

ENHANCEMENTS OF LEACH ALGORITHM FOR WIRELESS NETWORKS: A REVIEW

M. Madheswaran¹ and R. N. Shanmugasundaram²

¹Centre for Advanced Research, Department of Electronics and Communication Engineering, Mahendra Engineering College, India
E-mail: madheswaran.dr@gmail.com

²Department of Electronics and Communication Engineering, Vidyaa Vikas College of Engineering and Technology, India
E-mail: raja.nss1969@gmail.com

Abstract:

Low Energy Adaptive Clustering Hierarchy (LEACH) protocol is the first hierarchical cluster based routing protocol successfully used in the Wireless Sensor Networks (WSN). In this paper, various enhancements used in the original LEACH protocol are examined. The basic operations, advantages and limitations of the modified LEACH algorithms are compared to identify the research issues to be solved and to give the suggestions for the future proposed routing algorithms of wireless networks based on LEACH routing algorithm.

Keywords:

LEACH, Modified LEACH, Hierarchical Cluster Based Routing, Wireless Sensor Networks (WSN)

1. INTRODUCTION

Low Energy Adaptive Clustering Hierarchy (LEACH) protocol is widely used for the wireless networks which contain small battery powered devices, for example wireless sensor networks (WSN). When the battery power is drained in these devices/nodes then the network cannot be used and all the nodes spend most of the energy while transmitting the data. Therefore, to increase the lifespan of the network, each node has to do only minimal work for transmitting the data. LEACH protocol is widely used in WSN, because this protocol dissipates the energy in low level.

Routing in the wireless networks are categorized into 3 types based on the structure of the network. They are Flat routing, Hierarchical Routing and Location Based Routing [1]. In flat routing, all the nodes of the network perform the same functionality and work together to collect/generate the data and routing to the destination. The Sensor Protocols for Information via Negotiation (SPIN) protocol and Directed Diffusion protocol belong to flat network routing. In the hierarchical routing, the entire network is divided into many clusters to improve the scalability and utilize the energy of the nodes efficiently. For Example LEACH routing protocol. In Location based routing, location details of each node are monitored continuously to find the routing path for the communication. Global Positioning System (GPS) devices are used along with network nodes. For example: Geographic Adaptive Routing (GRS).

In LEACH protocol, all the nodes are grouped into the clusters, and in each cluster one of the nodes is assigned as a Cluster Head (CH). CH collects the data from the surrounding nodes and passes it to the base station. Usually, initial assignment of CH is random and the role of CH is rotated for every fixed duration so that each node will act as a CH at least once in its life span. LEACH algorithm has two phases. They are

set up phase and steady state phase. Setup phase is used to choose a CH and steady state phase is used to maintain the CH during the transmission of data. A node n is selected as a CH in next round based on applying the following formula. If $T(n)$ is 1 then the node n will be the CH in next round.

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

where, p is the probability of node n being selected as a CH, r represents the current round number and G is the set of nodes that are not selected as a CH in the last $1/p$ rounds.

Some of the unique features of the LEACH protocol [2] are,

1. The coordination and control in the cluster is localized in the set up phase.
2. The role of the CH is rotated and randomized to distribute the energy requirements among the nodes of the network.
3. To reduce the total amount of data transmission, local compression techniques are used in the CH.
4. LEACH is suitable for homogeneous networks.

The structure of the cluster of nodes in a wireless network is given in the following Fig.1. In the figure the non cluster nodes are represented in blue color, these nodes send the data to the corresponding cluster head and the cluster head forwards to the base station after performing aggregation or data fusion [3]. Cluster head allots the time intervals to the cluster member nodes so that non cluster nodes can transmit the data to the base station in the assigned schedule. Time Division Multiple Access (TDMA) schedule is maintained by the CH.

