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Survey on Multi Agent Energy Efficient Clustering Algorithms in Wireless Sensor Networks

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ABSTRACT

In the last few years, there are many applications for Wireless Sensor Networks (WSNs). One of the main drawbacks of these networks is the limited battery power of sensor nodes. There are many cases to reduce energy consumption in WSNs. One of them is clustering. Sensor nodes partitioned into the clusters so that one is chosen as Cluster Head (CH). Clustering and selection of the proper node as CH is very significant in reducing energy consumption and increasing network lifetime. In this paper, we have surveyed a multi agent clustering algorithms and compared on various parameters like cluster size, cluster count, clusters equality, parameters used in CHs selection, algorithm complexity, types of algorithm used in clustering, nodes location awareness, inter-cluster and intra-cluster topologies, nodes homogeneity and MAC layer communications.

Keywords. Multi Agent, Distributed, Clustering, Wireless Sensor Networks, Cluster Head

1. INTRODUCTION

Wireless sensor networks (WSNs) are very useful in many applications such as military and industrial control, home and health care delivery and environment surveillance [1]. These networks consist of tiny battery operated sensor nodes. One of the major problems in WSNs is reducing energy consumption and consequently prolonging network lifetime. To achieve this goal, one of the methods is clustering of nodes. Thus, some of nodes are selected to become cluster heads (CHs) and other ordinary nodes choose one of the CHs and join to its cluster. Ordinary nodes transmit their data to the CHs and cluster heads usually gathered their data and send them to the base station (BS). Each clustering approach has some properties and also they are some differences between them. We have mentioned these properties in the continuation.

1.1 CLUSTERING METHODOLOGY

There are different methodologies for clustering of sensor nodes like centralized (showed with C in table 1), distributed (showed with D in table 1) and hybrid (showed with H in table 1) [2]. In centralized clustering, the BS has general information about the network and nodes. So, it can select proper nodes as CHs. But centralized clustering is not scalable. Some centralized clustering algorithms are [3-7]. In distributed clustering, sensor nodes themselves decided to become CHs. Since it is scalable, but it doesn't have

a precision of the centralized clustering. Hybrid methodologies are composed of centralized and distributed approaches. Distributed approaches are used for coordination between CHs, and centralized manners are performed for CHs to build individual clusters [2]. The main purpose of this paper is gathering and comparing the multi agent clustering algorithms. So it is mostly covered distributed and hybrid clustering algorithms.

1.2 THE PARAMETERS USED FOR CHS SELECTION

Select proper nodes as CHs is the main issue in the clustering of WSNs. There are some parameters affecting the selection of CHs like initial energy, node centrality, density (it means the number of neighbor sensor nodes in the radio range of the sensor node), coverage area, the average energy of the network, the average residual energy of neighbors, residual energy, distance to the BS, distance to the neighbors, the cost of being CH and also some other parameters which are not very common. Each clustering approach considers none, one or more than one of these parameters to select the CHs which impressed their performance.

1.3 HIERARCHY LEVEL

After selection of CHs in the network, they should send gathered data to the BS. This can be one-hop (directly transmitting) or multi-hop (transmission with the help of other nodes). Since the amount of energy consumed to send data is straightly related to the distance, so this factor also can affect the energy consumption.

1.4 SENSOR NODES LOCATION AWARENESS

Some of the clustering approaches need the location of each sensor node, but some does not need this information for CHs selection. The node location awareness algorithms mostly used GPS to achieve the coordinates of the sensor node.

1.5 CLUSTERS EQUALITY

The main goal of clustering of WNNs is reducing energy consumption and accordingly prolonging the network lifetime. Some clustering approaches considered unequal clusters (showed with U in table 1) and other ones considered equal clusters (showed with E in table 1). Unequal clustering algorithms mitigate hotspot problem in the multi hop transition of data to the BS by CHs. When CHs cooperate with each other to forward their data to the BS, the CHs closer to the BS are burdened with heavier relay traffic and tend to die much faster, leaving areas of the network uncovered and causing network partitions [8]. Hence, to solve the hot spot problem of transmitting data, some clustering algorithms consider unequal size of clusters.

