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Clustering Algorithms of Wireless Sensor Networks: A Survey

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Abstract: In the recent few years the research on Wireless Sensor Networks (WSN) and its variants have risen enormously. The researchers all across the globe are trying to develop a routing protocol that is energy efficient and provides adequate security level in data communication. One of the techniques the researchers use is Clustering of the sensor network. This technique inherently consumes less energy during data communication as the nodes have assigned a dedicated task to perform. A total of 32 clustering algorithms / protocols have been surveyed and comparison of these protocols based on the metrics like heterogeneity, clustering method, size of the cluster etc. have been presented.

Keywords: Network lifetime, cluster size, cluster count, residual energy, node degree, average network energy

I. INTRODUCTION

The WSN organizes several sensing nodes that cooperate wirelessly among each other, are settled in three-dimensional way to intelligently monitor and record and subsequently convey desired information on intended environmental / physical phenomenon. Fundamentally, a WSN is a group of wireless sensor nodes which has the ability of self-configuration, as per the requirements. The researchers over a period of time have proposed hundreds of energy efficient protocols based different techniques. One of the techniques they utilized is Clustering. The clustering of sensor network is either take place soon after the deployment of sensor nodes in the target area or it takes place in the later stages of the deployment of the nodes. The sensor nodes in cluster based routing, present in the cluster elects its Cluster Head (CH) and then the member nodes of the respective cluster disseminate their recorded data to Base Station (BS) via elected CHs. The technique of clustering ensures in prolonging network lifetime.

The paper is further structured in four sections as mentioned. The Section 2 describes related work, section 3 discussed the cluster based routing protocols, section 4 summarizes the discussion and conclusion is given in section 5.

II. RELATED WORK

A lot of researchers have contributed in the development of cluster based energy efficient routing protocols during the past ten years. Several survey papers have been published by the academicians and researchers. The authors of these survey papers have not discussed and compared a large of clustering protocols in their papers. Thereby unable to clearly draft a wholesome picture of clustering pros and cons in WSN architecture. A short description of the related works is presented in Table 1 below

TABLE 1. RELATED WORK IN TABULAR FORM

Year	Authors	Literature	Main Contributions
2010[1]	Vivek Katiyar et al.	"Clustering Algorithm for Heterogeneous Wireless Sensor Networks : A Survey"	Discussion on 12 clustering protocols
2011[2]	Vinay Kumar et al.	"Energy Efficient Clustering Algorithms in Wireless Sensor Networks : A Survey"	Discussion on 22 clustering protocols and different variants of LEACH
2012[3]	Dipak Wajgi et al.	"Load Balancing Algorithms in Wireless Sensor Networks"	Discussion on 13 clustering protocols
2013[4]	D.J. Dechene et al.	"A Survey of Clustering Algorithms for Wireless Sensor Networks"	Division of 12 Protocols in terms of Heuristics, Hierarchical, Weighted and Grid Schemes
2014[5]	B. Revathy et al.	"Latest Algorithms in Wireless Sensor Networks for Energy Conservation : A Survey"	Discussion on 03 clustering protocols along with their Pseudocode
2015[6]	Gaurav Kumar Nigam et al.	"A Survey on Protocols and Routing Algorithms for Wireless Sensor Networks"	Discussion on 13 clustering protocols along with their advantages & disadvantages
2015[7]	Mohini Kumrawat et al.	"Survey on Clustering Algorithms of Wireless Sensor Networks"	Discussed 10 protocols and they were divided on the basis of connectivity, mobility, identification and combined weight.

III. CLUSTRING ALGORITHSMS & PROTOCOLS FOR WSN

The WSN algorithms and protocols can be categorized in several different ways. In this paper we have categorized the clustering algorithms / protocols of WSN on the basis of probalistic and non-probabilistic protocols and are described below:

A. Probabilistic Protocols

In probability based clustered routing protocols each sensor node at the time of deployment is assigned with a probability that how often that sensor node will likely to be selected as CH during the CH election process. The assigned probability of the senor node serves as the basic criterion for CH selection.

Low Energy Adaptive Cluster Hierarchical (LEACH) Protocol

The authors in [8] proposed a well-known cluster centered routing protocol known as Low Energy Adaptive Cluster Hierarchical (LEACH) routing protocol. In LEACH after every round the energy level of the current Cluster Head (CH) is checked and if its energy is drained and below the threshold value then based on the probalistic theory new CH will be selected. The responsibilities of the CH is to be rotated or shared among the sensor nodes of the network. This rotation of CH responsibility stabilizes the consumption of energy of network nodes such that no node will be overwhelmed.