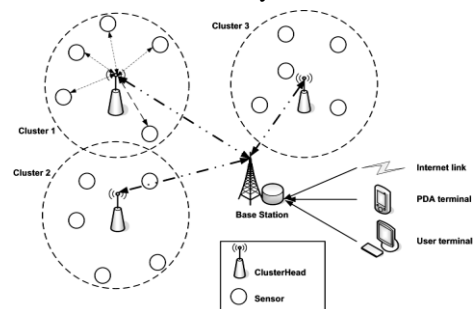


Fig.1. General Sensor Network Architecture

Most of the wireless sensor networks use heterogeneous devices and the remaining power of these nodes may differ. Based on simple random rotation, if any node with low remaining energy is selected as a CH, its energy evaporates

soon. CH has some extra privileges and also does some operations for intra and inter-cluster communications. Sometimes selection of CH based on the available resources of the node and distance with the base station will be suitable in some sensor networks. LEACH is the first hierarchical cluster based routing used for wireless networks.

Some of the limitations of LEACH routing protocol are,

1. Selection of CH is done randomly and does not consider the consumption of the energy. The possibility of selecting as a CH is equal to all the nodes.
2. LEACH clustering does not cover the entire network area.
3. Distribution of the CH is not uniform. Some of the clusters may have CH at the edge of the cluster.

Therefore, many number of LEACH routing with some enhancements were used by many researchers. The Fig.2 shows the enhancements of LEACH algorithms taken into consideration for this survey. The rest of the paper is organized as follows. Section 2 describes adaptive clustering algorithms. Section 3 describes energy aware LEACH routing algorithm. Section 4 describes the optimization of LEACH routing and section 5 describes comparison of these algorithms and section 6 concludes the survey.

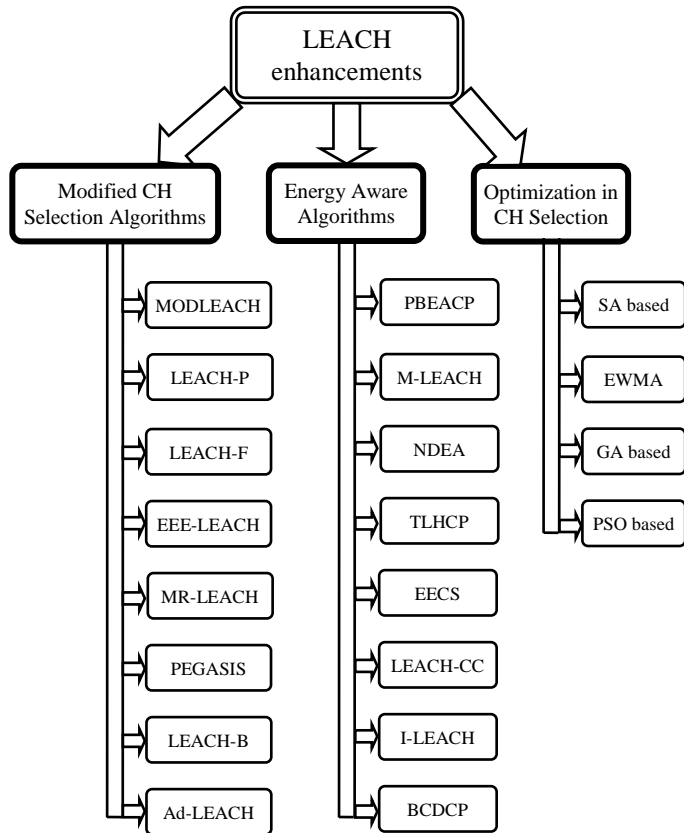


Fig.2. Classification of Modified LEACH Algorithms

2. MODIFIED CLUSTER HEAD SELECTION ALGORITHMS FOR LEACH

Mahmood et al. [4] proposed MODLEACH algorithm by extending the basic LEACH algorithm for WSNs to increase the throughput and lifetime of the network. Two ideas such as efficient cluster head replacement and dual transmitting power

levels were introduced in the MODLEACH algorithm. Cluster head replacement was done by checking the energy of current CH with the threshold. If the residual energy is greater than the threshold, then the CH remains same for the next round. Because the CH did not spend more energy in previous round, the residual energy remains approximately same and can be used for further rounds. This scheme saved the energy of new CH selection. Dual transmission power level was used to use different amplification power to transmit the data based on the distance to the destination. Because need of amplification of signal transmission by a node to the closest CH is less than transmitting to farthest base station.

