CLUSTERING ALGORITHMS FOR HETEROGENEOUS WIRELESS SENSOR NETWORKS – A BRIEF SURVEY

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Abstract

Wireless sensor networks (WSN) are emerging in various fields like disaster management, battle field surveillance and border security surveillance. A large number of sensors in these applications are unattended and work autonomously. Clustering is a key technique to improve the network lifetime, reduce the energy consumption and increase the scalability of the sensor network. In this paper, we study the impact of heterogeneity of the nodes to the performance of WSN. This paper surveys the different clustering algorithm for heterogeneous WSN.

Keywords:

CH, CH selection, Heterogeneous WSN, energy efficiency

1. INTRODUCTION

With the emergence of MEMS technology, WSN has become an interesting field of research. The sensor nodes can be homogeneous or heterogeneous. Homogeneous sensors hardly exist. This paper addresses the heterogeneous wireless sensor networks (HWSN) for increased reliability of the network. Clustering is a key technique to improve the network lifetime, reduce the energy consumption and increase the scalability of the sensor network. A scalable sensor network is obtained by means of clusters. A cluster head (CH) could be elected or pre-assigned. Various clustering algorithms have been studied namely LEACH [11], PEGASIS [12], TEEN [13], APTEEN [14]. Energy efficient routing is possible by means of cluster based routing.

A. **Advantages of clustering**
   a) Reduces the size of the routing table by localizing the route setup within the cluster.
   b) Conserves communication bandwidth
   c) Prolonged battery life of individual sensor
   d) No topology maintenance overhead.

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e) Reduce rate of energy consumption

In HWSN, inexpensive nodes perform sensing and cluster heads perform data filtering, transport and fusion. Real time deployments of sensors employ HWSN.

II. HETEROGENEOUS MODEL FOR WSN

A. Types of resource heterogeneity

a) Computational heterogeneity. A heterogeneous node has more complex processor and memory so that they can perform sophisticated tasks compared to a normal node.
b) Link heterogeneity. A heterogenous node possesses high bandwidth and long distant transceiver than a normal node proving reliable transmission.
c) Energy heterogeneity. A heterogeneous node is line powered (its battery is replaceable).
Out of the above the energy heterogeneity is the most important, since computation and link heterogeneity consumes more energy.

B. Impact of heterogeneity on WSN

Placing heterogeneous nodes in the sensor network, decreases response time and improve battery life time. As discussed in section 2.1, Computation and link heterogeneity decreases the waiting time thereby, decreasing the response time. The average energy consumption will be less in heterogeneous sensor networks for forwarding a packet from the normal nodes to sink, hence life time is increased. As a rule of thumb, if heterogeneity is properly used in a network, response time is tripled and the lifetime of the network can be increased by 5-fold. [21].

C. Performance measures

The performance measures that are used to evaluate clustering protocols are;

a) Network lifetime. It is defined as the start of operation of the sensor network to the death of the first alive node.
b) Number of cluster heads per round. This measures the number of elected cluster heads or pre-assigned cluster heads with their energy levels.
c) Number of nodes per round. Total number of nodes that hasn't expended all of its energy.
d) Throughput. Rate of data sent over the network. (Data sent from cluster head to sink + the rate of data sent by nodes to their heads).

III. Classification of clustering attributes

The following subsection summarizes set of attributes that are used to differentiate and categorize clustering algorithms for HWSN.

A. Cluster properties

For a generated cluster, the clustering scheme can be related to the internal structure of the cluster. The following are the relevant attributes.

a) Cluster count. Numbers of cluster heads are preset in some of the published approaches. [23, 24, 27]. CH selection algorithms generate variable number of clusters in general.

b) Intra-cluster topology. Certain sensors communicate directly to their designated CH, but sometimes multihop sensor to CH connectivity is required.
c) Connectivity of CH to base station. Connection can be direct or indirect (single link or multi hop link)

B. Cluster head capabilities

a) Mobility. CH can be stationary or mobile. But movements are limited within the region for better network performance.
b) Node types. Deployed sensor nodes equipped with more computation and communication resources are selected as CHs.
c) Role. CHs relay the traffic, fuse or aggregate the sense data.