Stable Election Protocol (SEP)

The authors in [9] introduced a clustering algorithm and named it Stable Election Protocol (SEP). In SEP, the authors have introduced a heterogeneity i.e. "Normal Nodes" and "Advanced Nodes" (nodes that have more initial energy when deployed) are present in sensor network. Only "Advanced Nodes" are capable of performing their duties as CHs while the Normal Nodes can either be as relay nodes or for transmission of its own data but cannot perform the function of data aggregation as it is specific for CHs.

Hybrid Energy Efficient Distributed Computing (HEED) Protocol

The authors in [10], in order to increase the balance of energy consumption among different parts of the sensor network, have utilized remaining or residual energy, degree of node or node density as a main parameters for the selection of CH. The HEED protocol works on the three main parameters i.e. distribution of energy consumption for increasing the lifetime of the network, the selection of CH is to be terminated after a fixed or pre-defined number of iterations and thirdly the CH are spread or located in such a manner that maximum number of nodes have an easy access to them.

Distributed Energy Efficient Hierarchical Clustering (DWEHC) Protocol

The researchers in [11] suggested an energy efficient routing protocol which is weight centered and it is developed to ensure the energy efficiency by creating the clusters of balanced sized and improving intra cluster network topology. Every sensor node in the network computes its corresponding weight in the network by measuring its remaining energy as well as total number of directly connected neighbors. A node which has the highest weight in the neighborhood will be regarded as the CH and other nodes will become the member nodes. The "Member Nodes" at that time are termed as "First Level Member" nodes.

Distributed Energy Efficient Clustering (DEEC) Algorithm

The authors in [12] developed a routing protocol that is multilevel clustering protocol explicitly engineered for heterogeneous WSNs. In the protocol a procedure for the selection of CH is established on the ratio of remaining energy of the sensor node which is being evaluated for the role of CH with that of the average network energy. In this protocol the authors have initially considered two levels of energy i.e. the sensor nodes distributed in network are of two energy levels or possess different amounts of energy. Each node of the network must have a knowledge of energy levels of all sensor nodes present in the sensing network.

Distributed Energy Balance Clustering (DEBC) Protocol

The authors in [13] proposed a clustering protocol similar to the DEEC protocol in that the selection of CH in each round is based on the residual energy of the sensor node that is being evaluated for the next round CH with that of the average energy of the remaining node of the network. The nodes of different energy levels are deployed randomly in target area and the nodes that have the higher initial energy will likely to be selected as CH number of times than their low energy counter parts nodes. This protocol increases the capability of existing classical LEACH and SEP protocols by employing two energy level heterogeneity.

An Unequal Cluster-Based Routing (UCR) Protocol

The authors of [14] proposed this protocol in order to mitigate the issue of hot spot in the sensor networks. This protocol is reactive or source driven routing protocol specifically designed for applications such as environmental monitoring, fire detection etc. The selection of CH is centered on the remaining energy of the neighboring sensor nodes. The CHs which are located near the BS have less quantity of nodes in their cluster as compare to the CHs that are situated farther from the BS.

Cluster Based Service Discovery (C4SD) Protocol

The authors in [15] have proposed a protocol in which each node of the network is assigned with a unique hardware ID and a numerical weight value. The node which has the highest level of capability must be assigned a task of CH. Such nodes perform the role of service directory for registration of nodes in the cluster.

This protocol ensures the less amount of maintenance overhead and construction overhead incur during the section process of CH.

Energy Efficient Heterogeneous Cluster (EEHC) Protocol

The authors in [16] have proposed a routing protocol in which the sensing nodes of three dissimilar energy levels are deployed randomly in the intended area. An election process of CH is centered on the weighted probability assigned to each sensor node of network. In this protocol the Member Nodes of the cluster connect with corresponding CH and then CHs of each cluster will transmit or communicate the aggregated data to the BS.

Stochastic Distributed Energy Efficient Clustering (SDEEC) Protocol

The researchers in [17] proposed an application specific clustering protocol that is basically the extension of DEEC protocol by implementing the stochastic approach to save energy by reducing the intra cluster transmission. This approach is useful once the intent is to get the max or min data values such as pressure, humidity, and temperature etc. from the target area of the deployed network. The CH chooses only the relevant information from the entire range of received data from the nodes and subsequently disseminates that selected data to the BS. In this way the nodes that have a critical information to share with its corresponding CH

Stochastic and Balanced Distributed Energy Efficient Clustering (SBDEEC) Protocol

The author is [18] proposed a clustering protocol with the purpose of decreasing energy consumption and increase the lifetime of network. The protocol helps in deploying the sensor nodes of two different energy levels. During the initial rounds of the CH selection the sensor nodes with the higher energy level are more likely to be selected as CHs and when the residual energy of these CHs becomes approximately equal to that of the nodes with initial lower energy levels are now become at parity and have identical probability to be selected as CHs.