1.6 CLUSTERING PROPERTIES

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Each cluster has some properties like cluster count, intra-cluster topology, inter-cluster topology and cluster size. Some of the clustering approaches consider a fixed number of clusters. Intra-cluster topology can be one-hop or multiple-hop. If the ordinary nodes send their data directly to the CHs intra-cluster topology is one-hops, but if they get help from other nodes to transmit their data, intra-cluster topology is multi-hop. Similarly, inter-cluster topology can be one-hop or multi-hop depends on the way CHs send their data to the BS. In some approaches, size of clusters is a constant value. It means the number of sensor nodes in all the clusters are a constant value, but in some others clusters size can be changed.

1.7 NODES HETEROGENEITY

WSNs consist of lots of tiny sensor nodes. In some clustering approaches, nodes are homogeneous but in some others they are heterogeneous in terms of initial energy, processing power or communication power. In this paper, we just mean heterogeneous in terms of the initial energy.

1.8 MAC LAYER COMMUNICATION

One of the seven layers of computer networks is data link layer and MAC layer is a sub layer of the data link. MAC layer provides control mechanisms for the nodes to communicate with each other within a multiple access network. In this paper, we mean of this parameter is the communication between ordinary nodes and CHs. There are some different mechanisms like TDMA and CSMA. When a CH uses TDMA method to receive data from nodes, it allows sensor nodes to share the same frequency channel by dividing the signal into different time slots. Each node sends data just in its time slot.

Another mechanism of multiple accesses is CSMA/CD in which each node considers feedbacks from others to determine whether another transmission is in progress or not. Sensor nodes can use the CSMA/CD mechanism to send their data to the CH terminating transition as soon as a collision is detected [9].

1.9 ALGORITHM PROPERTIES

Some approaches have complexities in implementation, but some of them are simple to implement. These complexities can be because of the iterations done to select CHs in each round or computing the probability of being CH is difficult. Also, there are some different types of algorithms used for clustering of WSNs. Some of these algorithms types are the subset of artificial intelligent algorithms like genetic algorithm, fuzzy logic, game theory or other ones. Since, some others use a random selection of CHs and usually the algorithm does not base on the known algorithms.

The rest of the paper is organized as follows, in section 2 we surveyed various multi agent clustering algorithms. Table 1 is determined to easily comparison of these algorithms. Also, the conclusion is presented in section 3.

2. CLUSTERING ALGORITHMS

In this section we present some of the well-known, basic or new clustering algorithms of WSNs. At the end, we provide a table (table 1) with the main properties of each algorithm to be compared easily.

- **LEACH-Centralized (LEACH-C)**

This is a centralized algorithm in which the BS computes the average energy of nodes [10]. Sensor nodes with the lowest energy power than the average energy cannot be CH. CH selection is random and the role of being CH rotates between nodes. Number of clusters are limited and the BS uses simulated annealing algorithm to find an optimum number of clusters in the network. Although because of centralized clustering, this algorithm is not scalable, but it has low complexity to implement.

- **Low-Energy Adaptive Clustering Hierarchy (LEACH)**

LEACH is the one of the well-known clustering algorithms for WSNs [11]. In this algorithm, the task of being CH is rotated randomly between nodes with a certain probability. Each ordinary node joins to a cluster with minimum energy consumption to communicate with its respective CH. This algorithm is simple. Hence, one of the advantages of LEACH is this.

- **Hybrid, Energy-Efficient, Distributed Clustering approach (HEED)**

This algorithm is one of the important clustering algorithms with some significant goals like terminates clustering in O(1) iterations, low message overhead and fairly uniform CHs distribution in the network [12]. HEED periodically selects CH according to first, residual energy of nodes and second node's degree. This algorithm also ensures connectivity of clusters in the network.

- **Unequal Clustering-based Routing (UCR)**

In the UCR algorithm [8], at the beginning, some of the nodes randomly selected as tentative CHs to compete with each other to be final CHs. Then tentative CHs broadcast a message in the network contains its residual energy. A tentative CH with more energy than its neighbors, become a final CH. In this algorithm, there is a threshold value for the distance from CH to the BS. If a distance between a CH and the BS is more than this threshold value, CH sends data to the BS by getting help from other CHs with less distance to the BS and more energy.