C. Selection criteria for CH

a) Initial energy. When any algorithm starts it considers the initial energy of the CH and the initial energy must be high.
b) Residual energy. After few rounds of selection, the CH election should be based on remaining energy of the node.
c) Energy consumption rate. This rate is defined as
$V_i(t) = [I_{nitial} - E_i(t)] / r$
Where I_{nitial} is the initial energy, $E_i(t)$ is the residual energy and r is the current round of CH selection.
d) Average energy of the network. It is the reference energy (ideal energy) of each node in current round to keep the network alive.

IV. Clustering algorithms for HWSN.

This subsection presents the literature survey of distributed algorithms for heterogeneous WSN. These algorithms are classified based on stability and energy efficiency. Our survey of heterogeneous clustering algorithm is also based on some of the attributes described in [22].

A. Stability oriented clustering protocols for HWSN
The protocols discussed in this section increase the stability period of a WSN. Protocols surveyed include SEP [25], EDPCM [26], Base Station initiated clustering [27] and ZREECR [29]

B. Stable Election Protocol for clustered HWSN
In reference paper [25], authors describe the drawback of LEACH protocol in the presence of heterogeneity for WSN. They propose a heterogeneity aware protocol called SEP which requires no energy sharing between nodes. A CH is elected based on weighted election probability. Authors argue that CH is randomly selected based on fraction of energy of each node, thus every node's energy is uniformly used. Also, this algorithm prolongs the stability period.

The problem with this type of approach is that when the same threshold is set for normal and advanced nodes, there's no guarantee that the number of CH per round per epoch is $n*p_{opt}$. A weight is assigned to the optimal probability.

Weight= Initial energy of each node

Initial energy of normal node.

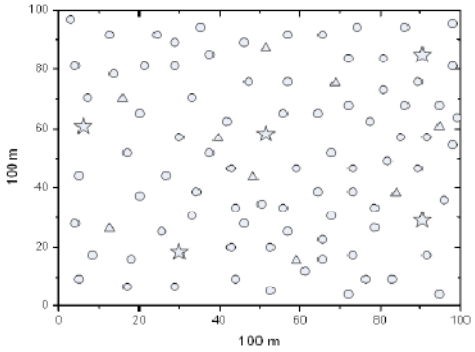
Average number of CH per round per epoch = n * p_{opt}

There are **n (1+αm)** nodes with energy equal to initial energy of normal nodes. If nodes are heterogeneous, then the number of CH per round per epoch is **n (1+αm) p_{nrm}**
where, α is the additional energy factor between normal and advanced nodes. m is the fraction of advanced nodes. p_{nrm} is the probability of advanced nodes. Weighted probabilities for normal and advanced nodes are

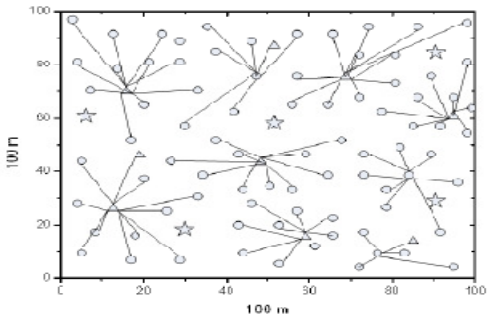
P_{nrm} = [P_{opt} / 1 + α m]
P_{adv} = [p_{opt} / 1 + α m] (1 + α)
P_{adv} is the probability of advanced nodes.

Authors have calculated the thresholds for normal and advanced nodes based on weighted probabilities. A big pitfall of SEP is that no CH is selected in most rounds. Thus the network is not reliable for real time transmission.

