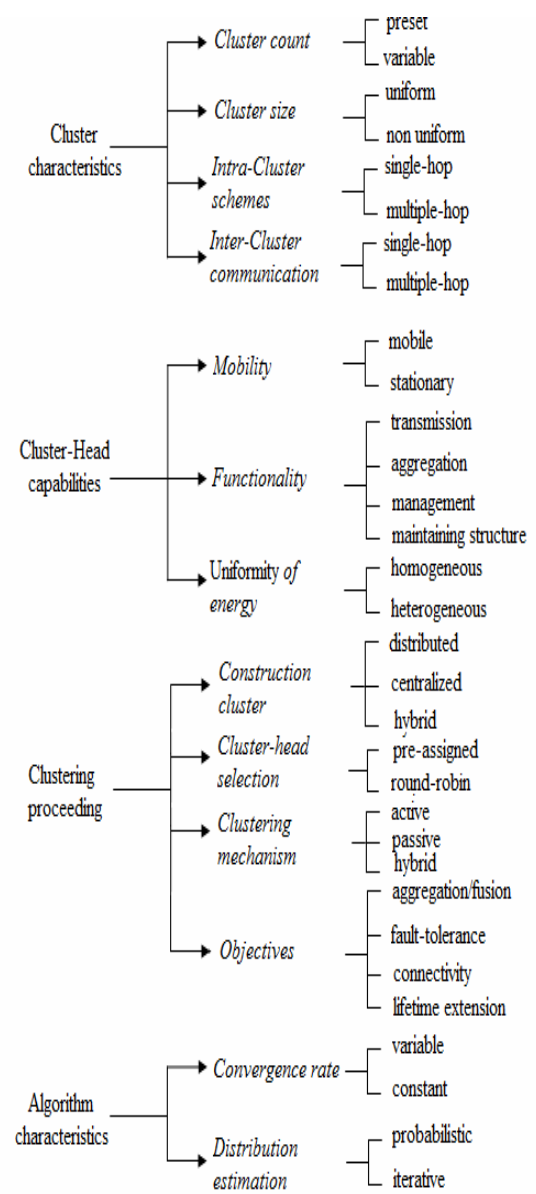

Figure-1. Taxonomy of the attributes of clustering in WSNs.

Clustering algorithms based on energy efficiency in WSNs

In this section, we present and analyze some popular clustering algorithms based on energy efficiency for WSNs.

LEACH (low energy adaptive clustering hierarchy)

LEACH is a hierarchical routing protocol dedicated to homogeneous sensor networks, proposed by Heinzelman *et al*., [15]. Initially a node can elect itself to be a CH with a probability p and broadcasts its decision. Each non-CH node chooses its cluster by determining the CH that can be reached using the least communication energy. The fundamental objective of LEACH is to rotate periodically the role of CH among the nodes of the cluster. The protocol proceeds in rounds to balance the load between the sensor nodes. Each round has two phases, a setup phase and steady state phase, in set up phase; the goal is to select cluster-heads and form clusters. Each node n has a random value between 0 and 1. If this value is less than threshold T (n), the node will become CH. The threshold function is defined as [16]:

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

Where

P = the priori probability of a node being elected as a cluster- head

r = the current round number

G = the set of nodes that have not been elected as cluster-heads

The new cluster-head will broadcast its status to neighboring nodes then Nodes members collect notification messages, and decide to join a particular cluster. The decision is based on the amplitude of the received signal: the cluster-head with the strongest signal is selected (i.e., the nearest node). In case of equality, a random cluster-head is selected and each member sends its decision to its cluster-head. In the steady state phase, the transfer of data to base station takes place, thus the cluster-heads will create a transmission schedule and transmit the schedule to all nodes in their respective cluster. The schedule consists of TDMA slots for each neighboring node. This scheduling scheme allows for energy minimization as nodes can turn off their radio during all but their scheduled time-slot [16]. Furthermore, no proposal about the time of re-election of CHs (time iteration) is made, and there are no restrictions on their distribution and their energy level. Hence, the cluster-heads can get together in one place and subsequently, there may be isolated nodes (without cluster-head). To avoid these problems, the authors propose an extension of the algorithm. They suggest a centralized algorithm (LEACH-C) [17]. It is an iterative algorithm, which forms clusters using the optimization method of "simulated annealing" at the base station [18]. In each iteration, the base station attributes the roles for different nodes in the network (CH or ordinary node). Next, the operation continues in the same manner as LEACH. However, the overhead of the network is increased because all the sensors will send their location information to the base station at the same time in each cluster- heads election phase.