Distributed Cluster Head Election (DCHE) Protocol

The authors in [19] suggested a cluster centered routing protocol for heterogeneous WSNs. The sensor nodes of three different energy levels are deployed in the sensor network and individual node of the network is allotted with a unique weight of probability to be elected as CH. In this protocol the "Member Nodes" of each cluster link with respective CH and then the CHs will communicate the aggregated data to BS. A node having highest current weighted value will be chosen as CH for that particular round.

Developed Distributed Energy Efficient Clustering (DDEEC) Protocol

The authors in [20] have suggested a clustering protocol that is basically founded on DEEC protocol. In that protocol, the nodes of the sensor network must have a global knowledge of the network nodes. Each node uses its initial energy and the residual energy during the CH election process. The sensor node having the highest amount of present energy will be chosen as the CH for that round.. Each member node of the cluster send the recorded data of its environment to the CH and the CH after performing data aggregation send that aggregated data to the BS.

Energy Efficient Clustering for Self-Organized (EECS) Protocol

The authors in [21] proposed an energy efficient clustering protocol based on three parameters. The election of CH for each round is based on the weighted probability assigned to each node in the initial phase of the network. As mentioned earlier the CH is elected for each round by considering the three parameters. Firstly, the amount of energy the node under evaluation for the role of CH presently possesses i.e. the difference between the initial energy and the energy depleted. Secondly, the amount of time the nodes takes to be selected as the CH and the time it takes to aggregate the received data and send it to the BS and thirdly the number of times the node selected as CCH in the past.

Mobile Node based Clustering Protocol (MNCP)

The authors in [22] proposed an algorithm that resolves the problem hot spot or energy hole created due to low residual energy of the sensor nodes. In this protocol the authors demonstrated that the mobile node can move anywhere in the network where the nodes are facing difficulty in the CH election process due to low residual energy of the competing sensor nodes. Whenever a node facing a problem in CH election process due to low residual energy level it sends a message intended for an active mobile node in the nearby area. The nearby mobile node will quickly respond to the message

Improved and Balanced LEACH Protocol

The authors in [23] proposed a self-organizing and adaptive clustering routing protocol for the heterogeneous wireless sensor networks. This protocol achieves the balanced energy consumption by using randomization technique in even distribution of workload among the sensor nodes. In this protocol the high energy nodes which are often known as NCG nodes takes the responsibilities of the CH and starts aggregating the data received form the cluster's member nodes and after the process of data fusion send that fused data to the chosen gateway nodes to further transmission to the faraway BS.

Energy Consumption & Lifetime analysis in Clustered Multi-hop (ECLCM) Protocol

The authors in [24] proposed an algorithm that estimate the energy consumption in multi hop wireless

senor network with each node having a predefined probability for CH selection. In this protocol each node selected itself as a CH with the probability defined initially and starts to inform its neighboring nodes or the nodes that are located in its transmission range. Each node receives a certain number of advertisement messages form the prospective CHs during a certain period of time and the node that node as their CH which is least number hops away from it.

Weighted Election Protocol (WEP)

The authors in [25] have proposed a routing algorithm that enhances the stability period of the network. In this protocol the weight to each node of the sensor network is assigned to the extent that each node has equal opportunity to be selected as CH. After the assignment of probability weights to each node of the network the cluster numbers are assigned and the CHs are selected in the same manner as selected in case of LEACH protocol. After that the CHs chain is to be built and hence the chain leader is to be selected in a random fashion.

Energy Efficient Cluster Based Data Aggregation (EECBDA) Protocol

The authors in [26] suggested an energy efficient protocol to increase the lifetime and stability period of the network. During the cluster formation phase of the EECBDA protocol a group of clusters are established in the sensor network. A Layer in the network must have 'n' number of clusters i.e. individual layer is additionally distributed into 'n' number of clusters. For the duration of the CH election process every individual sensor node is to be elected from each of the layers based on the current amount of remaining energy and Communication Cost Factor (CCF).

Density Control Energy Balanced Clustering (DCEBC) Protocol

The authors in [27] proposed an energy efficient routing protocol that works by electing the CH on the basis of present energy level of the sensor nodes and the probability threshold value. The protocol also taken into account the identification of redundant nodes and their deactivation to avoid traffic congestion and save energy.