C. Novel Stable Selection and Reliable Transmission Protocol for Clustered HWSN
In reference paper [26], the authors propose a protocol called EDFCM (Energy dissipation forecast and clustering management) for WSN. The algorithm provides longest stability period by balancing the energy consumption round by round. The heterogeneous network is composed of three types of nodes type_0 and type_1 and management nodes. The former two nodes do sensing of events and the management nodes manage the type 0 and 1 nodes. Previous depleted energy rate of nodes are also taken into consideration for electing new CHs. The operation of network is divided into two phases.



a) Network structure



b) Clustering in EDFCM [26]

Figure 1 Type_ 0 and Type_1 nodes are shown by circle and triangle, management nodes are shown by star.

a) cluster formation phase
b) data collection phase

The first phase is similar to leach except the selection probability is a weighted function and a stable number of CHs are guaranteed in each round.

D. Base station initiated dynamic routing protocol

Verma [27] has proposed a technique in which nodes that posses higher computational capability, more power and nodes that are location aware are elected the CHs. Basic assumptions made in this protocol are.

a) All nodes are deployed uniformly
b) A CH is considered dead only if the energy is very less.
c) No collision occurs between intra cluster and inter cluster communication
d) CH only does single hop communication.

A level is defined as the distance from base station to the CH. A CH is in low level if it is near to base station. Data flows from higher level to lower level.

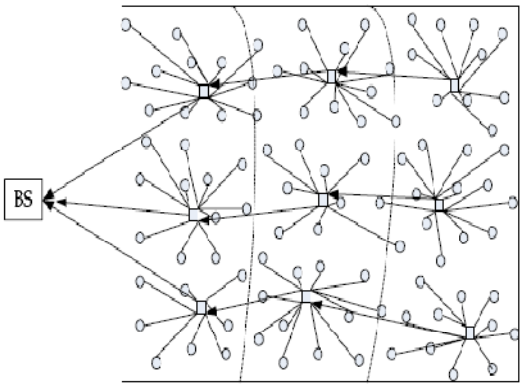


Figure 2. Cluster hierarchy in sensing field. [27]

The base station initiates communication by broadcasting a packet and set its level to 0. All cluster heads have varying signal strength compared to the normal nodes. All CH receive their packets and set their levels accordingly. CH at the first level is selected and they broadcast their levels. CH at lower levels receives packets according to their Radio Signal Strength (RSS). The above process is repeated so that all CH are connected and sensor nodes join their respective cluster heads according to their RSS.

All CH will send their energy, position and levels to the base station at the end of each round. The communication between CH and sensor nodes are single hop where as CH to CH are multihop transmissions.

E. Routing protocol for balancing energy consumption in HWSN

Li X [29] developed a protocol based on residual energy and energy consumption rate (REECR). But in this approach if the CH is very far or very near to the base station instability might occur. An improvement to this is zone based residual energy and energy consumption rate (ZREECR) which improves the stability period. The network is divided into zones depending on the distance and orientation from the base station. Clusters near the base station have smaller cluster size because CHs have to relay the data from the farther CH to the base station.

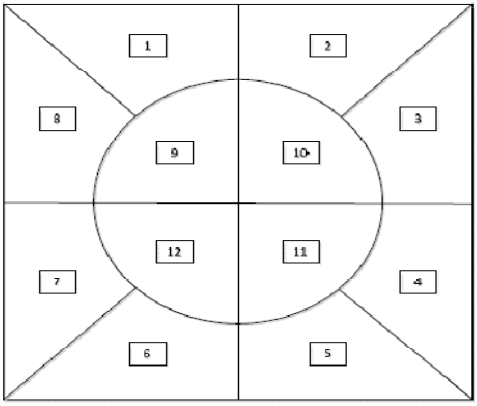


Figure 3. Different size zones in ZREECR.

The network comprises of two types of nodes Type_0 and Type_1 with varying energy. In the first round, the CH is elected at geometric centers so the pitfall of REECR is avoided. In the second round, CH election is based on residual energy and energy consumption rate.

$$\mathbf{P_i(t) = [E_i^{\alpha}(t) \ / \ V_i^{\beta}(t)]}$$

$P_i(t)$ is the probability of electing each node as cluster head.
α , β are weighted coefficients
$E_i(t)$ is the current residual energy of each node
$V_i(t)$ is the energy consumption rate
Even though this protocol is stable compared to RECCR, it is not energy efficient since CH are elected locally at the zone level not at the network level.