Wang and Yong [5] proposed cluster head selection by the pseudo cluster concept. Load monitor and Load leisure mechanism is used to balance the load and stability of the topology of the network. Simulation result shows that LEACH-P Protocol effectively increase energy utilization efficiency, lengthens network lifetime and balances network load. Bhadeshiya et al. [8] proposed an algorithm to select 4 or 5 % of fixed number of clusters in WSN based on the residual energy.

Azim et al. [6] proposed fixed LEACH algorithm based on the relay of nodes. The battery power in WSN nodes is saved by using LEACH and its various versions with clustering techniques to minimize the energy used up by maintenance of many of the nodes in sleeping mode but providing a good quality of service (QoS). But LEACH suffered on optimizing the life time of the network because of losing large amount of energy of sensor nodes elected as CH during data transmissions. But relay node based schemes used independent powerful relay nodes as heads to preserve the energy in the low energy sensor nodes. These relay based scheme also get difficulties from a number of problems like placement of relay nodes, blind spots and immature death of CHs. LEACH and modified LEACH except fixed LEACH, experience the problem of spending huge energy in the sensor nodes because of forming repeated cluster for every fixed time interval. Fixed LEACH solved the repeated clustering formation by constructing fixed clusters only once, but it wasted more energy and loss of information occurs because of premature death of cluster heads before expiring after a constant number of rounds. Therefore, LEACH-F can be used after the death of all the relay nodes, and the round time of fixed LEACH can be adjusted dynamically to reduce the probability of premature death of CHs.

EEE-LEACH or Energy Efficient Extended LEACH [7] is an approach that uses multilevel clustering technique to improve the energy efficiency by reducing its radio communication distance. In this multilevel clustering, first layer of clusters are formed between the nodes and the Base station using simple LEACH algorithm. In the first layer CHs are selected, then the normal nodes send their own data to their corresponding CH and CH uses the data fuse mechanism to aggregate the received data. In the second layer of clustering, the Master Cluster Heads (MCH) are elected. When CHs fuse and aggregate the data, they search for the nearest MCHs by computing the distance between them and then send the aggregated data to the corresponding MCHs. Once MCHs received the data from nearest CHs, it aggregates all the received data, compress them and transmit them to the base station (BS). The total number of CHs and MCHs are primarily decided by using a predetermined fractional

value p (election probability value) for CHs and p_m (election probability value) for MCHs. In the proposed EEE LEACH, the number of MCHs is selected as less than the number of CHs to reduce the overall communication distance between the sensor nodes and the base station. By various experiments, EEE LEACH protocol proved that the network life-time and energy-efficiency is better than LEACH protocol.

Wu and Wang [9] compared the performance of LEACH and LEACH-C. LEACH C is a centralized clustering algorithm. The steady state used in LEACH C is similar to set up phase of LEACH and in Leach-C each node sends the information about the current location and the level of energy to the base station. The base station utilizes this global information of the network and constructs the better clusters that use only the less energy for data transmission. This algorithm needs GPS or the other location tracking technique. The base station allows only the nodes with enough energy to compete in the selection of the cluster head and then broadcasts the information to all the nodes in the network. Leach-C uses a deterministic threshold algorithm which uses the amount of energy in the node and information of recent participation as CH. The control algorithm is centralized to form the clusters to produce the better clusters by the distribution of the CH nodes throughout the network.

Farooq et al. [10] presented Multi-hop Routing with Low Energy Adaptive Clustering Hierarchy (MR-LEACH) protocol for WSN. MR-LEACH divides the entire coverage area of the network into different layers of clusters. Cluster heads in one layer coordinate with the CH of adjacent layers to send the sensor's data to the base station. Non CH nodes link with cluster heads based on the Received Signal Strength Indicator (RSSI). The communication of nodes is coordinated by a Base Station (BS) which defines the Time Division Multiple Access (TDMA) schedule for each cluster-head. Usually, BS uses the upper layers of CHs to perform as super cluster heads for CHs at the lower layer. Thus, MR-LEACH uses multi-hop routing from cluster-heads to a base station to save energy, in contrast with the LEACH protocol. When evaluating the performance, it is proved that MR-LEACH yields significant improvement when comparing to the LEACH protocol and energy efficient routing for WSN.

