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Survey of Leach Variants

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***Abstract*—Wireless sensor network is a vastly growing technology that is being used in various fields for sensing and transmitting data. It is being used in various applications in both military and civil. Wireless sensor network consist of large number of nodes that is being deployed in a large area for sensing and transmitting data from its surroundings. To sense control and transmit the data a sensor and transmitter is used. This process requires some energy source, for that purpose generally a battery is used. Because of their small size the sensor nodes have a small battery source and it is not practical to charge or change them regularly. To solve this problem some routing techniques have been introduced which lowers down the amount of energy being used by the network. Leach is one of the major techniques which heighten the network lifetime. In this paper, we are going to discuss the working, advantages and disadvantages of the leach protocol and its descendant protocols. Each protocol will be compared and discussed on the basis of the energy consumption and network lifetime.**

Keywords*—WSN, medoids, LEACH, network lifetime, energy efficiency.

I. INTRODUCTION

Sensing technology has many major components which are on the developing stage and are being used in various fields in the human world. Wireless sensor network is one of those components. This network consists of thousands of nodes which are deployed in a large area for sensing the surrounding data. This information is being sensed, computed and transmitted to the center of the network. Since it is used in both civil and military applications different types of sensors are used depending upon the requirement. Since nodes are cheap so they are having less hardware configuration and small energy resources. In majority of the cases battery is employed as an energy source but replacement and recharging of the battery is not recommended. To solve this problem various protocols for routing are used. Three types of routing protocols are there [*1*]:-

1. Hierarchical.
2. Flat.
3. Location based.

Hierarchical is best in them when it comes to provide more energy efficient protocols. In hierarchical based protocols clusters are formed in a network in which one of the nodes is assigned as a cluster head which performs some special task. Hierarchical approach declines the energy consumption by decreasing the redundancy of data [*2*] and performing the data aggregation process which reduces the network overhead and declining unnecessary transmissions. Leach was the very first hierarchical protocol which is based on forming clusters in network each having a cluster head to which each node in cluster send the data and which will further aggregate this data to the base station. This indirect approach of aggregating data detracts the consumption of energy. We in this paper are going to focus only on hierarchical based leach descendants.

The rest of the paper is organized as follows. In section II we will discuss leach protocol. Section III will discuss the protocols based on the leach. In section IV these protocols will be compared, analyzed and their results of the simulation will be discussed.

II. LEACH PROTOCOL

In wireless sensor networks, first hierarchical protocol which was introduced to enhance the lifetime of a network is leach. It is a self-organizing cluster based protocol consists of various rounds. These rounds represent the different cluster formations as required by the network. In a cluster one the nodes is assigned as a cluster head and rest of the nodes act as its member nodes. These member nodes transmit the sensed data to cluster head which cluster head aggregate and convert to meaningful information and then transfer it to base station. We can say that cluster head work as an intermediate node between the base station and rest of the nodes. This approach will reduce the energy of that cluster head node more frequently as compared to other nodes which could result in the end of the node. To resolve this, rotation of the cluster head is essential. So, different rounds form different cluster depends upon the energy of the network. Leach protocol performs aggregation and compression of data before forwarding it to the base station results in maximization of network lifetime and degradation of energy consumption. As in leach nodes communicate to base station through cluster heads by using communication hierarchy as shown in fig.1

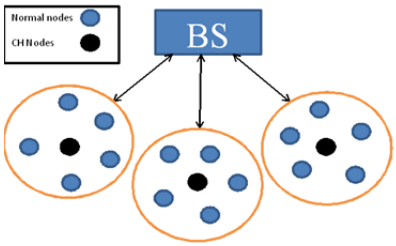

Fig. 1. Leach protocol working.

Every round in leach comprises of two phases i.e set up and steady state phase. Set up phase performs the task of formation of the clusters. In every cluster a single node acts as a cluster head node and other nodes act as normal.

In the cluster head selection process, a random value is taken ranging from 0 to 1. If this value is less than threshold *T(n)*, then the node will become CH, then threshold, *T(n)* is described through this expression [*2*].

$$T(n) = \begin{cases} \frac{p}{1-p(r \bmod \frac{1}{p})}. if\ n \in G \\ 0 \qquad\qquad otherwise \end{cases} \quad [1]$$

This expression is for the nodes which haven't been cluster head in last 1/p rounds otherwise *T (n)* will be zero. p is required percentage of cluster heads from all the nodes; r is the current working round. Advantage of this algorithm is that approximately every node in the cluster will become cluster head at least once in 1/p rounds. After 1/p-1 rounds, the threshold value *T(n)* will become 1 [*2*]. It means every node will be eligible again to become a cluster head. Now after election of the CH every cluster head broadcast the message to its cluster nodes by using CSMA MAC protocol [*1*]. Every node will select its CH based on the received signal strength. Then the nodes who want to join the cluster send its request to that CH. Then CH assigns TDMA schedule to every node which states when the data will be transmitted by the nodes. During this process the radio of all the CH should be in active mode.

In steady state phase, every node sends its sensed data to CH based on its allotted TDMA schedule. Cluster head receives the data and then the task of aggregation and compression is performed before transmitting the data further to the base station. After the end of steady state phase, new round begins.