- **Multihop Routing Protocol with Unequal Clustering (MRPUC)**

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This is a distributed clustering algorithm in which the clusters are unequal [13]. The radio ranges of clusters near the BS are smaller than the clusters far from the BS. The nodes with more energy than the others become CHs. Each ordinary node joins to the cluster with the smaller distance to its CH and also respective CH should have more energy compared to other CHs. For transmitting data to the BS, each CH selects CHs with more energy and closer to the BS to get help from.

- **Region-based Energy aware Clustering (REC)**

REC is a distributed clustering algorithm selecting CHs based on the residual energy and the coverage area of each sensor node [14]. Suppose there is a node with more energy but it is just one node in its sensitivity range. On the other hand, there is another node with less energy, but there are some nodes in its sensitivity range (the node with less energy and less critical in terms of coverage area). So, if any of these nodes die, there are other nodes covering this area. The algorithm tries to make a tradeoff between these two. Thus, the more the energy and the overlap coverage percentage, the higher the chance of being CH.

- **Clustered Routing for Selfish Sensors (CROSS)**

CROSS is a distributed clustering algorithm based on game theory [15]. In this algorithm, there are two strategies ND (Not Declare itself as CH) and D (Declare itself as CH) with utility functions for each strategy. The authors compute the mixed strategy Nash equilibrium of the game to obtain the probability of being CH for each node. This probability is based on the cost of being CH and the number of nodes in the network.

- **An energy-aware distributed clustering protocol in wireless sensor networks using fuzzy logic (ECPF)**

In ECPF algorithm authors use fuzzy logic to clustering of sensor nodes [16]. They use three techniques to select CHs. First, non-probabilistic CH selection. In which nodes become tentative CHs based on their residual energies. Second, fuzzy logic. There are two inputs for fuzzy logic, node degree and node centrality. For each tentative CH, the lower the fuzzy cost the higher the probability of being final CH. Third, on demand clustering. Instead of CH selection in each round, in this algorithm CH selection is on demand. If a CH energy is less than the specified value, the selection is done for the next round.

- **Energy Aware Clustering approach (EACA)**

EACA [17] is a distributed algorithm with extensions on LEACH [11]. The authors achieve an equation showing the probability of being CH for each node. This probability is a weighted probability used in the LEACH [11] and the weight can compute from the rate of the residual energy and distance of each node. The higher the residual energy and the less the distance to the neighbors, the higher the probability of being CH.

- **Distributed Clustering by Game Theoretical approach (DCGT)**

The authors use game theory for clustering of WSNs [18]. They consider four factors that affect the energy consumption in the networks like residual energy, the cost of being CH, distance to the BS and distance to the neighbors. Authors design a game and compute the mixed strategy Nash equilibrium of the game to achieve the probability of being CH for each sensor node. DCGT algorithm can be used for both heterogeneous and homogeneous networks. This algorithm can increase the network lifetime and in comparison to some other clustering algorithms, it has better performance.

- **Unequal Hybrid, Energy-Efficient, Distributed Clustering approach (UHEED)**

UHEED [19] is an unequal clustering algorithm based on HEED algorithm [12]. The authors try to solve the hot spot problem of HEED [12], wherein the CHs near the BS die earlier. So if the number of CHs near the BS is large, the death of CHs near the BS are postponed. Also, it causes more inter-cluster communication nearer to the BS. Consequently, the network lifetime is increased. The distance to the BS are used to compute the cluster size. The higher the distance to the BS, the larger the size of the cluster.

- **LEACH-Genetic Algorithm (LEACH-GA)**

LEACH-GA [20] is a distributed clustering algorithm which its CH selection is based on LEACH [11]. The difference of these two algorithms is in the inter-cluster topology. In LEACH [11] CHs send their data directly to the BS, but by LEACH-GA CHs transmit their data with the help of others. To select proper nodes to transmit their data, LEACH-GA uses genetic algorithm. The fitness function using to evaluate each chromosome is based on the length of links and the selection method is the roulette wheel.