V Energy efficient clustering scheme for HWSN

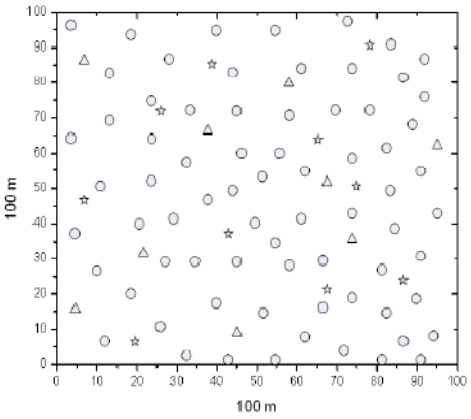
Many algorithms were formulated to reduce the energy consumption based on cluster structure of HWSN. [30-33]. every algorithm has 2 phases.

a) cluster setup phase
b) Steady state phase.

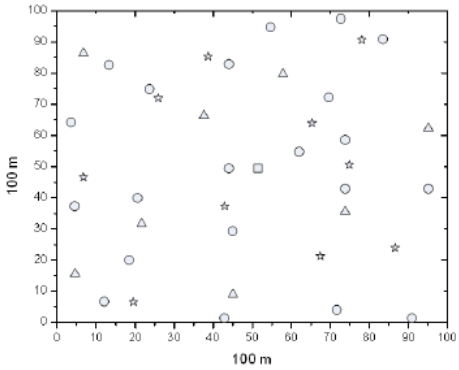
The key task is in selecting the CH. The following subsection discusses various energy efficient clustering protocols like EEHC [34], DEEC [34], SDEEC [37], DBEC [38] and C4SD [39].

A. Energy efficient heterogeneous clustering scheme.

In reference paper [34, 35], the CH is elected based on weighted election probability. This algorithm is based on LEACH where the number of CH per round is P_{opt}. Figure 4 shows heterogeneity of the network, the snapshots when all nodes are alive and how the normal nodes die after some rounds.



a) Network Structure



c) Network after some rounds.

B. Distributed energy efficient clustering algorithm for HWSN

CH is elected based on residual energy of each node and the average energy of the network. The initial and residual energy decides how long a node can be a CH. DEEC is also based on LEACH where the role of the CH is rotated so that energy of all nodes is depleted uniformly.
A basic assumption is made so that every node needs to know the total energy and lifetime of the network. These nodes need not posses' global knowledge of energy at every round.

Every node s_i computes the average probability P by the total energy E_{total}, the estimated value of R is broadcasted by the base station. Pi is used to get the election threshold T(si). This decides si to be selected as the CH or not.

An improvement to DEEC was proposed by Elbhiri, Sandane and Aboutajdini, called Stochastic DEEC [37].

The Stochastic energy is the key idea, it reduces the number of inter cluster transmissions. Unlike DEEC, it makes the non CH nodes to sleep, dividing the network into dynamic clusters.

Phase I: All non CH nodes send the data to their respective CH during an allocated time frame. CH receives data by keeping its receiver on. CH also does some compression in order to obtain a single signal of data.

Phase II: Each CH send data to the main CH. Each non CH nodes go to sleeping mode to conserve energy.
Drawback: The main pitfall of this approach is that the sleeping nodes doesn't know when and how to wake up for the next CH election round.

C. Distributed energy balance clustering Protocol for HWSN

DEBC [38] was proposed by Clangmin Duan and Hong Fan. It's different from LEACH in that each node can be a CH in $n_i = 1/p$ rounds. DEBC chooses n_i according to the node i and remaining energy E^k_i in round k. p_i denotes the probability of node i being cluster head in each n_i rounds. With the help of p_i, probabilities for advanced and normal nodes to be CH can be calculated and this can be further extended to multi-level heterogeneity.