EECS (energy efficient clustering scheme in wireless sensor networks)

EECS is a diagram of the clustering algorithm as LEACH, proposed by Ye *et al*., [19, 20], wherein the network is partitioned into a set of clusters with cluster-head in each cluster. In the deployment phase of the network, the base station (BS) broadcasts a "Hello" message to all nodes and then each node can deduce its power level and calculate the approximate distance from the BS. This distance is used to balance the load between the cluster-heads [21]. The nodes with more residual energy have more probability to be elected as cluster-heads. If a given node does not find a node with more residual energy; it becomes a cluster-head. In cluster formation phase, LEACH uses the minimum distance of nodes to their corresponding cluster-head. Different from LEACH, in EECS the dynamic sizing of clusters takes place which is based on cluster distance from the base station. Thus EECS resolves the problem that clusters at a greater distance from the sink requires more energy for transmission than those that are closer. And provides low message overheads and uniform distribution of CHs compared to LEACH.

EEUC (energy-efficient unequal clustering)

EEUC [22] is a distance based and distributed competitive scheme, where CHs are elected by localized competition. EEUC attributes pre-assigned competitive range to each node, which is smaller as it gets close to the BS. It also requires that every node has global identification such as its locations and distances to the base station.

To address the hot spots problem which is the main problem in WSNs because of multi hopping that takes place when CHs closer to the base station tend to die faster compare to another node in the WSNs, because they transmit much more traffic than remote nodes; EEUC divides the nodes into clusters of unequal size, and clusters near the sink node have smaller sizes than the clusters far away from the sink node in order to save more energy in intra-cluster communications and inter-cluster communications.

According to above discussion; EEUC tries to prolong the network lifetime and to balance the load among the nodes. However, the extra global data aggregation can result in much overhead for all nodes and deteriorates the network performance, especially for a multi-hop network.

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HEED (hybrid energy-efficient distributed clustering)

Hybrid Energy-Efficient Distributed clustering (HEED) [23] proposed by Younis and Fahmy, is a multi-hop WSN clustering algorithm. In HEED, the selection of CHs is based on two important parameters: One parameter depends on the node's residual energy, and the other parameter is the intra-cluster communication cost. This algorithm is based on two main phases: the construction phase of the cluster in which the nodes exchange the packets Hello to discover their neighbors and the stationary phase which involves the selection of cluster-heads and allows nodes to join their appropriate cluster-heads, based on the degree of connectivity.

Each node calculates its probability PCH to become cluster-head as follows:

$$P_{CH} = C_{prob} E_u / E_{max}$$

Where

E_u = Estimated current energy of the node u
E_{max} = Reference maximum energy
C_{prob} = Percentage of CHs among all nodes

The objective of this algorithm is to distribute uniformly the cluster-heads in the monitored area and generate balanced clusters size. However, it is not easy to calculate both Eu and Cprob parameters because HEED does not rely on central structure or use a routing protocol. On the other hand clusters built with HEED are not uniform and inter-cluster communication consumes more energy.

Distributed weight-based energy-efficient hierarchical clustering (DWEHC)

Distributed Weight-based Energy-efficient Hierarchical Clustering protocol (DWEHC), presented by Ding *et al*., [24], is a distributed clustering algorithm similar to HEED. It requires no assumptions about network size and density, and considering residual energy in the process of CH election. The main objective of DWEHC is to generate balanced cluster sizes and optimize the intra-cluster topology using location awareness of the nodes. After locating the neighboring nodes in its area, each node calculates its weight according the sensor's energy reserve and the proximity to the neighbors as following:

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

E residual = residual energy at node s
E initial = initial energy at node s
R = distance between CH and a node inside a cluster
d = distance between node s and the neighboring node u

Where the node with greater weight would be elected a CH and the other nodes become members. At this phase the nodes are considered as first-level members and communicate directly with the CH. A node tries progressively to reach a CH using the least amount of energy. By specifying the distance to its neighbors, a node can it can determine whether it is better to stay a first-level member or become a h-level one where h is the number of hops from the CH to itself. It is interesting to note that by doing so the node may switch to a CH other than its original one. The process continues until all nodes are fixed on the most energy efficient intra-cluster topology. Every cluster is assigned a range within which member nodes should set to limit the number of levels. Figure-3, illustrates the structure of the intra-cluster topology in DWECH.