Power-Efficient Gathering in Sensor Information Systems (PEGASIS) was proposed by Sharma et al. [11]. It is a near optimal chain-based protocol. Only at the end of each round all the nodes transmit the data to the BS and thus reducing the power consumption of data transmission data per round. This method also promises that the depletion of power at each node is uniformly distributed. The main objectives of PEGASIS are, 1) to improve the lifetime of each node and entire network by using collaborative techniques. 2) to permit only local coordination between nodes which are close together so that the consumption of bandwidth in transmission can be reduced. In contrast to LEACH, PEGASIS does not use cluster formation and uses only one node in a chain send the data to the BS instead of multiple nodes. Signal strength is used for locating the closest neighbor node, and the signal strength is adjusted, therefore only one node will hear in a greedy fashion. Simulation results proved that PEGASIS outperforms than original LEACH by about 100 to 200% with 1%, 25%, 50% and 100% of nodes die for different network sizes and topologies.

Tan et al. [12] introduced the wireless home sensor networks (WHSN) which has plug-in nodes. Plug-in nodes are free from energy consumption criteria and the modified the protocols such as LEACH, SPIN and DD in WHSN and named as LEACH-Pi, SPIN-Pi and DD-Pi, by changing the voting, assessment, and routing technique to greatly enhance their performance, life time and response time of network, and consumption of the energy.

Mu Tong et al. [13] proposed LEACH-B algorithm to balance the number of cluster heads based on the residual energy of the sensor nodes. Initial CH selection is based on simple LEACH algorithm and from the second round LEACH-B is used. LEACH-B is a near optimal routing method. L-LEACH is a modified LEACH proposed by Qian Liao [14] to select CHs based on residual energy and location information of nodes and optimize the threshold for electing cluster-head. Cost function is designed to improve the optimal cluster-head selection. Simulation results proved L-LEACH balances the node energy better than LEACH.

Iqbal et al. [15] proposed a static clustering called as Advanced Low-Energy Adaptive Clustering Hierarchy (Ad-LEACH) for heterogeneous WSN routing. The entire network is divided into small and static clusters and the head of each cluster is selected by using Distributed Energy-Efficient Clustering (DEEC). Small and static clusters need to broadcast messages within a small area and this reduces the power requirement of Ad-LEACH. Simulation proved that Ad-LEACH performs better than LEACH and DEEC in terms of energy efficiency and throughput. Wang and Zhu et al. [16] proposed LEACH-R routing to improve the selection of cluster-head by using the selection of relaying node. Both the residual energy of nodes and the distance with BS are used to find the relaying node from the CHs and selected node will be the relay node between the BS and other CHs.

3. ENERGY AWARE LEACH ROUTING ALGORITHMS

Dakshayani et al. [17] proposed an energy aware routing algorithm by assuming that nodes in a network are equipped with global positioning system (GPS). Initially the nodes are deployed randomly, and after deployment all the sensor nodes inform the location information to the base station before the set-up phase and steady state phase. After the location information is collected in the base station, the network coverage area A is divided into groups A_1, A_2, A_3 , etc. The groups are created based on the location of the node and cluster head election probability p . The group's creation is done by the BS and does not guzzle too much energy. In each group a CH is selected randomly for each round, therefore the elected cluster heads are distributed uniformly in the network. Then each CH sends identity message to the group member nodes before starting the steady state phase. In steady state phase, all the CHs receive and aggregate the data from group member nodes as in LEACH but instead of directly sending the data to the base station. Therefore CH reduces the radio communication distance. In the proposed LEACH the residual energy remains up to 460 rounds when compared to LEACH which remains only for 193 rounds because the modified LEACH distributes the energy equally among all nodes compared to LEACH. In the modified LEACH,

the first node dies in 240th round and in LEACH the first node dead at 102 rounds.

