A Survey on LEACH-Based Energy Aware Protocols for Wireless Sensor Networks

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***Abstract*-Due to the advances in wireless communications and electronics technology, Wireless Sensor Networks (WSNs) are used in many applications such as civil and military application. A WSN is composed on many nodes each of which is basically equipped with a sensing device to collect data from the environment, a processing unit to do some operations on data, a transceiver to send and receive collected, and an energy source to provide the required energy to operate (usually a battery). In most applications sensor nodes are randomly deployed in the field. Therefore, battery replacement or charging is considered not practical. As a result, routing protocols must be energy-efficient to prolong the network lifetime. Researchers have been working to develop routing techniques that enhances the WSN lifetime among which is the hierarchical routing. In this paper, we present a recent survey of hierarchical routing protocols which are based on LEACH protocol. Specifically, we will show the network life time and energy consumption for each protocol. Furthermore, a comparison of these protocols in terms of advantages (improvements over LEACH), disadvantages, assumptions, and the Cluster Head selection criteria are provided.**

***Index Terms*—wireless sensor network, LEACH, hierarchical routing, clustering, Ch selection, energy consumption, network lifetime.**

I. Introduction

Wireless Sensors Networks (WSNs) are widely considered as one of the interesting and rapidly developing fields. Sensor nodes have many different types such as seismic, low sampling rate, thermal visual, infrared, acoustic and radar [1]. According to these different types, a WSN can be applied to monitor many military and civilian environments (e.g. temperature, humidity, pressure, noise levels and many other conditions). A WSN typically consists of a large number of low-cost, low-power, and multifunctional wireless sensor nodes with sensing, wireless communications and computation capabilities.

WSNs have many several characteristics and constraints. In many applications, the sensor nodes are randomly deployed. Once deployed, the sensor nodes must organize themselves into a wireless network and perform a specific job. In addition, WSNs in most applications are battery powered which means it is very difficult to replace or recharge the batteries as soon as the nodes are deployed. Another constraint that reduces the efficiency of deployed nodes is data redundancy since nodes in most cases are densely deployed in a region of interest and that causes a redundant data from nearby nodes in the region. Based on these constraints, many techniques are proposed to achieve longer lifetime and efficient energy consumption. One of the interesting techniques is the Hierarchical Routing, which introduces the concept of cluster creation and assigning special tasks to selected sensor node within the cluster called cluster head (CH). Hierarchical Routing is an efficient technique to reduce energy consumption by doing data aggregation and fusion in order to reduce the number of transmissions to the Base Station (BS). The first hierarchical protocol is the Low Energy Adaptive Clustering Hierarchy (LEACH) that was introduced in [2]. The idea of LEACH is to form clusters of the sensor nodes based on the received signal strength and use local cluster heads (CHs) as routers to the sink. This enhances the energy consumption since the transmissions will only be done by the cluster heads rather than all sensor nodes. Many hierarchical protocols were emerged based on the idea of LEACH. Our goal is to provide a recent survey of LEACH based protocols.

The rest of the paper is organized as follows. Section 2presents the LEACH protocol. Section 3 surveys various LEACH-Based hierarchal routing protocols. Section 4 provides a summary table that compares between different surveyed protocols. We conclude the survey in Section 5.

II. Leach Protocol

LEACH is one of the most popular clustering algorithms used in WSNs to increase the network lifetime [3]. LEACH is an adaptive, self organizing and clustering protocol. It introduces the concept of Rounds. LEACH assumes that the BS is fixed and located far from the sensors, all sensor nodes are homogenous and have limited energy source, sensors can sense the environment at a fixed rate and can communicate among each other, and sensors can directly communicate with BS. The idea of LEACH is to organize the nodes into clusters to distribute the energy among the sensor nodes in the network, and in each cluster there is an elected

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node called a cluster head (CH). Fig. 1 shows LEACH communication hierarchy.

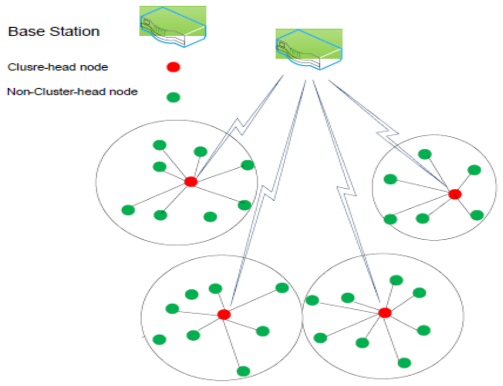

Figure 1. Illustration of LEACH protocol [4]

Each round in LEACH consists of two phases as shown in Fig. 2. Clusters are formed during the set-up phase and data transfer occurs during the steady-state phase.

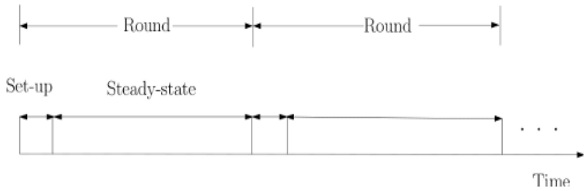

Figure 2. LEACH phases; setup and steady state phase.[5]

At the beginning of the setup phase, every single node picks a random number between 0 and 1, and then computes a threshold formula$T(n)$. If the picked random number is less than the computed threshold the node becomes a CH.$T(n)$ is computed as shown in (1) [2].

$$T(n) = \begin{cases} \frac{P}{1-P*(r \bmod \frac{1}{p})} & if n \in G \\ 0 & otherwise \end{cases} \tag{1}$$

where $p$is the desired percentage of CHs (LEACH protocol specifies that nodes become CHs with a probability of 5% under normal circumstances) [2], $r$is the current round, and G is the set of nodes that have not been CHs in the last $1/p$ rounds (eligible nodes to become CHs).Nodes that are CHs in round 0 cannot be CHs again in the next $1/p$ rounds.After$1/p-1$ rounds, the threshold value will be $T(n)$=1, and all nodes are eligible again to become CHs. After its selection each CH will broadcast an advertisement message to the rest of the nodes by using the CSMA MAC protocol [1]. After that each node selects a CH based on the Received Signal Strength Indication (RSSI) of the advertisement. Each node uses CSMA MAC protocol to transmit its selection [2]. During that, all CHs must keep their receivers ON. Then when clusters are formed, each CH creates a TDMA schedule according to the number of nodes in the cluster. Each node sends their sensed data to its CH during its allocated transmission time in the TDMA.

During the steady state phase, each sensor node senses and transmits data to its CH based on the TDMA schedule. The CHs receive all the data and aggregate it before being sent to the BS. After a certain time, which is determined a priori, the network starts another round by going back to the setup and steady state phases again.

LEACH protocol assumes a simple radio model which describe the energy dissipation though the electronic devices, transmitter, power amplifier and the receiver. Fig. 3 shows the radio model used to study LEACH and other LEACH-based protocols.

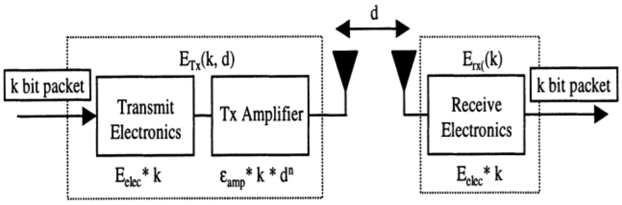

Figure 3. Radio energy dissipation model [6].

In [2] LEACH protocol has been simulated using MATLAB. Table I gives the parameters used in the simulation.

TABLE I. LEACH SIMULATION PARAMETERS.

