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Clustering and Energy Efficiency in Wireless Sensor Networks: A Study

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***Abstract*—A wireless sensor network comprises a number of small sensors that communicate with each other. Each sensor collects the data and communicates through the network to a single processing center that is a base station. The communication of node and process of message passing consumes energy. This energy consumption by the nodes to transmit data decreases the network lifetime significantly. Clustering is by far the best solution to save the energy consumption in the context of such network. Clustering divides the sensors into groups, so that sensors communicate information only to cluster heads and then the cluster heads communicate the aggregated information to the processing center so as to save energy. This paper studies and discusses various dimensions and approaches of some broadly discovered algorithms for clustering. It also presents a comparative study of various clustering algorithms and discussion about the potential research areas and the challenges of clustering in wireless sensor networks.**

Keywords-base station; clustering; cluster head;multi hop;nodes; sensors; single hop; WSN

I. INTRODUCTION

A wireless sensor network (WSN) includes a large number of small devices called sensors. These sensor nodes are responsible for collecting the sensory data from various nodes and transfer it to the base station through the intermediate nodes (***Figure 1***). The node which is near to the base station has to send more data than other nodes. One of the major limitations of wireless sensor networks is low battery capacity of the sensor nodes. These nodes use battery power which has limited energy.

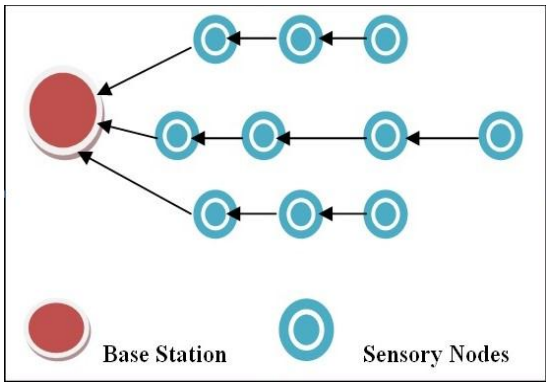

Figure 1. Wireless Sensor network

Sensor nodes use battery power to perform operations like data collection, data compression, data evaluation and their communications. Towards the end of the battery power, nodes will die which leads to the loss of information. In unsafe areas and difficult terrains there is no possibility of changing or recharging the battery of sensors therefore the energy has to be optimised so has to improve the network lifetime. This paper studies and discusses various dimensions and approaches of some broadly discovered algorithms for clustering. It also presents a comparative study of various clustering algorithms and discussion about the potential research areas and the challenges of clustering in wireless sensor networks.

A. Clustering in wireless sensor networks

To increase the life time of the network there is a need to use the energy in an efficient way. A number of energy efficient protocols address the issue; however clustering provides one the best solutions to the problem. Clustering is a technique for decreasing energy utilization and increasing network lifetime. In addition it also provides higher security, decreases redundant data and increases scalability. Clustering divides the nodes in a network into groups which are called clusters. Each cluster has a cluster head and all the members coordinate with it. Cluster heads have the responsibility to communicate with their own members and other cluster heads. There are various methods for selecting cluster head. In some methods, cluster head is selected by cluster members;

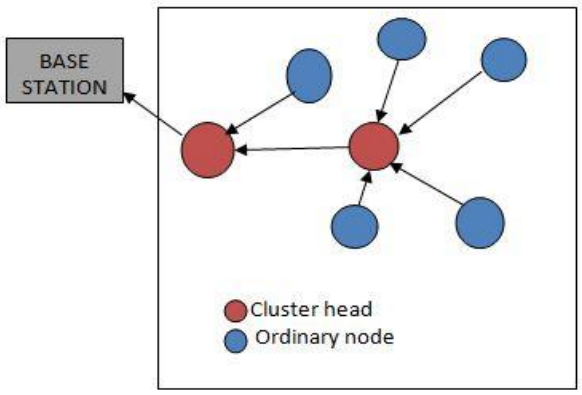

Figure 2. Clustering in WSN

While, in other methods cluster head is selected by the network designer.

Cluster head can be constant during network lifetime or change based on the algorithm. The same is true for the members of clusters as well. In clustering methods, each sensor is either a cluster head which introduces itself in a specific region or is an ordinary node which must introduce itself to cluster head and become its member. The members are only able to communicate with their own cluster head and transmit their data to it. Each cluster head receives data from its member nodes, aggregate that data and send it to the base station [11].