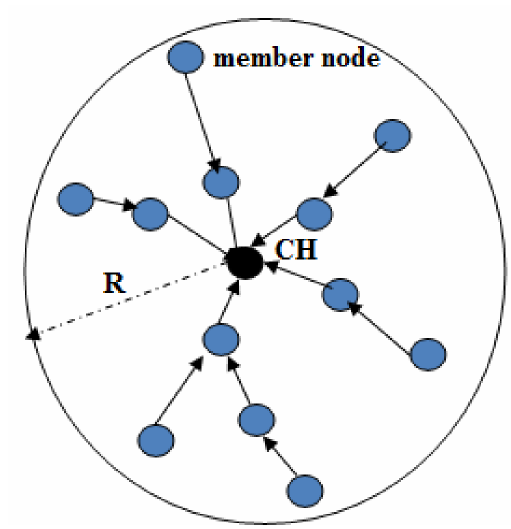

Figure-2. The topologie intr-cluster in DWEHC.

DWEHC is a fully distributed clustering method that generates more well-balanced CHs distribution and provides greatly lower energy consumption in intra-cluster and inter-cluster routing than HEED. By cons the iterative nature in the process of cluster formation provides a relatively high control message overhead compared to other protocols.

Energy efficient hierarchical clustering (EEHC)

Bandyopadhyay and Coyle [25] proposed EEHC; a distributed k-hop hierarchical clustering algorithm for WSNs with the objective of maximizing the network lifetime and minimizing the Energy consumption. Initially, each sensor node is elected as a CH with probability "p" and advertises itself as a clusterhead to the neighboring nodes within its communication range. This announcement is broadcast to all the sensors that are within "k"-hops distance from a "volunteer" CH. Consequently, any node that receives such CH election message and is not itself a CH, becomes a member of the closest cluster. By cons if it fails to reach any cluster, itself becomes a clusterhead; we call these cluster-heads the forced cluster-heads. The initial clustering process is recursively repeated at the level of CHs at the level of CHs to form h levels of cluster hierarchy. So there are h-hop connectivity between CHs and the base-station. Presumed that sensor nodes transmit the collected data to (i-1)-level CHs and The CHs at the i-level transmit the aggregated data to the (i+1)-level CHs with i=2,3,...h. At the h-level (highest level) of the clustering hierarchy, CHs transmit the aggregated data report to the base station. This hierarchical algorithm has a time complexity of O (k1 + k2 + · · · + kh), where ki is the corresponding parameter for each level. That was a considerable improvement over the O (n) time complexity that many of the existing algorithms, and made this algorithm quite suitable for large networks.

EEMC (energy-efficient multi-level clustering algorithm)

Energy-efficient multi-level clustering algorithm (EEMC) [26] is a valuable extension to EEHC of multi-level EEHC algorithm that includes additional CH election criteria and determines previously the expected number of CHs by analytical formulas. In the formation process, the probability of a node becoming a CH is proportional to the residual energy of the node as well as the distance of this node to the sink node (or to the CH it belongs to at lower levels). At each level the CHs are randomly selected according to its probability assigned and the optimal values of CH determined in their analysis. EEMC takes into account the distance parameter hen the CH should transmit the aggregated data to its next level CH. Contrariwise this transmission requires very high energy consumption if the distance between these two CHs is so large. Extensive simulation work is also provided, in which the EEMC protocol is shown to achieve longer network lifetime and less latency compared to LEACH and EEHC protocols.

Several simulation studies confirm that EEMC protocol achieves longer network lifetime and less latency compared to LEACH and EEHC protocols.

TEEN (threshold sensitive energy efficient sensor network protocol)

Threshold sensitive Energy Efficient sensor Network protocol (TEEN) [27], proposed by Anjeshwar and Agrawal, is a hierarchical protocol designed for reactive networks witch respond immediately to sudden changes in the relevant parameters of interest such as temperature. It‘s very similar to LEACH. In TEEN, a CH will send three parameters: attribute hard threshold (HT) and a soft threshold (ST):

- **Attribute:** it represents the requested task to sensor node.
- **Hard threshold (HT):** it is a threshold (absolute) value for the sensed attribute.
- **Soft threshold (ST):** is a threshold (minimal change) value of the sensed attribute.

Sensor nodes captured information continually from environment. If the information value beyond HT or the varied range of characteristic value beyond ST, the node will send sensing information to cluster head. So data transmission is done less frequently which can reduce more network traffic and favors the energy saving. By cons if the thresholds are not crossed, the nodes will never communicate thus TEEN does not support periodic reports.

Adaptive periodic-tEEN (APTEEN)

APTEEN [28] proposed by Manjeshwar and Agrawal, is an extension to TEEN and changes the periodicity or threshold values used in TEEN according to the requirement of users and the type of the application. In APTEEN once the CHs are elected, in each cluster period, they broadcasts the following parameters: Attributes (A); two threshold like TEEN hard threshold (HT) and soft threshold (ST); Schedule- this is a TDMA schedule, assigning a slot to each node; Count time (CT)- it is the maximum time period between two successive reports sent by a node.