Parameter	Value
Network size	100m*100m
Initial Energy	0.5j
p (CHs percentage)	0.5
Data Aggregation Energy cost	50pj/bit j
Number of nodes	100
Packet size	200 bit
Transmitter Electronics (EelectTx)	50 nj/bit
Receiver Electronics (EelecRx)	50 nj/bit
Transmit amplifier (Eamp)	100 pj/bit/m2

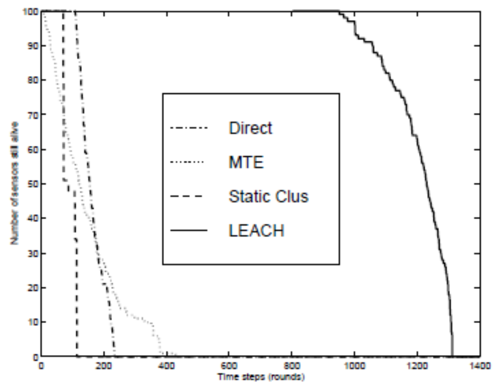

Figure 4. System lifetime using direct transmission, MTE routing, static clustering, and LEACH.[2]

Based on the simulation, LEACH more than doubles the useful system lifetime compared with the alternative approaches as shown in Fig. 4. LEACH enhances the reduction in energy dissipation over a factor of 7 compared to direct communication and a factor of 4-8 compared to the Minimum Transmission Energy routing protocol (MTE) and static clustering. For more information about the simulation results, the reader is advised to see [2].

Although LEACH enhanced the network lifetime and reduced the energy dissipated, it has some drawbacks. For example, LEACH assumes all the nodes starts with the same initial energy, which is not the case in real-time problems. Furthermore, the protocol assumes nodes are static. Therefore, it is difficult to be applied for mobile nodes. Also, the failure of CHs creates a lot of problems, and the existent of multiple BSs is not taken into account. Finally, there is an extra overhead to do dynamic clustering. According to these drawbacks many protocols were emerged to improve and enhance LEACH. In the next section we will present a number of protocols based on LEACH which tried to solve LEACH's drawbacks.

III. Hierarchal LEACH-based Routing Protocols.

A. LEACH-B (Balanced)

Authors in [7] introduced LEACH-B (Balanced) which proposes an enhanced version of LEACH by finding the number of CHs which are near optimal.

In LEACH-B, there is a second stage for selecting CHs through considering the residual energy of candidate nodes to become CHs, which modifies the number of CH sat the set up phase considering the node's residual energy. This protocol can save energy consumption by ensuring that the clusters are balanced. Authors in[7] have proved that the optimal number of CHs is between 3 and 5 from total 100 nodes (3% - 5%).

LEACH-B works similar to LEACH by selecting a random number between 0 and 1 and calculating the threshold value shown in eqn.1. However, LEACH-B introduced another selection stage: All candidate CHs that are elected will be ordered descendingly according to their residual energy, and only (n*p) of them, (where n is total number of sensor nodes, and p is the percentage of CHs) will be considered as CH and the remaining candidate and will resume their normal node role. By doing that, LEACH-B guarantees the optimal number of CHs.

Simulation results of LEACH-B shows an enhancement of lifetime compared to the original LEACH. Fig. 5 shows the result of simulating LEACH-B and LEACH on prolonging lifetime.

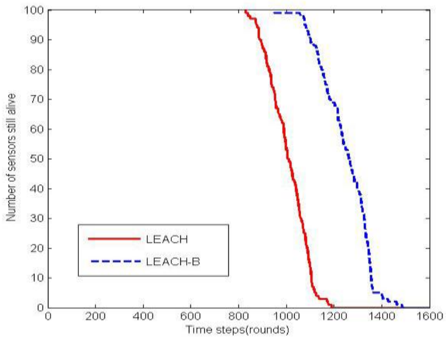

Figure 5. System lifetime using LEACH and LEACH-B.[7]

B. LEACH-C (Centralized)

Authors in [8] introduced LEACH-C (centralized). Recall that in LEACH all nodes select CHs by themselves and the result will be a number of CHs, some normal nodes, and formed clusters. In LEACH-C, authors made an improvement over LEAH protocol such that during the rounds of the CH selection stage the BS should know the remaining energy of all the nodes and there location. Accordingly, the BS selects the most suitable nodes to be CHs, and divides the rest of the nodes between CHs to form the clusters.

Simulation results of LEACH-C shows an enhancement based on the first dead node compared to LEACH and the traditional routing protocols; (MTE and static clustering) since most of the energy is consumed in the BS. Fig. 6 shows the network lifetime for LEACH-C, LEACH, MTE and static clustering.

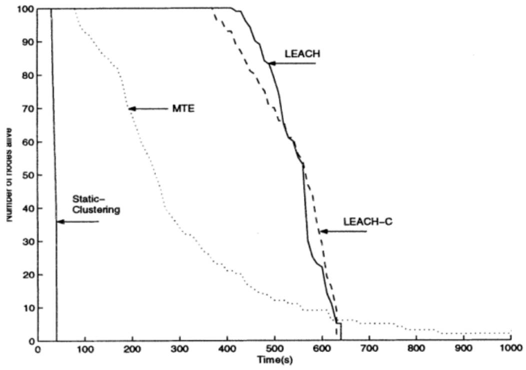

Figure 6. Number of nodes alive over time [6].

C. Energy Efficient Weight Clustering (EWC)

Authors in [9] introduced the Energy Efficient Weight Clustering (EWC) protocol. Despite that it is based on LEACH, it differs in the way it elects CHs. This protocol takes several metrics into consideration to select a CH such as residual energy, distance, and node degree (which is the number of neighbors a node has). EWC assumes that the nodes are distributed randomly, the nodes are homogeneous, static, and location unaware. It utilizes both channel modes:

1) free space with d^2power loss
2) multipath fading with d^4 power loss

The selection of cluster head is done based on several weight metrics:

1) Residual energy, the node with more residual energy is more likely to be chosen as CHs.
2) Distance between CHs, nodes and BS. A better CH can be chosen by minimizing the total sum of square distance between CH and nodes of the cluster and the BS.
3) Node degree: nodes with more neighbors can save more energy by serving more nodes, and will reduce extra energy by reducing the transmission from CHs to BS. Node with higher degree is more likely to be chosen.

This protocol needs extra processing so more energy is consumed to select CHs, but as a result for this extra power consumption it will reserve more energy and prolonging the network lifetime. Fig. 7 shows that EWC enhanced network life time compared to LEACH and LEACH-C.

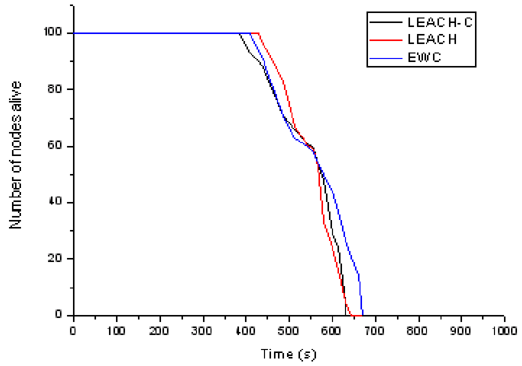

Figure 7. Number of nodes alive over time [9].

D. Energy-Efficient Cluster Head Selection (NECHS)

Authors in [10] introduced an Energy-Efficient Cluster Head Selection (NECHS) algorithm based on fuzzy logic such that a CH is selected based on two metrics: the neighbor nodes and the remaining energy. It uses the same radio model of [9] in which the transmitting and receiving operations consume energy as shown in (2) and (3) respectively.

$$E_{TX}(k,d) = E_{TX-elec}(k) + E_{TX-amp}(k,d)$$

$$= \begin{cases} E_{elec} * k + \varepsilon_{fs} * d^2 d < d_o d_o = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp}}} \\ E_{elec} * k + \varepsilon_{fs} * d^4 d \geq d_o \end{cases} \quad (2)$$

$$E_{RX}(k) = E_{elec} * k \quad (3)$$

where k is the message size and d is the distance. This protocol uses fuzzy logic model, in which the input to the model have to be fuzzified, and rules of inference are used. Then the output must be defuzzified to get crisp output. The input to the model is the remaining energy and node degree. When clusters are being created, each node calculates its probability for being a CH based on its remaining energy and node degree, and the node which has higher probability has more chance to become a CH.