Traffic Bases Clustering (TBC) Protocol

The authors in [28] have proposed a cluster based routing protocol in which the topology of the network is adaptive. The network topology is dependent on the pattern of the traffic and the node density of the target area. The CH that is situated near the BS have to perform dual responsibilities both of sending the data collected from its own cluster members and the data received from other CHs that are not in the transmission range of the BS. Therefore, in this scenario the CHs that located nearer to the BS will be depleted soon.

Probability Driven Unequal Clustering (PRODUCE) Protocol

The authors in [29] proposed an algorithm that organizes the sensor network that has clusters of unequal sizes. The clusters which are away from the BS have greater number of sensor nodes than the clusters which are situated near the BS. To elect the CH different probability values are assigned in each level of the network.

Energy and Distance Based Clustering (EDBC) Protocol

The authors in [30] developed a protocol that considers the residual energy as well the distance of each sensor node with the BS in the CH election process. In a large network of sensor nodes some of the nodes are deployed near to the BS while other nodes are deployed far from the BS. The nodes that are deployed away from the BS high transmission power to send data to the BS. In order to avoid this the authors have divided the entire network area into concentric circular regions around the BS.

Distributed Clustering with Load Balancing (DCLB) Protocol

The authors in [31] proposed a distributed clustering algorithm that builds clusters of different sizes in every step depending on the load of the network. The volume of data that is required to be sent to the BS is to be measured in every step. The part of the network that has greater volume of data, a large number of clusters will be built there to share the data for the purpose of load balancing.

Density and Distance Based Cluster Head Selection (DDCHS) Protocol

The authors in [32] developed an algorithm in which the election of CH is based on the distance and density of sensors in the network. In the protocol the area of clustering is divided into four quadrants of equal sizes by drawing two perpendicular diameters. The CH from each quadrant is to be elected based on the node density and distance from the BS.

Energy Efficient Clustering Scheme with Self-Organized ID Assignment (EECSIA)

The authors in [33] developed an energy efficient cluster based routing protocol that considers both the network topology and current energy levels of the sensor nodes. The protocol makes the sensor network scalable by assigning unique Identification Number (ID) to each of the sensor nodes which helps in reducing the communication overhead and thereby increasing the network lifetime. Furthermore, the EECSIA routing protocol ensures that an energy of CH will not drain due to the reception of large amount of data

Fault Tolerant Energy Efficient Distributed Clustering (FEED) Protocol

The authors in [34] proposed an energy efficient algorithm that uses four parameters namely density of the nodes in the network, current energy level of the

sensor nodes, distance between the sensor nodes and the centrality of the nodes in the network. The authors have proposed a supervisory node that is to be nominated and placed in every cluster as a backup of CH. In case of ailure of CH the supervisory node will take over as a CH for that cluster.

B. NON - PROBABILISTIC PROTOCOLS

In non – probabilistic based clustered routing protocol the selection process is more specific depending on several factors such as connectivity of sensor nodes, position of the nodes, number of neighboring nodes etc.

Location Based Clustering (LBC) Algorithm

The authors in [35] have proposed a routing protocol in which the clustering of the network will take place once in the lifetime of the network. The CH are formed on the basis of the residual energy of the nodes present in a particular cluster. The rotation time for the change in CH is dependent on the type of application for the nodes are performing their duties as different application.

Node Degree Based (NDB) Protocol

The authors in [36] have proposed a routing protocol in which they deployed two types of sensor nodes i.e. Advanced Nodes and Normal Nodes. The Advanced Nodes have more energy than the Normal Nodes. The nodes having higher energy level i.e. Advanced Nodes are likely to be selected as CHs of their respective clusters. The communication overhead for the election of CH has been reduced.

Power Efficient Zoning Clustering Algorithm (PEZCA)

The authors in [37] have proposed cluster based energy efficient routing protocol. The authors combined two well-known clustering protocols; LEACH and PEGASIS to get the optimum performance from their proposed protocol. In this protocol the BS is positioned in the center of the fan-shaped sensor network and the clusters that are away from the BS have more nodes density than the clusters which are near to the BS.

Voting on Grid Clustering (VoGC)

In [38] the authors have used the methods of voting and clustering to produce an energy efficient and secure localization of the sensor nodes. Instead of using conventional clustering method the authors have adopted Voting-On-Grid method to reduce computational cost.