II. LITERATURE REVIEW

In this paper [1], author proposed a Load-balanced energy efficient clustering protocol (LBEEC) to increase the life time of the nodes and balance the load of nodes. The research introduced a virtual circle which with an innovative strategy in protocol architecture causes balancing of energy consumption throughout the network. In this protocol leader node is responsible for collecting and compressing data from the ordinary nodes and further sending it to the head of the cluster. In this algorithm nodes send data to the leader node and then leader node sends that data to the nearest cluster head that has been selected with a decentralized approach. An appropriate measure will then send data to the base station using multi hop way. Nodes compete with each other to select the leader node and cluster head. This protocol has a setup phase and a steady phase. In the ***setup phase*** cluster head selection, leader node selection, next hop selection and path between each node to the base station is determined. In the *Steady phase*, the network data is matched by defined topology in setup phase, collected from nodes and sent to the Base Station (BS) through cluster heads.

In this paper [2] author proposed a protocol that is Low energy adaptive clustering hierarchy (LEACH) protocol. In this protocol, in each round cluster heads are selected, then the non-cluster head nodes give information to the nearest cluster head and the cluster head after gathering and compression of data sends that data to the base station for further processing as illustrated in ***Figure 2***. This protocol performs all the steps of selecting cluster heads to data collection in a decentralized way. Numerous clustering based protocols have been developed till date and all of them attempt to overcome the challenges involved in this LEACH protocol. In LEACH, whole operation is divided into rounds and in every round the algorithm executes two phases first is setup phase and second is steady state phase. In setup phase each node calculates its probability of becoming a cluster head (CH) by generating a random number between 0 and 1. If a node's random number is less than a threshold (Th) value, the node is selected as CH and it sends CHADV message to all other nodes. The nodes that have value greater than threshold are not selected as CH, and they send join message to the nearest CH. LEACH protocol ensures that each node will become CH at least once in 1/p rounds, where p is the required number of cluster heads in the network. In this protocol, each node by generating a random number and comparing it with a threshold value decides whether it must be a cluster head in this round or not. Then all the nodes that have decided to be a cluster head will notify their decision to the entire network. Among the problems of this protocol, the possibility to choose low-energy nodes as cluster head and the possibility of improper distribution of cluster heads can be pointed.

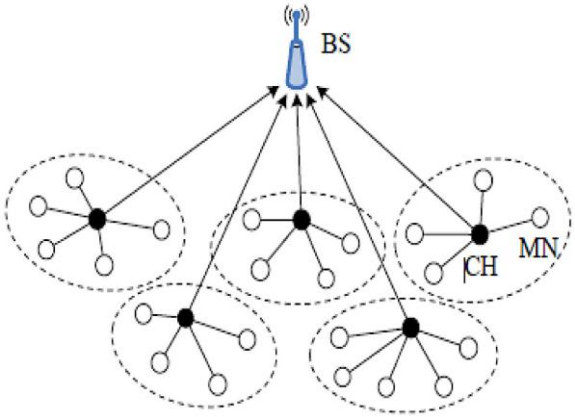

Figure 3. LEACH Algorithm

In this paper [3] author proposed protocol called PEGASIS (Power-Efficient Gathering in *Sensor* Information Systems), that is a chain based protocol. It is near optimal for data gathering application in sensor networks. The protocol may not be counted as a clustering protocol, but its method for reducing energy consumption alike all clustering protocols is reducing the size of data sent to the centre by compression and elimination of redundant information. The key idea in PEGASIS is to form a chain among the sensor nodes so that each node will receive from and transmit to a close neighbor. This protocol gives the idea to save the energy without cluster formation. Gathered data moves from node to node, get fused, and eventually a designated node transmits to the base station. Nodes take turns transmitting to the base station so that the average energy spent by each node per round is reduced. Building a chain to minimize the total length is similar to the travelling salesman problem, which is known to be intractable. However, with the radio communication energy parameters, a simple chain built with a greedy approach performs quite well.

PEGASIS performs better than LEACH as it eliminates the requirement of formation of dynamic clusters and also it provides better load balancing as fusion is done at each node rather than creating overhead at a single node which may

lead to a situation where all nodes will die nearly at the same time. But PEGASIS also has some limitations as it requires prior knowledge of network topology which is quite impractical in large distributed systems and also if a single node dies it will break the whole network which will reduce reliability.