Simulation of NECHS shows an improvement on network lifetime compared to LEACH, as shown in Fig. 8.

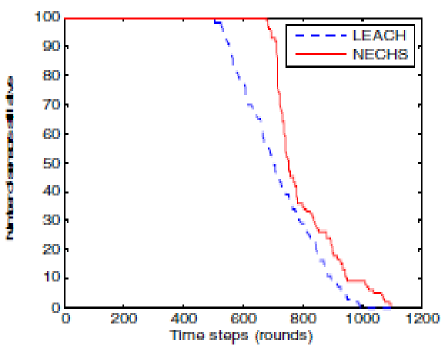

Figure 8. Number of nodes alive over time [10].

E. Energy Efficient Cluster Head Selection for Wireless Sensor Network

Authors in [9]introduced an Energy Efficient Cluster Head Selection for WSN as an extension to LEACH. The proposed protocol used a stochastic CH selection by altering the probability of each node to become CH based on the remaining energy level of sensor node. In the proposed protocol the threshold $T(n)$ is adjusted by incorporating residual energy and initial energy as shown (4).

$$T(n) = \left(\frac{p}{1-p(rmod1/p)} \cdot \frac{Eresidual}{Einitial}\right) . k_{opt}$$

$$k_{opt} = \sqrt{\frac{N}{2\pi}} \cdot \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp}}} \cdot \frac{M}{d^2{}_{toBS}} \quad (4)$$

where $k_{opt}$is the optimal number of CHs.

Simulation of the proposed protocol shows an improvement on network lifetime compared with LEACH, as shown in Fig. 9.

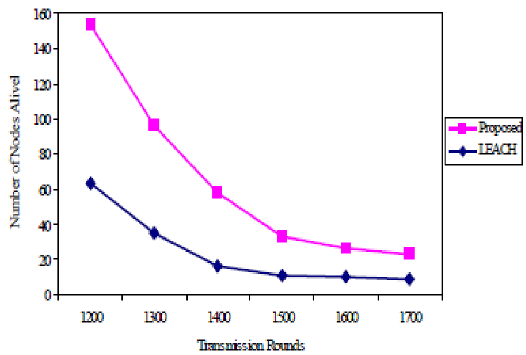

Figure 9. Number of nodes alive in different transmission rounds [9].

F. Energy Efficient Clustering Algorithm for Event Driven (EECED)

Authors in [11] introduced an Energy Clustering Algorithm for Event Driven (EECED) which aims to prolong the WSN lifetime by balancing energy usage of nodes. This protocol assumes that:

1) The Base station is located at the center of the nodes and has enough memory and able to process messages.
2) The network is static.
3) Nodes are equipped with power control capabilities.
4) Assuming Event driven protocol architecture.

EECED contains rounds similar to LEACH. Each round consists of the clustering phase and the data transmitting phase. Each round begins with a clustering phase, where clusters are organized followed by a data transmission phase in which data are transferred from nodes to CHs when events are driven. An initial phase is performed only once at the beginning of network operation.

Simulation results of EECED shows a greater network lifetime compared to LEACH. In Fig. 10 different numbers of nodes are used within simulation; 100 nodes and 300 nodes, and the result shows that EECED has prolonged network lifetime (number of rounds)more than LEACH.

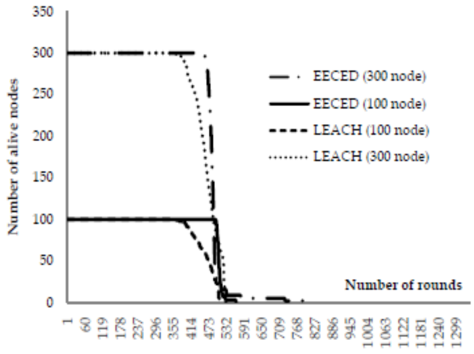

Figure 10. Number of living nodes in each round with same initial energy is used and total number of nodes 100 and 300.[11]

G. LEACH-P(Performance)

Authors in [12] introduced the LEACH-P protocol which considers the probability selection of EAMR (Energy Aware Multipath Routing) into LEACH algorithm and makes a better choice of selecting CHs and optimizing the chance of cluster rebuilding. EAMR protocols [13]build several paths between the source and the destination nodes as well as select and empower a certain probability for the path according to communication energy consumption of the node and the residual energy of the node in the path to prolong the life time of the network. The main energy saving measures can be divided into two broad categories: sleep control mechanism and data transmission control mechanism. The optimal energy saving result can be realized only through the cooperation of these two measures. The proposed protocol is based on LEACH and EAMR protocols. The node in the network selects the next hop node according to some probability. The EAMR finds the next hop selection probability of the node. The node calculates the selection probability for each next hop in the routing table according to (5).

$$P_{N_j,N_i} = \frac{1/C_{N_j,N_i}}{\sum_{k\in FT_j} C_{N_j,N_i}} \quad (5)$$

where node N_j select node N_i as the probability of the next hop through the calculation with the method in the above formula, CN_j , CN_i represents the cost of sending data to the destination node by node N_j though node N_i, and FT is optional nodes in the routing table. The calculation of threshold value is based on LEACH and this protocol extends it with the selection probability as shown in (6).

$$T(n) = \begin{cases} \frac{p}{1-p*(r mod 1/p)} * \frac{1/C_{N_j,N_i}}{\sum_{k\in FT_j} C_{N_j,N_i}} & if n \in G \\ 0 , & otherwise \end{cases} \quad (6)$$

Simulation results show that LEACH-P has improved network lifetime compared with LEACH. Fig. 11 shows how LEACH-P prolonged network lifetime.

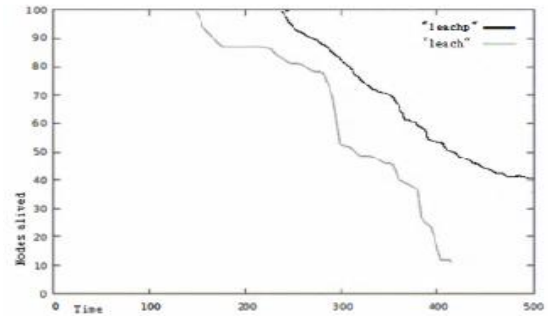

Figure 11. LEACH-P network lifetime compared with LEACH.[12]

H. A Novel Energy Efficient Redundant Routing Tree for WSNS (EE-RRT)

Authors in [14] introduced a Novel Energy Efficient Redundant Routing Tree for WSNs (EE-RRT) which has the following three features:

1) It improves virtual grid ideas to divide each cluster into M×N square area and select a working node in each grid to reduce redundant information and economize energy.
2) EE-RRT improves energy utility by changing the activity of wireless communication module of sensor nodes, energy model, and state transition of sensor nodes.
3) EE-RRT builds a redundant routing tree as the transmission agents to realize the information exchange between the cluster and base station, so that the energy consumption of normal nodes and cluster head can be decreased and reduce the dynamic clustering time to save energy.

EE-RRT protocol has six phases:

1) Initializing.
2) Working node selection.
3) Selecting redundant node phase.
4) Building redundant routing tree phase.
5) Data Sensing.
6) Data Sending.

When a CH has collected information, it then sends the information to a redundant node in its cluster, and the information will be along redundant routing tree to sink node. Simulation of EE-RRT shows an enhancement in energy consumption due to the redundant routing tree which saves energy compared with LEACH and RNTA protocols, the reader is advised to see [15] for more information about RNTA protocol.