- **Energy efficient Cluster Based Data Aggregation (ECBDA)**

This clustering algorithm has four phases: cluster formation, CHs election, data aggregation and maintenance [21]. The first phase is used to split the network to *k* clusters in each layer. In the second phase, a node from each cluster with more residual energy and less communication energy is selected as CH. In the third phase, ordinary nodes transmit their data to the CHs. Then CHs aggregate data and send them to the BS. The fourth phase, checks the residual energy of CHs. If the residual energy of a CH is less than the threshold value, a new CH is selected from the same cluster. A disadvantage of this algorithm is the fixed number of clusters.

- **Density Control Energy Balanced Clustering (DCEBC)**

This is a clustering algorithm for the dense WSNs [22]. In DCEBC algorithm, the sensor nodes with more residual energy than the threshold value are becoming CHs. The threshold value is variable for each round and it is based on the density of the cluster. So, for dense regions, the threshold value is higher than the regions with lower density. Thereupon, the number of CHs selected in the dense regions is more than the other ones.

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- **Node Degree Based Clustering (NDBC)**

NDBC is a distributed clustering algorithm in which the initial energy of all nodes are not equal [23]. The main goal of this paper is to select the optimal number of nodes with more initial energy (they are called advanced nodes) as CHs. Firstly, all advanced nodes calculates their density and broadcast this in the network. If an advanced node has more density than its neighbors, it becomes CH. After a round, if the residual energy of a CH is less than the specified threshold value, it will be replaced by another neighbor with maximum density.

- **A Novel Routing Protocol with Lifetime Maximizing Clustering Algorithm for WSN**

In this clustering algorithm, the probability of each sensor node to become CH is calculated from the residual energy and the average energy of all nodes [24]. The selection of CHs continues until the number of selected CHs reached to a predefined number. Each ordinary node joins to a cluster with less energy consumption to transmit data to its CH. All CHs used spanning tree to choose the next CHs to get help from to transmit data to the BS. A drawback of this algorithm is the fixed number of CHs (and clusters).

- **Universal-LEACH (U-LEACH)**

This distributed clustering algorithm has a fixed number of clusters which are formed based on nodes x coordinate [25]. It means that, authors partitioned the x coordinates of the network to a fixed number. Each partition determines a cluster. Every sensor node with x coordinates in the partition intervals are in the same cluster. The node with more value for initial energy/residual energy is selected as CH in each cluster. As mentioned before, the fixed number of clusters is a disadvantage for an algorithm. Also, this algorithm has weak performance when the node distribution is not uniform which is needed in some applications.

- **Heterogeneity aware Hierarchical Stable Election Protocol (HSEP)**

In HSEP algorithm, the probability of being CH is determined from the residual energy/initial energy of each node [26]. CHs named primary CHs in this paper. Then, each primary CH computes its distances to others and selects the CH with minimum distance to it as a secondary CH. Every primary CHs transmit their aggregate data to the respective secondary CH and they send data to the BS. Because a node can be selected as secondary CH of more than one primary CH, the primary CHs use TDMA to transmit their data to the secondary CHs.

- **Energy aware Clustering algorithm (EADC)**

This is a distributed clustering algorithm that the CH selection is based on the ratio between the average residual energy of the neighbor nodes and node itself [27]. Every

ordinary node joins to a cluster with less distance to its CH. Each CH chooses another CH with higher residual energy and less number of members in cluster to get help to transmit its data to the BS. Thus, every CH has a routing tree. If a CH distance to the BS is less than the predefined threshold value, it chooses the BS as its next hop. Otherwise, the CH chooses another CH with the highest residual energy, smaller number of members and smaller distance to the BS and get help from this CH.

- **An Improvement for LEACH Algorithm in Wireless Sensor Network**

In this algorithm, the authors try to compute a lower bound for the number of members in clusters [28]. They get help from the LEACH-C [10] to compute this value. This algorithm also uses LEACH [11] algorithm probability to select CHs. If the number of members in a cluster is less than the specified value, these nodes do not form a cluster and waiting for another CHs to introduce themselves as CH. If they do not hear any CH announcement in a predefined time interval, they send their data directly to the BS. Each CH considers the number of members it have in its cluster and computes the number of rounds it can be CH based on its consuming energy in each round. Thereupon, these numbers of rounds blow over, the members in the cluster do not send their data to the CH and wait for the next CH selection.