APTEEN uses the same mechanism as well TEEN nodes listen to the medium continuously and when a node detects a information value beyond HT or the varied range of characteristic value beyond ST it sends its captured data to CH, but if a node does not transmit data over a period of time CT, it should take a snapshot of its data and transmit them to the cluster-head. Thus APTEEN can control energy consumption while varying the threshold values and the time interval CT, however the implementation of the functions of thresholds and time period CT is not easy, it requires a large additional complexity.

GRIDS (geographically repulsive insomnious distributed sensors)

GRIDS [29] is an energy-aware cluster formation protocol which increase the lifespan of a sensor network by using an efficient selection mechanism of critical (or not) nodes. This mechanism allows balanced energy consumption among the sensor nodes without requiring additional overheads including additional signaling, time synchronization and global information. GRIDS is based on an energy model which delivers node's residual/remaining energy level in real time and selects critical nodes among energy rich nodes, eFDW and eGSH models are the basic ideas of this protocol. This information is piggybacked in the nodes packet header. Each sensor determines being insomnious or not based on its residual energy and the number of neighboring insomnious nodes and their energy level. An efficient flooding during each wake up period determines insomnious nodes in the network. GRIDS selects insomnious nodes well distributed in the sensor deployed area. GRIDS inherit PC for constructing and maintaining clusters.

The main differentiator is that a set of nodes in a cluster with higher energy levels have higher probability

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to become critical nodes, i.e., CH or GW. In PC, CHs keep their cluster status until there is a CH collision, i.e., the hop distance between two CHs becomes 1, and one of them resigns from CH. In GRIDS, an energy abundant node can challenge CH and usurps the role. Even if there is a CH declaration, nodes can challenge when their energy levels are higher than the one of CH. These nodes keep their cluster status even if they receive packets from the current CH. GRIDS distributes "evenly" the duty cycles among sensor nodes and thus considerably increase the network's lifespan as the result.

Advanced passive clustering (APC)

APC (Advanced Passive Clustering) [30] is a protocol based on the Passive Clustering - PC that does not use any specific protocol control packets. It exploits the data packets to transmit neighbor's information. At startup, all nodes are in the initial state. A node changes its state only when it receives a packet from its neighbors. In APC the CH selects from its neighbors list a CH_Bakup, this is the node that has the highest energy among all its neighbors. Once the CH leaves the cluster, CH_Backup replaces the CH and chooses its CH_Backup from its neighbors list. So APC maintains the structure of the cluster even at the leaving of CH, increases the lifetime of the network and reduces energy consumption.

Advanced passive clustering -threshold (APC-T)

Similarly, considering the APC algorithm, a valuable extension (that includes the concept of energy threshold) is proposed in ref [31]. (APC-T) where the information is included in the packet and the energy level of nodes is taken into account in the data transmission. Once the cluster is formed, the CH will select its CH_Backup from its neighbors list like APC algorithm; this is the node that has the highest energy among all its neighbors. In APC-T, if the CH leaves the cluster, or its energy is below a given threshold T, CH_Backup replaces the CH and chooses its CH_Backup from its neighbors list. Figure-2 describe APC-T algorithm.

By this way, APC-T maintains cluster longer than APC and allows balanced energy consumption between the nodes of network.

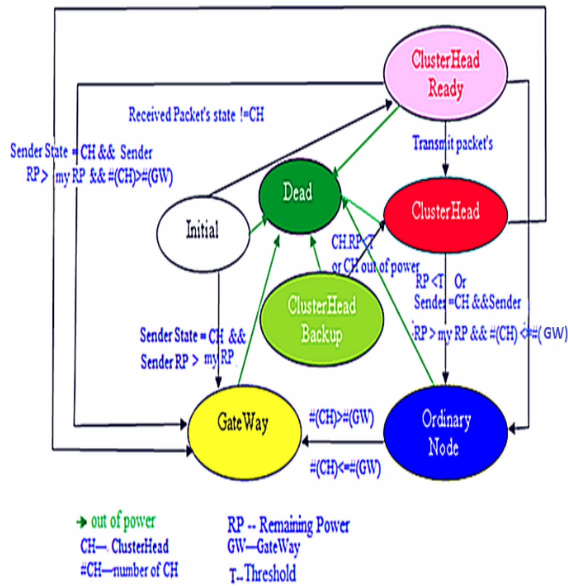

Figure-3. State diagram of APC-T.