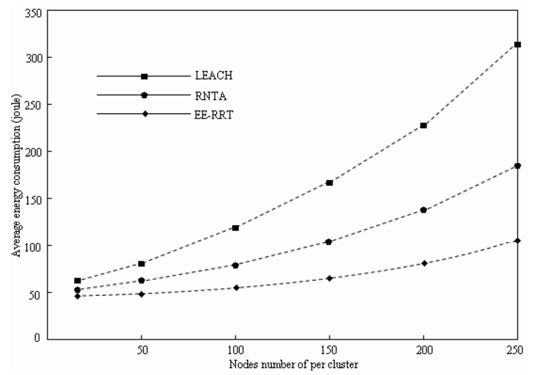

Figure 12. Average energy consumption of different nodes number in each cluster. [14]

Fig. 12 shows that the average energy consumption of LEACH, RNTA and EE-RRT in different nodes number in each cluster.

I. LEACH-M (Mobile) and LEACH-ME (Mobile Enhanced)

Authors in [16] introduced a new version of LEACH with a mobility factor. LEACH-M uses the same threshold formula $T(n)$ of the original LEACH to calculate the threshold, but LEACH-M takes into consideration the mobility of nodes during data transfer phase, which LEACH does not. The mobility itself is a challenge because mobile node can leave cluster while it is transmitting data to a CH. LEACH-M solves this problem by confirming whether a mobile node still able to communicate with CH or not according to TDMA schedule. At the beginning of each TDMA slot, the CHs transmit the message REQ-DATA-TRANSMITION. If the mobile node is unable to receive the message, the CH waits for the request in the next TDMA slot. If the node misses two successive TDMA frames, it considers itself out of range, and the CH will remove unreachable nodes from its member list.

Furthermore, authors in [17]introduced LEACH-ME as an enhanced version of LEACH-M. LEACH-ME was proposed to enhance LEACH-M by selecting the less mobile nodes relatively to its neighbors to be CHs. Each node contains cluster head transitions it has made during the steady state phase while transmitting data. Nodes transmit a transition count to its CH during the TDMA slot. The CH calculates the average transition count of its members for the few last cycles. As a result, an active slot will rise when the number of transition count is beyond the threshold value. During active slot, nodes broadcast their IDs and each node estimates the distance to all nodes and calculate mobility factor according to (7)

$$M_i(t) = \frac{1}{N-1} * \sum_{j=0}^{N-1} d_{ij}(t) \tag{7}$$

where $M_i(t)$is the mobile factor based on remoteness of node *i* to all other nodes, N is the number of neighbors of node *i*, and $d_{ij}(t)$ is the distance of node *i* from its neighbors *j*. After calculating the mobile factor, the nodes with least mobility factor value are selected to be CHs, taking into consideration the energy level of that node is not below a certain threshold. The steady state phase is the same for both LEACH-M and LEACH-ME.

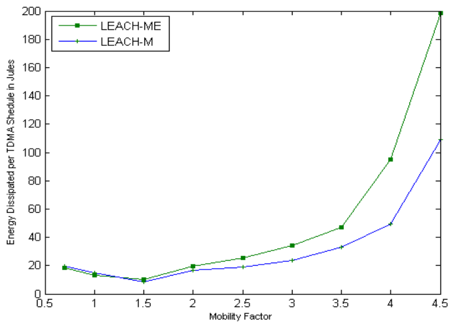

Figure 13. Remaining energy of the network. [17]

LEACH-M and LEACH-ME were simulated as shown in Fig. 13 which shows the amount of energy dissipations for the data packets transmitted for both protocols.

J. An Adaptive Cluster Based Routing Scheme for Mobile Wireless Sensor Networks

Authors in [18] introduced an Adaptive Cluster Based Routing Scheme to improve the cluster formation in mobile sensor networks by taking into consideration the relative direction of the node mobility.

This protocol contains two phases: Set up phase and steady state phase. In this protocol the steady state phase is divided into a fixed number of TDMA frames. The protocol works as follows: at the set up phase nodes broadcast there ID twice at t1 and t2. Thus, each node can estimate its distance to neighbors by RSSI (Received Signal Strength Indication).There will be two distances $d_{ij}(t1)$ and $d_{ij}(t2)$. If $d_{ij}(t1) - d_{ij}(t2)$ is negative, it means the two node *i* and *j* are moving away from each other. Otherwise, they are moving towards, or they are stationary. Each node calculates its relative direction to its neighbors based on mobility factor Mi(t) as shown in (8).

$$\mathrm{Mi(t)} = 1 - \frac{Noofnodesmovingawayfromi}{N} \tag{8}$$

where N is the number of neighbors for node *i*.

If Mi(t) >0.5, which means the number of nodes which are stationary or moving towards node *i* is more than the nodes moving away, a node determines to be a CH or not. CHs declare themselves as CHs by broadcasting CH–ADV message. The rest nodes collect this message from neighbors CHs and calculate the formula in (9).

$$\frac{\mathrm{diCH(t1)-diCH(t2)}}{\mathrm{t2-ti}} \tag{9}$$

According to this value, each node decides which CH it will join by transmitting JOIN–REQ message to the CH. After clusters are formed, each CH prepares and transmits a TDMA schedule to its members. During steady state phase, the operation of data transmission is divided in to fixed number of TDMA frames. The proposed protocol uses LEACH-M technique where CHs send REQ-DATA message to its members at the beginning of each TDMA slot. If a CH does not receive data from a member for two TDMA frames it considers the node unreachable and removes it from its member list.

The proposed protocol was simulated and compared with LEACH-M. The results show that the proposed protocol consumes less energy compared to LEACH-M. Fig. 14 compares the average residual energy of nodes for the two protocols. As a result of reducing the energy consumption the proposed protocol shows an enhancement on the network lifetime compared with LEACH-M. Fig. 15 shows the number of the alive nodes in the network over time.

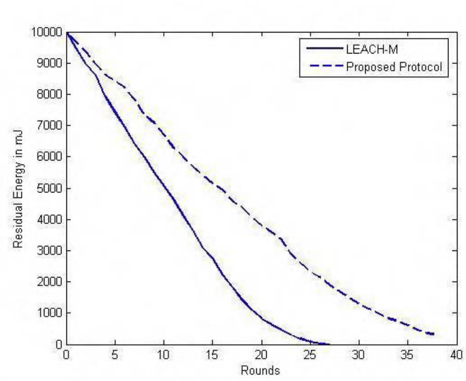

Figure 14. Average residual energy of nodes with mobility.[18]

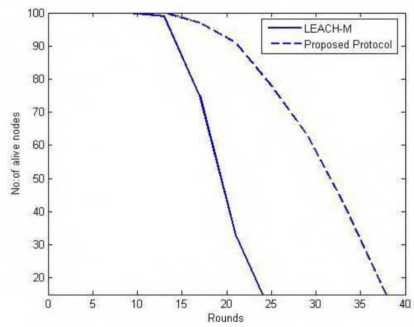

Figure 15. Network Lifetime Comparison with increased mobility.[18]

K. Power Efficient Communication Protocols for Data Gathering on Mobile Sensor Networks

Another protocol for mobile sensor network is proposed to address the issue of power efficient communication for data gathering in sensor network. The protocol is called Clustering Mobility (CM) [19], and it consists of three phases:

1) Cluster Head Election
2) Organizing Clusters
3) Massage Transmission.

This protocol has some assumptions. First, the BS is fixed and located far away. Second, all nodes are homogeneous and are power limited. Third, each sensor node is equipped with a GPS device, and finally all nodes are capable of moving, which itself is a problem. Since the nodes can move, each node has to calculate its distance to all its neighbors. This protocol introduces the concepts of invalid round, valid round and super round. If there are no CHs at all in some rounds, they are called invalid round (CM-IR) since they consume energy without being useful. On the other hand, when some CHs are elected in some round, these are called valid rounds. The super round consists of a valid round and some consecutive invalid rounds in cluster head election phase.