In this paper [4], author proposed an energy efficient hierarchical clustering (EEHC). It uses a distributed, randomized clustering algorithm to organize the sensors in a wireless sensor network into clusters. The algorithm is further extended to generate a hierarchy of cluster heads and observe that the energy savings increase with the number of levels in the hierarchy. Results in stochastic geometry are used to derive solutions for the values of parameters of the algorithm that minimizes the total energy spent in the network when all sensors report data through the cluster heads to the processing centre.

This algorithm is performed in two stages; first is the initial stage and second is the extended stage. In initial stage, every node elects itself as cluster head with probability P and forwards a message to its neighboring nodes within its transmission range. These clusters are called as volunteer cluster heads. In second stage, the nodes that are within k-hop region of any volunteer cluster head and are itself not a cluster head will join the closest cluster head. If announcement message does not reach any node within a specified time interval then that node becomes forced cluster head considering that it is not k-hop away from any CHs.

In this paper [5] author proposed a Hybrid Energy Efficient Distributed (HEED) approach which is also a clustering protocol that uses multi-level energy feature to select the cluster head node. It uses the combination of adjacent degree with neighbours and residual energy of each node to form clusters. In this algorithm, cluster heads are suitably distributed and sending data to the Base Station is performed in a multi-hop way.
The algorithm of HEED has three phases:

i) Initialization phase

Initial percentage of cluster heads is given by designer of network. This value is used to control CH declaration messages to other sensors and by utilizing this value each node calculates its probability of being a Cluster Head.

ii) Repetition phase

This is an iterative phase in which a recursive approach is applied to elect CHs. Every node continues to repeat this phase until it discovers the CH to which it can forward data with minimum transmission. If a node does not find a CH after some specified iterations, it selects itself to be a CH and sends a declaration message to its neighbors that contains present status of that node. Finally, each sensor doubles its CH probability and move to the next iteration of that particular round and stops performing this phase when this probability reaches 1.

iii) Finalization phase

During this phase, final decision is taken by the nodes considering their status. It either decides to become CH or join any other CH with minimum cost.

HEED provides better load balancing than LEACH and reduces message overhead. But HEED requires repeated iterations to calculate cluster heads due to decrease in residual energy that increases complexity.

The paper [6] through Energy Efficient Unequal Clustering (EEUC) proposed by Li et al. is a distributed competitive clustering algorithm that elects cluster-heads by local competition. EEUC provides an improvement by considering that nodes closer to the base station have to forward more data than the nodes farther from base station because they have to participate more in inter-cluster communication. In WSNs, network gets more congested near the base station. Congestion in a network is the reason that the nodes that are deployed nearer to base station will deplete their energy rapidly and die earlier. EEUC reduces work load of nearer nodes of base station by diminishing intra-cluster communication and remove hot spot problem. If a node nearer to base station has less intra-cluster communication load then it can participate in inter-cluster communication more efficiently. So EEUC introduces the concept to create clusters of unequal sizes by finding competitive range which is calculated by considering its distance from base station.

In the paper [7], author considers a heterogeneous wireless sensor network with two different types of sensors that have different initial energy as well as different data message length to transmit. Each sensor node in this type of network systematically collects and transmits sensed data to a base station for further processing. In this paper authors develop and analyze the protocol based on residual energy and energy consumption rate (REECR), which is an energy efficient routing protocol. The research shows that REECR protocol is more energy efficient than Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol. This paper proposes a routing protocol that is zone-based REECR (ZREECR) so as to balance the energy consumption of nodes in the networks. Simulation results in this paper showed that all the nodes that die become lesser and the balance of energy consumption between nodes is improved.

In paper [8], author proposed a reliable and energy-efficient forwarding (REEF) scheme for wireless sensor network. In REEF, a sender in cluster $(k-1)$ sends a packet to nodes in neighbouring cluster k. For Energy-efficiency, REEF elects one node among receivers in cluster k. The elected node

sends an acknowledgment message (ACK) back to the sender in cluster ($k-1$) and then sends the packet to nodes in neighbouring cluster ($k+1$). The binary exponential back off algorithm is employed for the election. Through both analysis and simulation, it shows that REEF is more reliable and energy-efficient than unicast based and broadcast based forwarding schemes in a cluster-based sensor network.