Comparison of different clustering algorithms based on energy efficiency for WSNs

In this section, we summarize the different clustering algorithms based on energy efficiency for WSNs according to a variety of clustering attributes discussed in section 2 as shown in Table-1. Furthermore, we compare those different clustering approaches in WSNs based on a few important metrics in Table-2.

SUMMARY AND CONCLUSIONS

In the last decade clustering in sensor networks has been of great interest and there are already a large number of published works that result. Throughout this paper, we have tried to present the main characteristics of the most considerable protocols that have been proposed in the literature. In wireless sensor networks, the energy limitations of nodes play a crucial role in designing any protocol for implementation [32].

In this paper, we have presented a rather extensive summary on clustering protocols based on energy efficiency in WSNs. We have also developed a novel taxonomy of clustering methods for WSNs based on rather detailed clustering attributes. Finally, we compared these different approaches based on our taxonomy and some primary metrics.

To summarize, we want to specify some future directions for the field. Firstly, further research would be needed to address QoS requirements in the resource-constrained WSN environment. Moreover, further studies are necessary to solve the problem of node mobility, including the sink and sensor nodes. Finally, with the increase of the network scale in WSNs, more redundant information is created thus it is necessery to reduce the degree of redundancy. So the challenge is to found a trade-off between consumption of energy and redundancy reduction.

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Table-1. Classification of different clustering protocols in WSNs.

Clustering protocols		LEACH	EECS	EEUC	HEED	DWEHC	EEHC	EEMC	TEEN	APTEEN	GRIDS	APC-T
Cluster characteristics	Cluster count	variable	variable	variable	variable	variable	variable	variable	fixed	variable	variable	variable
	Cluster size	uniform	Non uniform	uniform	uniform	uniform	Non uniform	Non uniform	uniform	uniform	uniform	uniform
	Intra-Cluster schemes	Single-hop	Single-hop	Single-hop	Single-hop	Multiple-hop	Multiple-hop	Multiple-hop	Single-hop	Multiple-hop	Single-hop	Single-hop
	Inter-Cluster communication	Single-hop	Single and multi-hop	Single-hop	Single and multi-hop	Single-hop	Multiple-hop	Multiple-hop	Multiple-hop	Multiple-hop	Multiple-hop	Multiple-hop
Cluster-Head capabilities	Mobility	stationary	stationary	stationary	stationary	stationary	stationary	stationary	stationary	stationary	stationary	mobile
	Functionality	Agregation and relaying	Agregation and relaying	Agregation and relaying	Agregation and relaying	Agregation and relaying	Agregation and relaying	Agregation and relaying	Agregation and relaying	Agregation and relaying	Agregation and relaying	Agregation and relaying
	Uniformity of energy	homogeneous	homogeneous	homogeneous	homogeneous	homogeneous	homogeneous	homogeneous	homogeneous	homogeneous	homogeneous	homogeneous
Clustering proceeding	Construction cluster	distributed	distributed	distributed	distributed	distributed	distributed	distributed	distributed	distributed	distributed	distributed
	Cluster-head selection	round robin	round robin	round robin	round robin	round robin	round robin	round robin	round robin	round robin	round robin	round robin
	Clustering mechanism	reactive	reactive	reactive	reactive	reactive	reactive	reactive	reactive	reactive	passive	passive
	Objective	save energy	load balancing periodical data communications	load balancing	save energy	save energy	save energy	save energy	lifetime extension	proactive scenes	load balancing	Load balancing/ lifetime extension
Algorithm characteristics	Convergence Rate	constant	constant	constant	constant	constant	varialble	variable	variable	variable	constant	constant
	Distribution estimation	probabilistic	probabilistic	probabilistic	iterative	iterative	probabilistic	probabilistic	probabilistic	probabilistic	iterative	iterative

Table-2. Comparison of different clustering protocols in WSNs.

Clustering approaches	Energy Efficiency	Cluster Stability	Scalability	Node mobility	Load Balancing	Algorithm Complexity
LEACH	very low	moderate	moderate	Fixed BS	moderate	low
EECS	Moderate	high	low	Fixed BS	moderate	very high
EEUC	High	high	high	Fixed BS	high	high
HEED	Moderate	high	moderate	stationary	moderate	moderate
DWEHC	very high	high	moderate	stationary	very high	moderate
EEHC	High	moderate	low	no	moderate	very high
EEMC	Moderate	moderate	low	no	moderate	very high
TEEN	very high	high	moderate	possible	high	high
APTEEN	Moderate	Low	moderate	possible	moderate	very high
GRIDS	High	high	moderate	possible	high	high
APC-T	very high	very high	high	possible	high	high