Simulation results show that CM and CM-IR protocols make the network lives longer compared to LEACH. Fig. 16 shows the system lifetimes when each sensor node has initial energy 1.0 J in areas of 200m × 200m.

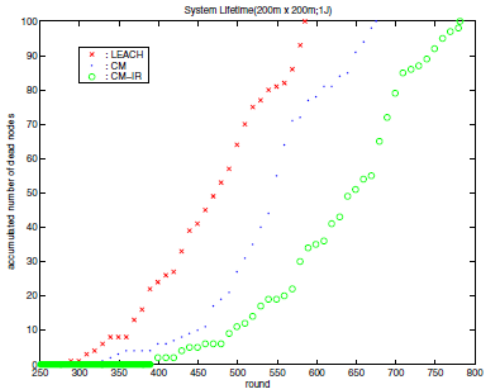

Figure 16. The system lifetime of the wireless mobile sensor network.[19]

L. TL-LEACH(Two-Level)

Authors in [20] introduced a new version of LEACH called Two-Level LEACH. In this protocol, a CH collects data from other cluster members as original LEACH does. However, rather than transfer data to the BS directly, it uses one of the CHs in the path to the BS as a relay station. TL-LEACH consists of four phases

1) Advertisement Phase.
2) Cluster Setup Phase.
3) Schedule Creation.
4) Data Transmission.

During the advertisement phase each node decides if it wants to be a primary CH_i, secondary CH_{ij} or simple node (SN). Each secondary CH_{ij} node decides which primary CH_i node it will join, and each simple node also decides which secondary CH_{ij} it will join. Fig. 17shows the nodes formation after the cluster setup phase is completed.

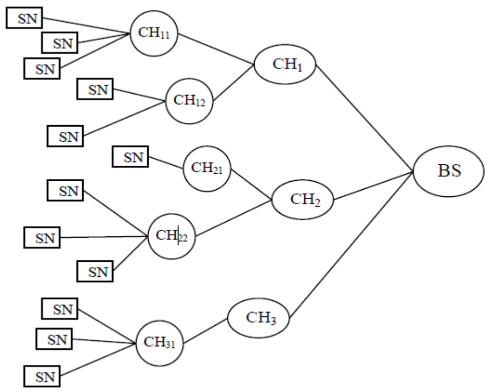

Figure 17. The topology network after the setup cluster phase is complete in TL-LEACH. [20]

Simulation results of TL-LEACH show a great enhancement of the energy dissipation and network life time compared with LEACH. Fig. 18 shows the total energy dissipated over time and Fig. 19 shows the number of nodes alive over time.

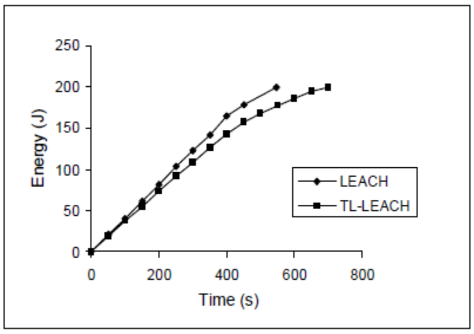

Figure 18. The total amount of energy dissipated in the system over time. [20]

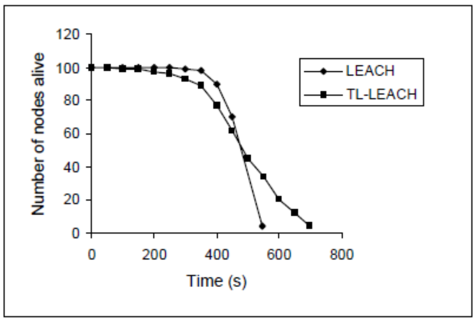

Figure 19. Number of nodes alive over time.[20]

M. V-LEACH(Vice)

Authors in[21] introduced the Vice-LEACH protocol, in which the cluster contains a CH (which is responsible only for sending data that is received from the cluster members to the BS), a vice-CH (the node that will become a CH in case the old CH dies), and cluster nodes (for gathering data from environment and send it to the CH). In the original leach, the CH is always on to receive data from cluster members, aggregate these data, and then send it to the BS that might be located far away from it. The CH will die earlier than the other nodes in the cluster because of its operation of receiving, sending and overhearing. When the CH dies, the cluster will become isolated because the data gathered by cluster nodes will never reach the base station. In V-LEACH protocol, besides having a CH in the cluster, there is a vice-CH that takes the role of the CH when the original CH dies. By doing that, data collected by the cluster nodes will always reach the BS. Therefore, no need to elect a new CH each time the CH dies. This will extend the overall network lifetime.

Simulation of V-LEACH shows that it consumes less energy compared with LEACH, as result of that the network lifetime is prolonged. Fig. 20 shows energy consumption for V-LEACH and LEACH.

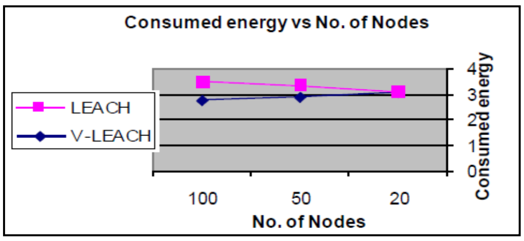

Figure 20. Consumed network energy. [21]

N. MULTI-Hop Leach

When the network diameter is increased beyond a certain level, LEACH (in which the BS is at single-hop to the CH) becomes inefficient. In this case energy dissipation of cluster-head is not affordable. To address this problem, authors in [4] introduced the Multi-Hop LEACH which aims to increase energy efficiency of a WSN. Like LEACH, in Multi-Hop LEACH some nodes elect themselves as CHs and some associate themselves with the elected CHs to complete the cluster formation in the setup phase. In steady state phase, a CH collects data from all nodes in its cluster and transmits data directly or through other CH to the BS after aggregation.

Multi-Hop LEACH allows two types of communication operations. These are the inter-cluster communication and the intra-cluster communication. In Multi-Hop intra-cluster communication, when the whole network is divided into multiple clusters, each cluster has one CH. This CH is responsible for communication between all nodes in the cluster; it receives data from all nodes at a single-hop distance and aggregates and transmits the data directly to the BS, or through intermediate CH(s). In Multi-hop inter-cluster communication, when the distance between the CH and the BS is large, the CH uses intermediate CH(s) to communicate to the BS. Simulation of Multi hop-LEACH is shown in Fig. 21.

O. E-LEACH (Energy)

Authors in [22] introduced the Energy-LEACH protocol to improve the CH selection procedure. It uses the residual energy of node as the main metric to decide whether the nodes turn into a CH or not after the first round. Similar to the LEACH protocol, the E-LEACH is divided into rounds. In the first round, every node has the same probability to turn into a CH, which means nodes are randomly selected as CHs. In the next rounds, the residual energy of each node is different after one round of communication and is taken into account in the selection of the CHs. As a result, nodes which have more residual energy will become CHs probably more than nodes with less residual energy.

Simulation of E-LEACH shows improvement over LEACH and Multi hop-LEACH with the energy consumption due to the enhanced way of the CH selecting process. Fig. 21 shows total residual energy of E-LEACH, LEACH and Multi hop-LEACH.