In paper [9], a new regional energy-aware clustering method with isolated nodes for WSNs, called Regional Energy Aware Clustering with Isolated Nodes (REAC-IN) is proposed. Like LEACH, REAC-IN enables each node to use energy uniformly by rotating the CH role among all the nodes. REAC-IN selects the cluster head based on the threshold value involving the residual energy of each sensor and the regional average energy of all, whereas LEACH selects the CHs based on the threshold considering a predetermined probability only. REAC-IN entails adapting the revolving epoch of every node to its energy and indicates the problem of node isolation. Improperly designed distributed clustering algorithms can affect the node that becomes isolated from CHs. Such isolated nodes communicate with other sink by consuming an excess amount of energy. Furthermore, the regional average energy and the distance between sensors and the sink are used to determine whether the isolated node sent its data to a CH node in the previous round or to the sink.

This paper [10], proposed a new energy-efficient dynamic clustering technique for large-scale sensor networks. It monitors the received signal power from its neighbouring nodes. Each node calculates the number of active nodes in real time and computes its optimal probability of becoming a cluster head, so that the amount of energy used in both intra- and inter-cluster communications can be minimized. Based on the cluster architecture, this paper also proposes a simple multi-hop routing algorithm that is designed to be both energy-efficient and power-aware, so as to increase the network lifetime. The new clustering and routing algorithms proposed claims to scale well and converge fast for large-scale dynamic sensor networks, as indicated by the extensive simulation results.

III. COMPARISON OF CLUSTERING ALGORITHMS

The common objective of all the clustering algorithms of WSN considered and studied in this paper is energy efficiency so as to maximize the lifetime of the network, however they can be compared on the basis of secondary objectives, approach and methodology, limitations and their unique characteristics that make them suitable in different environments. So, comparison of these clustering based algorithms has been made in ***Table I*** on the basis of some parameters like energy efficiency, hop count, existence of hot-spot problem, technique and objectives of algorithm.

LBEEC emphasizes on load balancing and achieves higher energy efficiency than LEACH without facing a hot-spot problem. PEGASIS performs better than LEACH as it eliminates the requirement of formation of dynamic clusters and also it provides better load balancing as fusion is done at each node, however it also has some limitations as it requires prior knowledge of network topology which is quite impractical in large distributed systems and also if a single node dies it will break the whole network which will reduce reliability.

TABLE I. COMPARISON OF DIFFERENT ALGORITHMS/PROTOCOLS

Protocol	Energy Efficiency	Hops	Hot-Spot Problem	Objectives
LBEEC	Very High	Multi Hop	Does not exist	Balance the load and increase the network lifetime
LEACH	Very Low	Single Hop	Exists	Achieving maximum lifetime
PEGASIS	Low	Single Hop	Exists	Load balance and prolonging network lifetime
EEHC	Medium	Multi Hop	May Exist	Prolonging network lifetime
HEED	Medium	Multi Hop	May Exist	Load balancing, Achieving maximum lifetime
EEUC	Very Low	Multi Hop	Does not exist	Load balancing, prolonging network lifetime
ZREECR	High	Multi Hop	Does not exist	Improve performance of nodes
REEF	High	Multi Hop	Does not exist	To provide High Reliability and maximum lifetime
REAC-IN	High	Multi Hop	Does not exist	To provide energy Efficient and stable network

HEED provides better load balancing than LEACH and reduces message overhead. But HEED requires repeated iterations to calculate cluster heads due to decrease in residual energy that increases complexity. REECR protocol is more energy efficient than (LEACH) protocol as it provides a routing protocol that is zone-based REECR (ZREECR) so as to balance the energy consumption of nodes in the network thereby providing high energy efficiency and also does not face the hot spot problem. REEF also provides high reliability by deploying multi hop technique and overcoming the limitations of LEACH. REAC-IN selects the cluster head based on the threshold value involving the residual energy of each sensor and the regional average energy of all, whereas LEACH selects the CHs based on the threshold considering a predetermined probability only. The

energy efficiency is therefore high and hotspot problem does not exist and the network is thereby more stable.

IV. CONCLUSION

In this paper various hierarchal clustering algorithms have been considered on the basis of the conditions in which these algorithms are suitable to use and where they do not provide efficient results. In wireless sensor network limited energy and network lifetime is a crucial issue. Vast research has been done to give different approaches of reducing energy consumption in various forms of network. Clustering is one of these approaches that achieve better energy utilization by dividing the whole network into various clusters. LEACH protocol serves as the base of all the techniques discussed in the study and they more or less try to overcome the limitations imposed by it. The study in my paper suggests that the various protocols and techniques discussed achieve the desired aspect of energy efficiency by deploying varied methodologies and overcome the limitations of LEACH thereby giving a more stable and reliable WSN but with an added dimension of complexity. It is a matter of choosing the right technique or protocol for the right situation depending upon the results desired.

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