Dong et al. [18] proposed Coverage Preserving routing for WSN. To maximize the life time of the energy limited WSN, energy efficient routing algorithms are needed. Energy efficient algorithms arrange the nodes into hierarchy and make sure the collaboration among nodes. The clustering-based LEACH is one of the widely used classic routing protocols among them. The author proposed a modified version of LEACH called as PBEACP, which concentrates on the selection of cluster-head nodes in the network. The remaining residual energy and the nodes' geographic distribution of nodes are considered for the selection of cluster-head nodes, which lead to even distribution of the energy consumption among nodes. PBEACP also guarantees the sensing coverage of cluster-head nodes, even the topology of the network is dynamic when there are nodes running out of energy. Simulation results proved that the mean of nodes' life time is increased, the deviation is decreased and also the number of cluster-head nodes in the network is more stable.

Nguyen et al. [19] proposed energy efficient routing for Mobile WSN. If the sensor nodes are highly mobile, the prediction of current location and movement is a difficult task. Therefore the sensing area of WSN is divided into sub-areas and tries to optimize the location of cluster-head in these sub-areas. To allow the mobility, LEACH and LEACH-C are modified in the set up phase. In the Setup phase of M-LEACH, each node transmits the details of the node including locations, velocity and energy level to BS. Based on these information received at the BS, BS discover the cluster-head set and send the schedule to all nodes. Each node sets up its cluster-head and schedule to send the data on its own time slot using DSSS spreading code to make sure the minimal inter-cluster interference. During the transmission, each node sends its data only in its allocated transmission time slot and this duration of time slot is constant. Each node can schedule its next allocated time slot based on the number of nodes in this cluster. After collecting the data from the sensor nodes, cluster head aggregates the data and sends the pre processed data to the BS.

Luan et al. [20] proposed an algorithm based on LEACH by combining Node Degree and Residual Energy of WSNs. Since the battery capacity and memory size for node is limited in the WSNs, the efficient routing protocol designing is one of the most critical challenges for decreasing the energy consumption and enhancing the lifetime of the network. The author analyzed LEACH protocol and its limitations, and proposed a new weight defined by using the node degree and residual energy of node. This algorithm selects CH based on the assigned weight. Simulation results proved that the improved algorithm NDEA (Node Degree and Energy-Aware routing protocol) algorithm optimize the clustering of network, balance network load and improve the network lifetime greatly.

Taneja and Bhalla [21] proposed an enhanced version of LEACH: Three Levels Hierarchical Clustering LEACH Protocol (TLHCLP) for Homogeneous WSNs. Base station is considered as the location centre and a pre defined radius is used. Nodes are categorized as nodes inside the radius and remaining nodes in the outside radius. Cluster Heads that are situated in the outside the radius discover the nearest Cluster Head which is inside the radius and forward the data to the CH inside the radius. Then

these inside Cluster Heads aggregate the data and send it to the Base Station. The proposed TLHCLP technique is compared with the original LEACH protocol. Simulations were conducted to evaluate the performance of these two protocols and good results are obtained. Simulation results proved that TLHCLP improves network lifetime by an order of magnitude compared with LEACH.

Mao Ye et al. [22] proposed EECS: An Energy Efficient Clustering Scheme for periodical data collecting applications in WSNs. During the election phase for CHS, a fixed number of candidate nodes are elected and competitor nodes are checked based on their residual energy. The competition is conducted locally and with no iteration, thus decreasing the message overhead and also helps in the even distribution of the cluster heads. To distribute the energy consumption among the sensors in the cluster formation phase a novel approach is used. EECS is fully distributed and highly energy efficient than LEACH. The simulation results proved that EECS prolonged the network lifetime as much as 135% of LEACH.