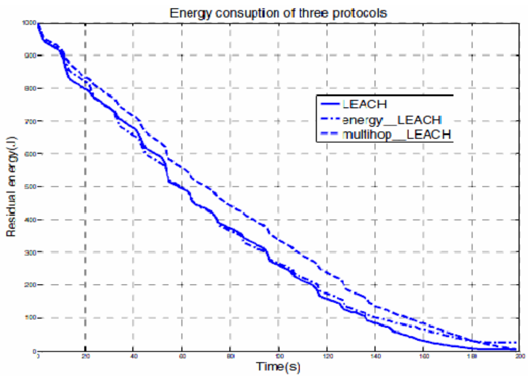

Figure 21. Residual energy of three protocols. [22]

P. Zone Division Multi Hop Hierarchical Clustering for Load Balancing

Authors in [23] introduced an Energy Efficient Zone Division Multi hop Hierarchical Clustering Algorithm for Load Balancing in WSNs. The proposed protocol consists of two different phases: the setup phase and the steady state phase. Within the setup phase there are super nodes known as CHs and vice super node known as temporary CHs. During the steady state phase, which is usually longer than the setup phase, data is transmitted to the BS. In the setup phase, the algorithm divides the full region into four zones and finds the centre area of that region. In addition, it makes a set of temporary super nodes and also selects a node super node. The zone can or cannot be divided again depending on efficiency of the super node.

Simulation results shows that the proposed algorithm improved network lifetime compared with LEACH and VLEACH as shown in Fig. 22. Furthermore, Fig. 23 shows that the proposed algorithm enhanced the energy consumption compared with LEACH and VLEACH.

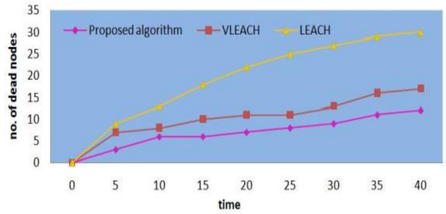

Figure 22. .Dead node comparisons in network.[23]

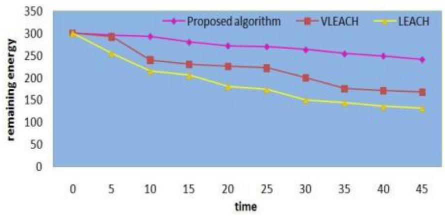

Figure 23. Remaining energy comparison in network.[23]

Q. Efficient Cluster Head Selection Scheme for Data Aggregation in Wireless Sensor Networks (ECHSSDA)

Authors in [24]introduced a new version of LEACH: Efficient Cluster Head Selection Scheme for Data Aggregation in Wireless Sensor Networks (ECHSSDA). ECHSSDA introduced an associate CH node beside the normal CH, which will become a CH in case the original CH energy level becomes lower than the average energy, which computed by the BS. A CH is responsible only for receiving data from the cluster members, performing aggregation process over the received data, and sending the data to the BS. When the original CH dies, data gathered by cluster nodes will never reach the BS. Therefore, selection of a new CH becomes important. This happens when the original CH energy level is lower than the average energy level. Therefore, the associate CH will become the CH in the next round.

ECHSSD re-clustering reduces the overhead of clustering process, the load over CH, and the energy consumption within cluster in large-scale and dense sensor networks.

Simulation of ECHSSD shows an improvement in prolonging network lifetime due to less energy consumption of nodes in process of the CH selection than LEACH and LEACH-C protocols. Fig. 24 shows network lifetime.

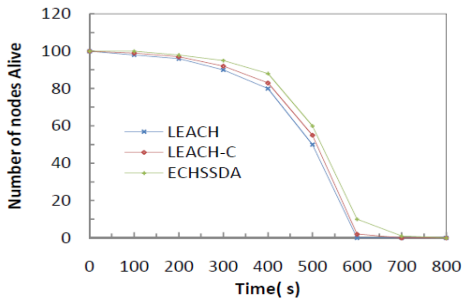

Figure 24. Network lifetime.[24]

R. MELEACH-L

Authors in [25] proposed a protocol called More Energy-efficient LEACH for Large-scale WSNs (MELEACH-L)as an extension to MELEACH[26].In MELEACH authors have improved LEACH by shortening the communication distances between sensor nodes and improving the load balance between them, but similar to LEACH it still requires a direct communication between sensor nodes including the BS. This requirement is applicable for small WSNs, but when it comes for large scale WSNs it is so costly to equip each sensor node with powerful radio transceiver. In MELEACH-L authors overcome this restriction and make the functions of MELEACH applicable for large scale WSNs. By controlling the size of each cluster and separating the CHs from the backbone nodes, MELEACH-L solves the problems of the channel assignment among neighbor clusters and the cooperation among CHs during data collection.

The procedure of MELEACH-L is divided into rounds. Each round is comprised of quad sequential phases:

1) The Cluster Head Selection Phase
2) The Backbone Tree Construction Phase
3) The Spanning Tree Construction Phase
4) The Data Collection Phase.

The time-line of MELEACH-L is shown in Fig. 25.

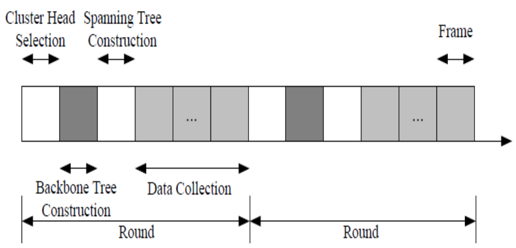

Figure 25. Timeline of MELEACH-L[25]

MELEACH has been simulated using C++, where the deployment region of the WSN is a square of size M×M, the BS is settled at one of the corners of the square, and N sensor nodes are deployed uniformly and randomly.

Simulation results of MELEACH-L shows that it enhanced the network lifetime compared with LEACH, PEGASIS [27] and MELEACHdue to the schemes that shorten the communication distance and improve the load balance. In addition, the energy efficeny is further improved and the network lifetime increased about 10% compared the MELEACH [25]. Fig. 26 illustrates how the number of living sensor nodes descends with the time in the simulation (M =200 m and N =1000 nodes).

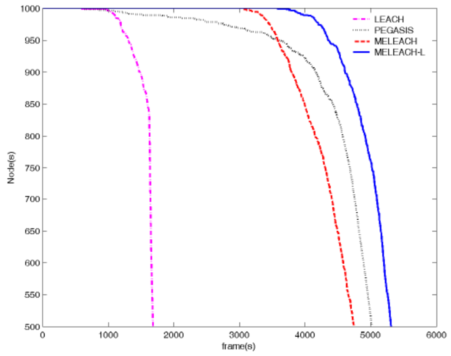

Figure 26. Channel assignments among Clusters [25].

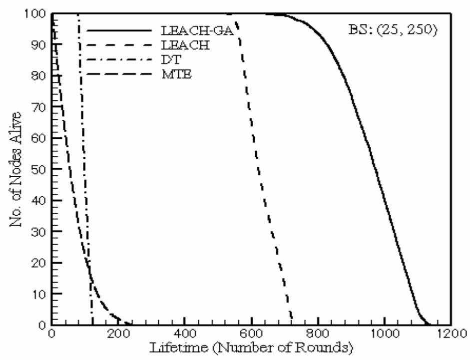

Figure 27. Network lifetime (number of rounds) [28]

S. LEACH-GA

Authors in [28] introduced a genetic algorithm-based clutering to determine P_{opt} which is the optimal value of CH percentage. LEACH-GA assumes the same radio model used in LEACH.Equation (10) presents the required energy consumed by a CH per round.

$$E_{CH}(l,d) = \begin{cases} l \times \left[E_{elec}\left(\frac{n}{k}-1\right) + E_{DA}\frac{n}{k} + E_{elec} + \varepsilon_{fs} \times d_{toBS}^2\right] if\, d_{toBS} < d_0 \\ l \times \left[E_{elec}\left(\frac{n}{k}-1\right) + E_{DA}\frac{n}{k} + E_{elec} + \varepsilon_{mp} \times d_{toBS}^4\right] if\, d_{toBS} \geq d_0 \end{cases} \quad (10)$$

where $d_0 = \sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$, is the threshold distance, n is the total number of sensor nodes and k is the number of clusters, l is the size if of the message and d is the distance. The energy consumed by non-CH node is presented in (11).

$$E_{non-CH}(l,d) = l \times E_{elec} + l \times \varepsilon_{fs} \times d_{toCH}^2 \quad (11)$$

LEACH-GA assumes a preparation phase before setup phase and steady state phase and it is done for one time. Initially each node decides whether or not it should be a candidate CH (CCH) using the same CH selection procedure as LEACH. After that, each node sends its ID, location information, and whether it is a CCH or not to the BS. When the BS receives all messages sent by all nodes, it applies genetic algorithm operations to find out the optimal probabilityP_{opt}. As soon as P_{opt} is calculated, the BS broadcasts the value of $P_{opt}$to all nodes, then the setup phase and steady phase are begin as in LEACH.