- **LEACH-Selective Cluster (LEACH-SC)**

This algorithm uses the LEACH algorithm [11] for CHs selection, but just with one different [29]. In LEACH [11] after CHs selection, ordinary nodes join to the cluster with closer CH to it. But in the LEACH-SC ordinary nodes join to a cluster which its CH is closest to the middle point between the sensor node itself and the BS. From the curves presented in the [29], it is considered LEACH-SC has better performance than LEACH [11].

- **A Reliable Clustering Algorithm base on LEACH Protocol in Wireless Mobile Sensor Networks (LEACH-D)**

Authors of LEACH-D [30] do some basic improvements in the LEACH [11]. 1) They changed the probability of being CH for each node by adding two weights. First the ratio of residual energy to initial energy of the node and second, the ratio of the node degree to the average degree of the nodes in the network. So, the node with more residual energy and density has much more chance to be a CH. 2) The cluster radius (size) is different for nodes. Clusters near the BS have smaller size than the farther clusters. If an ordinary node is in the range of more than one CH, it joins to a cluster that the respective CH has more energy than the others. 3) The inter-cluster communication is intended multi-hop. CHs use DIJKSTRA algorithm [31] to find the shortest path to transmit data to the BS.

- **Adaptive Cluster Head Election and Two-Hop-LEACH (ACHTH-LEACH)**

In this clustering algorithm, every sensor nodes tagged as near or far node [32]. If a node distance to the BS is less than a predefined threshold value, it tags as a near node. Otherwise, it tags as far node. All the near nodes are in the one cluster. For the far nodes, the Greedy K-means

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algorithm [33] is used. In each cluster a node with high residual energy becomes CH. Each far CH node can transmit the aggregated data directly to the BS or gets help from the nearest CH node.

- **Multi-hop Routing-LEACH (MR-LEACH)**

MR-LEACH is a distributed clustering algorithm in which the network partitioned to the layers [34]. The nodes in the first layer can reach the BS in one-hop, the second layer nodes can reach the BS in two-hop and it go on similarly. In each layer, the node with more energy than its neighbors becomes CH. Each CH gets help from its adjacent layer CHs to transmit its aggregated data to the BS.

- **Weighted Spanning Tree (WST-LEACH)**

WST-LEACH [35] algorithm is also based on LEACH [11]. It uses the same probability of being CH as LEACH [11] but just with a weight. This weight is based on the residual energy, initial energy, total number of nodes in the network, the number of neighbors, the distance to the BS of each node and likewise some coefficients. Also, every CHs have a weight. The higher the residual energy of the CH and fewer the distance to the BS and the number of neighbors, the higher the weight of the CH. CHs use the weighted spanning tree to choose proper node to get help from to transmit aggregated data to the BS. The root of the tree is the BS. So, the level of CH in the tree is higher, too.

3. CONCLUSION

According to the excessive applications of WSNs in recent years, their position in people's life is clear. One of the main problems of these networks is limited energy power. Clustering is a technique to reduce the energy consumption of sensor nodes and prolonging network lifetime. In this paper, we present a detailed survey of multi agent clustering algorithms. Most of the recent clustering algorithms consider parameters like residual energy, distance to the BS, density and etc. for CHs selection having a direct effect on reducing energy consumption. These surveyed algorithms obtains a probability of being CH for each node based on none, one or more than one of the mentioned parameters. Most of the clustering algorithms lead to variable clusters count and clusters size. It seems the clustering algorithms with variable clusters count and size reduce the energy consumption more than the other ones. Because, as the time passed, some nodes die. So, the determined constant value for clusters size and count are not optimum. The comparison between various distributed and hybrid clustering algorithms is shown in table 1.