Gupta et al. [23] proposed a low energy-consumption chain-based routing protocol LEACH-CC. LEACH-CC uses a centralized clustering algorithm, minimize the distance between non-cluster-nodes to cluster nodes, and use only one cluster-head transmission to the base station per round. LEACH-CC distributes the energy and load to all the nodes thus increasing the lifetime and quality of the network. The authors simulated LEACH CC and it is proved that LEACH-CC performs better than LEACH by 1.12 times the lifetime of network even when 80% nodes die. LEACH-CC can be improved even further when the size of the network increases. After selecting the cluster head, cluster formation is done by using the cost function. A cost is computed at each node to decide about to which CH it can join. Cost function uses the remaining energy and signal power strength of Cluster head. A node joins the cluster head of largest cost value. $Cost(i) = CH(i)_{\text{remaining energy}} + CH(i)_{\text{signal strength}}$, where $CH(i)_{\text{remaining energy}}$ and $CH(i)_{\text{signal strength}}$ are the remaining energy and signal strength of Cluster Head numbered as i . Each node calculates the cost value and join the cluster head with maximum cost value by sending the join message to cluster head.

As huge amount of energy in the sensor nodes of a WSN is spent for the inner-network communications, energy efficient routing must be saved in the inner-network communications energy. Beiranvand et al. [24] proposed I-LEACH which selects a node with higher residual energy, many numbers of neighbors, and smaller distance to the BS as CH node. Based on the CH formation, all the sensor nodes managed to form the clusters in such a way to maximize WSN lifetime and minimize average energy dissipation per each sensor node. Using MATLAB simulator, I-LEACH algorithm is simulated and the performance is compared with algorithms such as LEACH, DBS, and LEACH-C algorithms. Results proved that I-LEACH improved the performance at least 65%, decreases the consumption of energy up to 62%, and improves the successfully PDR by at least 56% as compared to the these algorithms for WSN.

Muruganathan et al. [25] proposed a centralized protocol called as base-station controlled dynamic clustering protocol (BCDCP) to distribute the dissipation of energy uniformly among all sensor nodes. BCDP improved the lifetime of the

network and average energy savings when compared to the LEACH, LEACH-centralized and PEGASIS.

4. OPTIMIZATION IN LEACH ALGORITHM

Shou et al. [26] proposed a simulated annealing (SA) algorithm to discover the optimal solution with better position to minimize the energy loss of cluster heads. Initially, a group of CHs are selected by LEACH-C algorithm. For reducing the number of retransmission and considering the acknowledgment, a CH energy consumption model is created. This model use the quadratic sum of the distances from the CH to its member nodes and the largest energy consumption for a single CH for the next round is estimated, and all nodes that has residual energy greater than the computed energy consumption will be used for a new round of SA to give a better solution. Therefore, loss of the energy in CH can be minimized, to increase the lifetime of WSN.

In WSN most of the communication links only exist temporally and establishing end to end connection is not possible for data delivery. Therefore routing is done based on the probability of nodal contact. Ramesh and Somasundaram proposed [27] a energy efficient clustering protocol OFZ-LEACH to solve the issue by forming Far-Zone. Far-Zone is a set p of sensor nodes which are moving at the locations where the energies of those nodes are smaller than a threshold. Exponentially Weighted Moving Average (EWMA) scheme is applied for finding and updating nodal contact and based on EWMA; some functions are used for forming clusters and selection of gateway.

In this paper [28] proposed angle optimization for split sensors using Genetic algorithm. Several LEACH protocols use circular grid by using sink at the centre of the network. Combining angle optimization to LEACH efficiently form better clusters and enhance the WSN lifetime. Rahmanian et al., [29] proposed evolutionary algorithms in centralized clustering. LEACH-C is combined with evolutionary algorithm, and proper selection of evolutionary operators an efficient clustering is formed based on each node's energy. The results of proposed work are compared with the results of the Simulated Annealing method.