Simulation results in Fig. 27 shows that LEACH-GA protocol prolongs network lifetime compared to LEACH with the BS located at (25, 250).

T. MR-LEACH

Authors in [29] introduced the Multi-hop Routing with Low Energy Adaptive Clustering Hierarchy (MR-LEACH). MR-LEACH partitions the WSN into different layers of clusters and the CH in each layer collaborate with adjacent layer to transmit the collected data from its members to the BS. MR-LEACH uses the same radio model introduced in LEACH. MR-LEACH consists of three phases:

1) Cluster formation at lowest level.
2) Cluster discovery at different levels by the BS.
3) Scheduling.

In the cluster formation phase, each node builds a table that holds node ID, residual energy level, and node status. The table is built at the beginning of each round. When clusters are formed, the CH will store nodes ID's of its members. The node status could be one of three values: unknown, cluster member, or CH. A node will be selected as a CH based on its residual energy. Nodes will choose to join a CH with the highest RSSI. The cluster discovery phase is done by the BS. The BS will broadcast its ID and all CHs that hear the message will record the BS ID. CHs close to the BS will form layer one since they are at single hop form the BS. After that, the BS will broadcast a control packet with layer one CH ID's. All CHs in the network will reply (except CHs of layer one) to this packet.This reply will not reach BS directly, rather that, it will reach CHs in layer one. At the scheduling phase, TDMA scheduling scheme is applied. The following Fig. 28 shows the whole process.

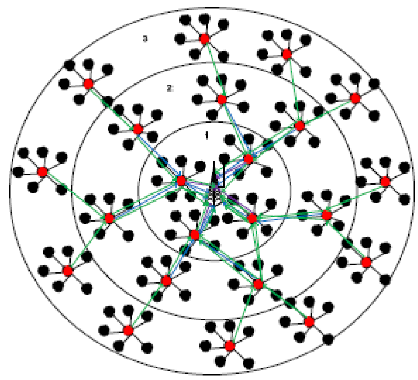

Figure 28. Partitioning of Network into layers and cluster head discovery at multiple Layers by the BS.[29]

Fig. 29 shows that energy consumption deceases when applying MR-LEACH compared with Direct Communication (single hop) and LEACH.

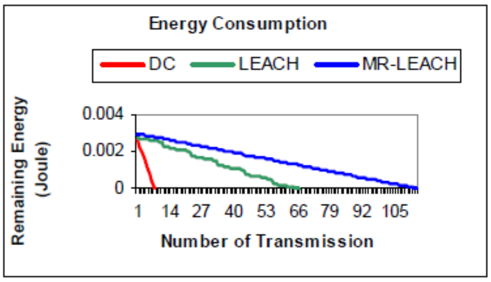

Figure 29. Energy Consumption vs. No. of Transmissions.[29]

U. FL-LEACH (Fuzzy Logic)

Authors in [30] introduced an extended LEACH protocol which employs Fuzzy-Logic to find out the number of CHs that should be selected in a WSN. A fuzzy logic system is composed of a fuzzifier, a fuzzy inference system, rules, and a defuzzifier. FL-LEACH uses the Mamdani method as fuzzy inference which consists of four steps:

1) Fuzzification which is done by taking the crisp values of the input variables and determining their fuzzy sets and membership value.
2) Rule evaluation by applying the fuzzified inputs to the antecedent and consequent parts of each fuzzy rule.
3) Aggregation at the output fuzzy sets of the output variable.
4) Defuzzification to calculate the crisp value of the output.

Fig. 30 shows the block diagram of the FL-LEACH protocol.

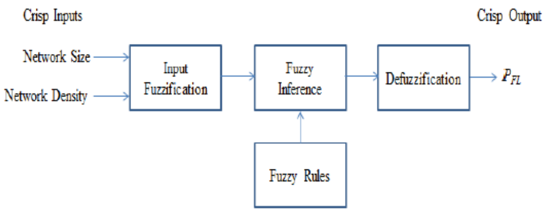

Figure 30. Block diagram of the input and output fuzzy variables [30].

FL-LEACH uses two variables as an input to the fuzzy logic system: The number of nodes in the WSN and the network density. Equation (12) shows the computation of CHs (P_{FL}) percentage.

$$P_{FL} = \frac{\int x * \mu_{FL} * dx}{\int \mu_{FL} * dx} \tag{12}$$

where μ_{FL} is the aggregated output membership and x represents the universe discourse.

FL-LEACH was simulated using MATLAB and compared with LEACH and LEACH-GA in terms of live nodes per round. Simulation results show that FL-LEACH improves the network lifetimes about 51% on the number of alive nodes compared to LEACH [30], due to the enhanced procedure of selection CHs percentage P_{FL} value. Fig. 31 shows the number of live sensor nodes for the LEACH, LEACH-GA, and FL-LEACH.

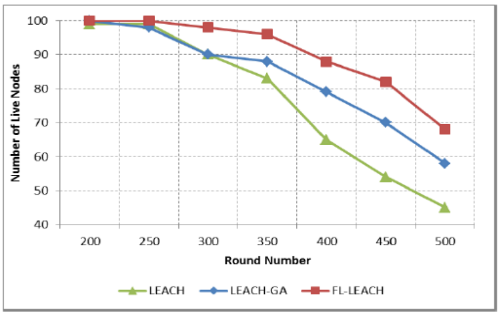

Figure 31. Live sensor nodes for the three algorithms. [30]

IV. Coparison Among the Different LEACH-Based Routing Protocols for WSNs

Our survey shows that each of the various LEACH-Based routing protocols has its own assumptions, CH selection criteria, advantages (improvements), and disadvantages. We summarize them in Table II. In the first column, we specify the section number in which each protocol is explained.

TABLE II. Comparison of Different LEACH Extending Protocols

Protocol	Assumption	CH selection	Improvement over LEACH	Disadvantage
LEACH-B	all sensors in the network are simple and inexpensive but have a power Control mechanism to vary the amount of transmits power.	Two stages: Random, residual energy.	proposed a new adaptive strategy to choose cluster heads and to vary their election's frequency considering The dissipated energy. Network lifetime prolonged.	LEACH's disadvantage, Extra overhead for electing CHs.
LEACH-C	Each node sends information about its current location (possibly determined using GPS) and residual energy level to the sink.	BS selects CHs based on the Residual energy	LEACH-C achieves a higher number of rounds in small area networks	Extra overhead on the BS. LAECH-C does not fit for large area networks.
EWC	the nodes are distributed randomly, the nodes are homogeneous, static, and location unaware	Residual energy, distance, node's degree	Network lifetime prolonged	extra overhead processing so more energy is consumed to select CHs
NECHS	the nodes are distributed randomly, the nodes are homogeneous, static, and location unaware	Residual energy, node's degree	NECHS model to improve energy efficiency of cluster head Selection using fuzzy logic.	no guarantees non-CH node belongs to cluster because of collisions of advertisement, or join packets