Battery Aware Reliable Clustering (BARC)

In [39] the authors have proposed an energy efficient cluster based routing protocol in which the authors have used Z-MAC protocol for data communication and the CH rotates among the available active nodes as per the defined battery recovery schemes.

IV. CLUSTER BASED ROUTING PROTOCOLS : A COMPARISON

Below in Table 1 we have compared the above discussed routing protocols.

TABLE II. COMPARISON OF WSN ALGOS & PROTOCOLS

Clustering Approach	Node Deployment Uniform / Random	Heterogeneity (Y/N)	Heterogeneity Level	Clustering Method Distributed (D)/ Centralized (C) /Hybrid (H)	Location Awareness (Y/N)	Cluster Head Mobility Fixed (F)/ Mobile (M)	Clustering Properties						CH Selection based On				
													Probability Based		Non Probability Based		
							Cluster Count Variable (V) /Fixed (F)	*Cluster Size Variable (V) /Fixed (F)*	*Cluster Density Variable (V) /Fixed (F)*	*Message Count Yes (Y) /NO (N)*	*Intra-cluster Topology*	*Connectivity of CH to BS*	*Pure Probability (Y/N)*	*Weighed Probability(Y/N)*	*Neighbor (Y/N)*	*Distance (Y/N)*	*Location (Y/N)*
LEACH [9]	Random	N	-	D	N	F	V	V	V	N	Single Hop	Direct Link	Y	-	-	-	-
SEP [10]	Random	Y	Two	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
HEED [11]	Random	N	-	D	N	F	V	V	V	N	Single Hop	Direct Link	Y	-	-	-	-
DWEHC [12]	Random	N	-	D	N	F	V	V	V	N	Single Hop	Direct link	-	Y	-	-	-

DEEC [13]	Random	Y	Two/ Multi	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
DEBC [14]	Random	Y	Two/ Multi	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
UCR [15]	Random	N	-	D	N	F	V	V	V	N	Single Hop	Multi Hop	Y	Y	-	-	-
Improved LEACH [16]	Random	N	-	D	N	F	V	V	V	N	Single Hop	Direct Link	Y	-	-	-	-
EEHC [17]	Random	Y	Three	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
SDEEC [18]	Random	Y	Two	D	N	F	V	V	V	N	Single hop	Direct Link	-	Y	-	-	-
SBDEEC [19]	Random	Y	Two	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
TDEEC [20]	Random	Y	Two/ Multi	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
DDEEC [21]	Random	Y	Two	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
HSR [28]	Random	Y	Two	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
EECS [22]	Random	N	-	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
MNCP [23]	Random	N	-	D	N	M	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
IB-LEACH [24]	Random	N	-	D	N	F	V	V	V	N	Single hop	Direct Link	Y	-	-	-	
ECLCM [25]	Random	N	-	D	N	F	V	V	V	Y	Single Hop	Direct Link	-	Y	-	-	-
WEP [26]	Random	Y	Two	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
EECDBA[27]	Random	N	-	D	N	F	V	V	V	Y	Single Hop	Direct Link	-	Y	-	-	-
TBC [29]	Random	Y	Two	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
PRODUCE[30]	Random	Y	Two	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
EDBC[31]	Random	Y	Two	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
DCLB[32]	Random	Y	Two	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
DDCHS[33]	Random	Y	Two	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
EECSIA[34]	Random	Y	Two	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
FEED[35]	Random	Y	Two	D	N	F	V	V	V	N	Single Hop	Direct Link	-	Y	-	-	-
LBC[36]	Random	N	-	C	Y	F	F	F	V	Y	Single Hop	Direct Link	-	-	-	-	Y
NDBC [37]	Random	Y	Two	D	N	F	F	V	V	Y	Multi Hop	Single Hop	-	-	Y	-	-
PEZCA [38]	Random	Y	Two	D	N	F	V	V	V	N	Single Hop	Single Hop	-	-	Y	-	-
VoGC [39]	Random	Y	Two	D	N	F	F	V	V	Y	Multi Hop	Single Hop	-	-	Y	-	-
BARC [40]	Random	Y	Two	D	N	F	V	V	V	N	Single Hop	Single Hop	-	-	Y	-	-

CONCLUSION

The energy efficiency of WSN is of critical importance as the sensor are using low energy batteries and usually deployed in hostile environment. We have surveyed 32 clustering algorithms in which the authors have used metrics like node density, residual energy, node degree, average energy of the network etc. in the election process of CH which ensures consumption of less amount on node energy in totality. However, some of these protocols lead in the formation of variable cluster sizes and variable cluster counts and some of the protocols create a hole near the BS which then consumes more energy in message communication.

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