D. Cluster based service discovery for HWSN

Marin [38] proposed C4SD (Clustering for Service Discovery) protocol which is a service discovery protocol for HWSN. It aims to reduce the workload of resource constraint devices. Each node has a hardware identifier and a weight (capability grade). Higher the capability grade more chance to become CH. The higher capability grade nodes act as distributed service registries for nodes in the clusters. Service discovery messages are exchanged only among capability grades, thus communication cost is reduces. The algorithm makes decisions based only on 1-hop neighbors for major topology changes. Therefore, this algorithm constructs sparsely distributed CHs. The clustering algorithm is simulated and compared with distributed mobility adaptive clustering (DMAC). [40]. The result shows that it outperforms DMAC

VI. CONCLUSION

Wireless sensor networks are not always homogeneous, they may be heterogeneous too. This paper surveys research protocols for clustering in heterogeneous wireless sensor networks. Clustering is a good technique to reduce energy consumption and to provide stability in wireless sensor networks. We classified all protocols according to stability and energy efficiency of network. We summarize a number of schemes, stating their strengths and limitations. Finally on the basis of survey work, we conclude that the heterogeneous wireless sensor networks are more suitable for real life applications as compared to the homogeneous counterpart.

TABLE 1
Comparison of the Clustering Algorithms for HWSN

Clustering Approach	**Energy Efficient**	**Cluster Stability**	**Type of heterogeneity**	**Clustering methodology**	**Level of heterogeneity**
SEP	Low	Good	Energy	Distributed	Two
EDFM	Low	Very Good	Computation and energy	Distributed	Three
Base station initiated clustering	Low	Good	Computation and energy	Centralized	Two
ZREECR	Low	Good	Computation and energy	Centralized	Two
EEHC	High	Moderate	Energy	Distributed	Three
DEEC	High	Moderate	Energy	Distributed	Two
SDEEC	High	Good	Energy	Distributed	Two
DEBC	High	Good	Energy	Distributed	Two/Multi
C4SD	High	Moderate	Energy and link	Centralized	Multi

TABLE 2
Classification based on clustering Properties.

Clustering Approach	**Cluster count**	**Intra-cluster topology**	**Connectivity to base station**
SEP	Variable	Fixed (1 hop)	Direct link
EDFM	Variable	Fixed (1 hop)	Direct link
Base station initiated clustering	Fixed	Fixed (1 hop)	Multi-hop
ZREECR	Fixed	Fixed (1 hop)	Multi-hop
EHC	Variable	Fixed (1 hop)	Direct link
DEEC	Variable	Fixed (1 hop)	Direct link
SDEEC	Variable	Fixed (1 hop)	Direct link
DEBC	Variable	Fixed (1 hop)	Direct link
C4SD	Variable	Multi-hop	Multi-hop

TABLE 3
Classification based on cluster head selection.

Clustering Approach	**Mobility**	**Node type**	**Role**
SEP	Fixed	Resource rich	Aggregation
EDFM	Fixed	Resource rich	Aggregation
Base station initiated clustering	Fixed	Resource rich	Aggregation Compression
ZREECR	Fixed	Resource rich	Aggregation
EEHC	Fixed	Resource rich	Relaying
DEEC	Micro mobile/ fixed	Resource rich	Aggregation
SDEEC	Micro mobile/ fixed	Resource rich	Aggregation
DEBC	Micro mobile/ fixed	Resource rich	Fusion and relaying
C4SD	Mobile	Resource rich	Relaying

TABLE 4
Classification based on cluster head capability.

Clustering Approach	**Initial energy**	**Residual energy**	**Energy Consumption rate**	**Average energy of network**
SEP	**X**	√	**X**	**X**
EDFM	**X**	√	**X**	**X**
Base station initiated clustering	√	**X**	**X**	**X**
ZREECR	**X**	√	√	**X**
EEHC	**X**	√	**X**	**X**
DEEC	**X**	√	**X**	√
SDEEC	√	√	**X**	**X**
DEBC	**X**	√	**X**	√
C4SD	√	**X**	**X**	**X**

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