Energy efficient cluster head selection for wireless sensor network	the nodes are distributed randomly, the nodes are homogeneous, static, and location unaware	Residual Energy Level	Enhanced network lifetime	Extra overhead to find k_opt of CHs
EECED	BS is assumed to know all the node locations. All sensor nodes are immobile and have a limited energy. All nodes are equipped with power control capabilities to vary their transmitting Power. event-driven protocol architecture	Residual Energy Level	Network lifetime prolonged, consumes less energy compared with LEACH.	Extra overhead on the BS and elector nodes to select CHs.
LEACH-P	the nodes are distributed randomly, the nodes are homogeneous, static, and location unaware	Introducing EMAR probability selection into LEACH protocol	Network lifetime prolonged	Extra overhead to calculate probability selection formula for selecting CHs.
EE-RRT	Singles BS in the network. Location aware. Nodes are homogeneous distribution in each cluster.	Residual Energy Level	EE-RRT improves virtual grid ideas to divide each cluster into M×N square area and select a working node in each grid to Reduce redundant information and economize energy. EE-RRT improves energy utility by changing the activity of wireless communication module of sensor nodes, Energy model and state transition of sensor nodes. EE-RRT significantly reduce in Energy consumption and prolong the network lifetime.	Extra overhead processing to select CHs
LEACH-M	all nodes are homogeneous in sense of antenna gain, all nodes have their location information through GPS and Base station is considered fixed	Residual energy and mobility of the node	Support node's mobility by Membership declaration to the existing LEACH protocol. The LEACH-Mobile outperforms LEACH in terms Of packet loss in mobility environment. LEACH-M ensures the communication of a node with a CH even if node is in motion	LEACH-M is not considered efficient in terms of energy consumptions and data delivery rate because a large number of packets are lost if the CH keeps moving before the selecting a new CH For the next round.
LEACH-ME	all nodes are homogeneous in sense of antenna gain, all nodes have their location information through GPS and Base station is considered fixed	Residual energy and node's mobility	Support node's mobility, remoteness concept for cluster head Election. LEACH-ME ensures the communication of a node with a CH even if node is in motion	Extra overhead on electing CHs.
Adaptive CH based routing scheme for mobile WSN	Sensor nodes are mobile, All nodes are location unaware and homogeneous with same battery power and Architecture.	Relative direction of the node's neighbors, mobility factor of the node.	Relative direction of node mobility is considered.	Extra overhead on calculating node's movement direction.
Power Efficient Communication Protocol for data gathering	The BS is fixed and located far away from the sensor nodes. All the sensor nodes are homogeneous and power limited. Each sensor node is equipped with a GPS (Global Positioning System) device. Each sensor node is capable of moving: each sensor node has a constant speed and fixed direction. All sensor modes are time-synchronized	CH election like LEACH, introduces the valid and invalid rounds	Solved the case when there is no CHs in a round. Outperforms LEACH in terms of energy consumptions.	Add extra overhead on electing CHs.
TL-LEACH	The base station is fixed and localized far from the Sensors. All nodes in the sensor are homogeneous and energy constrained. There are no "high-energy" nodes through the communication can proceed.	Random, Introducing primary CHi, and secondary CHij	Introducing a new level of hierarchy to elaborate the Information to transmit to a Base Station (BS) over two different levels and this permit to better use the energy in the network.	Extra overhead for electing secondary CHs and cluster formation.
V-LEACH	The base station is fixed, all nodes are homogenous and have same energy levels, and all nodes are stationary.	Random	Introducing vice-CH that takes the role of the CH when the CH dies	Extra processing for selecting vice-CH.
Multi-Hop LEACH	Fixed base station. All the sensor nodes are considered static,	Random	Supporting Energy minimizing techniques like Multihop	Problems arise in case one of CHs hops die as result

	homogenous and energy constrained. The sensor nodes are expected to sense the environment continuously and thus have data sent at a fixed rate		communication, clustering and data aggregation. Multihop-LEACH uses both inter cluster as well as intra cluster communication.	the gathered data will be lost.
E-LEACH	The base station is fixed, all nodes are homogenous and have same energy levels, and all nodes are stationary.	Residual Energy Level	It improves the CHs selection process. It determines that the required number of cluster heads has to scale as the Square root of the total number of sensor nodes to minimize the total energy consumption.	The CHs must keep its receiver turned on to receive all the data
Zone Division Multihop Hierarchical Clustering For load Balancing	The base station is fixed, all nodes are homogenous and have same energy levels, and all nodes are stationary.	Residual energy, Divide the region on the network and nodes as close as centre is called set of super node.	This algorithm makes the best use of node with low number of cluster head know as super node. This algorithm forms multilayer communication.	Overhead on controlling and management of the zones
ECHSSDA	all nodes have no mobility, each node knows its own location and remaining energy level, All nodes are homogeneous. The location of the sensors and the base station are set and known priori. Sensor nodes location aware, i.e. equipped with GPS capable antenna. Nodes are left unattended after deployment,	Residual Energy Level	Proposed algorithm focuses on avoiding re-clustering, reduce the overhead of clustering process, reduce the load over cluster head, and reduce the energy consumption within cluster in large-scale and dense sensor networks with the help of cluster head selection and cluster formation. No need to select cluster head periodically.	Extra processing for selecting CHs.
MELEACH	The base station is fixed, all nodes are homogenous and have same energy levels, and all nodes are stationary. sensor nodes are deployed uniformly and randomly	Residual Energy Level	MELEACH improved LEACH by further reducing the mean transmission distance and improving the load balance between sensor nodes.	Inappropriate for Large scale WSNs because providing a powerful enough radio on each sensor node for MELEACH is costly
MELEACH-L	The base station is fixed, all nodes are homogenous and have same energy levels, and all nodes are stationary, sensor nodes are deployed uniformly and randomly	Residual Energy Level	MELEACH-l solved the problems of the channel assignment among neighbor clusters and the cooperation among cluster heads during data collection	utilization of multiple channels increases economic cost taking much frequency spectrum, and the cluster, the backbone tree and the spanning tree must be rebuilt periodically due to the assumption that every node must know the coordinate information of the entire network. The former makes the protocol uneconomical and the latter incurs much overhead
LEACH-GA	Sensor nodes are homogenous and are assumed to be uniformly distributed in the sensor field and have same energy levels, and all nodes are stationary. The base station is fixed. Location aware e.g.(GPS)	BS selects CHs based on residual energy using GA.	GA-LEACH Determines the optimal probability to use in the CH selection mechanism.	Complexity and extra overhead on the BS to evaluate the CHs percentage.
MR-LEACH	sensor nodes are randomly deployed in the square field, sensor nodes and BS are stationary, Base Station can be placed any where inside the sensing field or away from it. Nodes use power control to tune the amount of send power according to the transmission distance.	Residual Energy Level	MR-LEACH introduces the concept of equal clustering i.e., any node in the given layer will reach the BS in equal number of hops.	Extra overhead on the BS, probability of message failure and routing the sensed data of Multi hop could fail.
FL-LEACH	Sensor nodes are assumed to be static and homogenous in terms of initial energy. Sensors are deployed uniformly over the sensor field BS is fixed.	Random	Applying fuzzy logic on LEACH protocol to determine the percentage of CHs has enhance the network lifetime	Complexity and the accuracy in the fuzzification and defuzzification process.

V. Conclusion

One of the main challenges in the design of routing protocols for WSNs is how to efficiently consume energy because energy resources are very limited. The ultimate objective behind the routing protocol design is to keep the sensors in operation for as long as possible, thus extending the network’s lifetime. The energy consumption of the sensors is dominated by data transmission and reception. Therefore, routing protocols designed for WSNs should be as energy efficient as possible to prolong the lifetime of individual sensors, and hence the network's lifetime. In this paper we have surveyed various LEACH-based protocols and discussed how they improve energy consumption in WSNs and increase network's lifetime. Furthermore, we provide a table summary showing the advantages, disadvantages, CH selection criteria, and assumptions for each protocol.

Due to the drawbacks of LEACH, many protocols have been emerged to solve these problems. However, more work is still needed to find more efficient, scalable and robust clustering scheme to enhance energy consumption and prolonging networks lifetime in small and large WSNs.

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