TABLE 1.
Comparison of Clustering algorithms for WSNs

	Clustering Approach	Clustering methodology	Initial energy*	Node centrality*	Density*	Coverage area*	Average energy of network*	Average residual energy of neighbors*	Residual energy*	Distance to the BS*	Distance to the neighbors*	Cost of being CH*	Hierarchy level	Nodes location awareness	Clusters equality	Clusters count**	Intra-cluster topology**	Inter-cluster topology**	Clusters size**	Nodes heterogeneity	MAC layer communication	Algorithm complexity***	Algorithm type***
LEACH-C [10]	C						x						2	Y	E	F	one	one	V	HM	TDMA	low	Rn
LEACH [11]	D												2	N	E	V	one	one	V	HM	TDMA	low	Rn
HEED [12]	H				x				x				2	N	E	V	one	one	V	HM	NM	high	-
UCR [8]	D								x				multi	Y	U	V	one	multi	V	HM	TDMA	low	-
MRPUC [13]	D								x				multi	N	U	V	one	multi	V	HM	TDMA	low	-
REC [14]	D					x			x				multi	N	E	V	one	one	V	NM	TDMA	low	-
CROSS [15]	D											x	2	N	E	V	one	one	V	HM	TDMA	low	GT
ECPF [16]	D	x	x						x				multi	N	E	V	one	multi	V	HM	TDMA	med	FL
EACA [17]	D								x		x		2	Y	E	V	one	multi	V	HM	NM	low	-
DCGT [18]	D								x	x	x	x	2	N	E	V	one	multi	V	HM-HT	TDMA	low	GT
UHEED [19]	H				x				x				multi	N	U	V	one	multi	V	HM	NM	high	-
LEACH-GA [20]	D												multi	N	E	V	multi	multi	V	HM	TDMA	high	Rn
ECBDA [21]	D								x			x	multi	N	E	F	one	multi	F	HM	TDMA	low	-
DCEBC [22]	D								x				multi	N	E	V	one	multi	F	HM	NM	med	-
NDBC [23]	D				x				x				multi	N	E	V	multi	multi	V	HT	TDMA	med	-
[24]	D												multi	N	E	F	one	multi	V	HM	CSMA CD	low	-

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	Clustering Approach	Clustering methodology	Initial energy*	Node centrality*	Density*	Coverage area*	Average energy of network*	Average residual energy of neighbors*	Residual energy*	Distance to the BS*	Distance to the neighbors*	Cost of being CH*	Hierarchy level	Nodes location awareness	Clusters equality	Clusters count**	Intra-cluster topology**	Inter-cluster topology***	Clusters size**	Nodes heterogeneity	MAC layer communication	Algorithm complexity***	Algorithm type***
U-LEACH [25]		D	x						x				multi	Y	E	F	one	multi	V	HT	NM	low	-
HSEP [26]		D							x				multi	N	E	V	one	multi	V	HT	TDMA	low	-
EADC [27]		D						x	x				multi	N	E	V	one	multi	V	HT	NM	low	-
[28]		D											multi	N	E	V	one	one	V	HM	TDMA	low	Rn
LEACH-SC [29]		D											2	Y	E	V	one	one	V	HM	TDMA	low	Rn
LEACH-D [30]		D	x		x				x				multi	N	U	V	one	multi	V	HM	TDMA	med	-

	Clustering Approach	Clustering methodology	Initial energy*	Node centrality*	Density*	Coverage area*	Average energy of network*	Average residual energy of neighbors*	Residual energy*	Distance to the BS*	Distance to the neighbors*	Cost of being CH*	Hierarchy level	Nodes location awareness	Clusters equality	Clusters count**	Intra-cluster topology**	Inter-cluster topology**	Clusters size**	Nodes heterogeneity	MAC layer communication	Algorithm complexity***	Algorithm type***
ACHTH-LEACH [32]		D							x				multi	N	E	F	one	multi	F	HM	TDMA	low	-
MR-LEACH [34]		D							x				multi	N	E	V	one	multi	V	HM	TDMA	low	-
WST-LEACH [35]		D	x		x				x	x			multi	N	E	V	one	multi	V	HM	TDMA	med	-

Distributed (D) Centralized (C) Hybrid (H) - Equal (E) Unequal (U) Not Mentioned (NM) Variable (V) Fix (F) - Homogeneous (HM) - Heterogeneous (HT) - Random (Rn) - Game Theory (GT) - Fuzzy Logic (FL)

* The parameters used for CHs selection

** Clustering properties

*** Algorithm properties

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