Jeng Long et al. [30] proposed a GA based adaptive clustering using an optimal probability prediction to yield better performance in terms of lifetime of network in WSN. In the LEACH preparation phase is added before starting the first round. In the preparation phase, all nodes do the process of CH selection and send their statuses about a candidate CH or not, node IDs, and their positions to the BS. Then the BS searches applies GA to find an optimal probability of nodes being cluster heads by minimizing the total energy consumption required for completing one round in the sensor field. Then an advertisement message is broadcasted by BS to send optimal value of probability to the all nodes. After the advertisement, the set up and steady state phase are used and similar to LEACH. Dexin Ma et al., [31] proposed an Adaptive Assistant-Aided Clustering Protocol using Niching Particle Swarm Optimization (AAAC-NPSO) to enhance the lifespan and rate of data delivery by optimizing energy dissipation of the WSN.

Singh et al. [32] used PSO approach for constructing energy-aware clusters by optimal selection of CHs. The semi distributed PSO algorithm is used to minimize the cost of locating optimal position for CH of a cluster. The objective function is selected by using the residual energy, intra-cluster distance, node degree and head count of the probable cluster heads. The performance PSO optimization is compared with LEACH-C and PSO-C. The simulation results proved that lifetime, average packet transmissions, cluster head selection rounds supported by PSO and average energy consumption are better in the proposed method. Satyesh et al., [33] used PSO algorithm by using cost function based on the energy level of nodes to find K number of optimal clusters. The set up and steady state phase were similar to LEACH, but the BS executes the PSO algorithm to determine the best K cluster heads that can minimize the cost function.

5. COMPARISONS

Several modification and enhancements are being done on LEACH to surpass its existing performance. The following table shows the advantages and the limitations of various enhancements made on LEACH algorithm.

Table.1. Comparisons of Modified LEACH Algorithms

Author	Algorithm Proposed	Communication pattern	Energy efficiency	Advantages	Limitations
Sharma et al.	PEGASIS	Chain based	High	No.of rounds are 100 to 200 % higher than LEACH.	Excessive delay for distant nodes.
Khan et al.	Ad-LEACH	Single hop	High	The network life time is 66 % more than LEACH. Increases the number of rounds around 1500 to 2500 rounds.	Instability region is 40% more than LEACH.
Dakshayini et al.	E-LEACH	Single hop	Very High	Reduces the radio communication range by proper selection of CH. No. of rounds is 200% higher than LEACH.	The network should equipped with GPS for monitoring the position of the nodes and CH.
Nguyen	LEACH-C	Chain based	Very High	Number of data received at bas	Not give good performance if the

et al.				station is 8% more than LEACH.	nodes are mobile.
Dembla et al.	EE-LEACH	Single Hop	Very high	Energy consumption is reduced up to 43% for 100 nodes and 44 % for 200 nodes.	CH need to be distributed uniformly.
Taneja et al.	TLHCLP	Multipath model	High	Life time is improved from 20 % to 42 % for 100 nodes.	Algorithm should ensure that all nodes become cluster members
Gupta et al.	LEACH-A*	Chain based	Very high	Lifetime of the network increases 80% and throughput increases 1.2 times than LEACH.	A multi path route algorithm based on energy hops is proposed to reduce the energy consumption.
Bhadeshiya et al.	LEACH Sub CH	Single hop	High	Fixed number of CH increased throughput and reduced the energy consumption significantly.	Optimal number of clusters must be selected for best results.
Mao et al.	EECS	Single hop	Very high	Life time increases 135 % and energy utilization is 93 % more than original LEACH.	Future work should include multi hop communication.
Nguyen et al.	M-LEACH	Multihop	Very high	Throughput is 8 times greater than LEACH- C.	Velocity threshold and round time models should be developed. Location monitoring is an overhead.
Mu Tong et al.	LEACH-B	Single Hop	High	Residual energy of nodes is considered for CH selection and 25% efficient than LEACH	Other parameters like node degree, distance are yet to be considered for best CH selection

6. CONCLUSION

In this survey, the advantages and limitations of various enhancements of modified LEACH were discussed. Each version of LEACH was implemented to solve some limitations of original LEACH algorithm like delay, stability, localization and mobility of nodes, uniform distribution of CHs, multi-hop routing, and optimal CH selection. It is observed that future research on LEACH algorithm aims to use the multi hop communication pattern and optimal number and election of cluster heads.

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