The radio model which is used by the Leach to describe the energy dissipation through devices like transmitter, amplifier and receiver is shown in fig.2 [*2*].

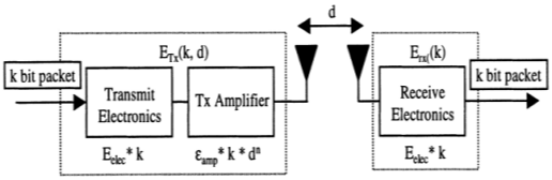

Fig.2. Energy dissipation model [*3*].

Leach had overtaken the disadvantages of some of the previously used approaches and enhanced the reduction of energy used in the network. System lifetime graph of leach is shown in fig3.

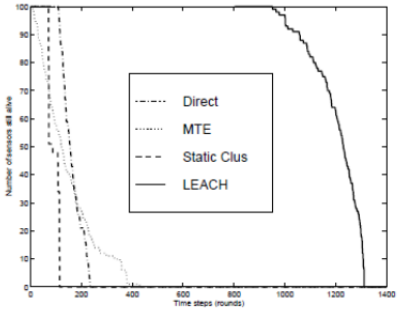

Fig.3. System lifetime using direct transmission, MTE routing, Static clustering and LEACH [*2*].

Leach has brought the concept of energy efficiency to a whole new level. Having many advantages it also has some disadvantages. It assumes that all the nodes in the network starts with same initial energy which is not valid in a real time environment. It is not much efficient when it comes to large scale networks. It is not applicable for mobile nodes, only valid for static nodes. To cover the drawbacks of LEACH many other protocols have been introduced which will be discussed in the next section.

III. Other Heirarchical Protocols Based On Leach

A. *LEACH-M*

It is a mobile version of leach proposed in [*4*]. Mobility of the nodes is allowed in this protocol which was not present in the original LEACH. During the data transfer phase the concept of the mobility is used however the threshold use for CH selection remains same. It is not easy to maintain the mobile nodes in the network as it allows the node to move away from its cluster. This creates problems when the transmission of data is going on. To resolve this problem this protocol proposes a solution by checking whether the node is in range of CH for communication at its provided TDMA slot or not. A data transmission request message is sent to at the starting of every TDMA slot .If the node does not respond it again send a request message in the next allotted TDMA slot. If the problem of receiving any response from mobile node still persists the mobile node is considered as out of range node and then it is deleted from the list of the member nodes.

B. *LEACH-ME*

It is an enhanced version of LEACH-M which is proposed in [*5*]. It enhances the performance of the LEACH-M by selecting the CH which selects less number of mobile nodes as compared to its neighbors. Number of CH transitions is counted which are made at the time of TDMA slot. Average transition count for CH members is counted by the CH for few previous cycles. When the number of transition count is more than the threshold value then the active count will increase. Mobility factor is calculated with each node calculates its distance with all other nodes and broadcast their IDs during the active slot. Mobility factor is counted as [*5*].

$$M_i(t) = \frac{1}{N-1} * \sum_{j=0}^{N-1} d_{ij}(t) \quad (2)$$

The mobile factor $M_i(t)$ is based on the separation of mobile node *i* to other nodes. Total number of neighbors of node i are defined as N and distance of node i from its neighbors j is $d_{ij}(t)$. When the mobile factor is calculated then the nodes having less mobile factor value are selected as CHs. In CH selection the energy level of the node is also considered. The graph shows the better results of LEACHME over LEACHM.

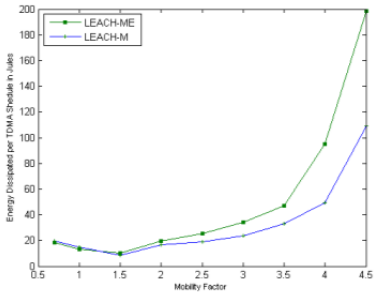

Fig.4.Remaining energy of the networks of LEACHM AND LEACHME [*5*].

C. MULTIHOP LEACH

Sometimes the diameter of the network is widened and nodes distance from the cluster heads increased then communication wastes ample amount of energy. This wastage of energy is not acceptable. To resolve this drawback, MULTIHOP LEACH protocol was introduced [*6*]. MULTIHOP LEACH is a distributed clustering based protocol which enhances the energy dissipation of this kind of network. Its setup phase is like leach i.e. some nodes elect themselves as a cluster head and rest nodes are its member nodes.

In its steady state phase, two kinds of communication are performed. First is inter-cluster and other is intra-cluster communication. In inter-cluster communication, the member nodes transfer the data to its CH through single hop and then CH forwards the data to BS. In Intra-cluster communication, when the distance from the BS is large, then the data will travel through other intermediate CHs. That means CH to CH communication is followed.

D. E- LEACH

E-LEACH protocol was introduced [*7*] to improve the CH selection process. After the first round, for the cluster head selection process the residual energy of the nodes is the deciding factor. Like LEACH in initial round, probability of each node to become a cluster head is same. But after first round, every node has different level of residual energy and this residual is the considered as a decisive factor for CH selection. Nodes having more residual energy are more favorites for becoming CH. E-LEACH is having better performance in energy efficiency. E-LEACH, LEACH AND MULTIHOP LEACH are compared on bases of energy efficiency as shown in fig.5

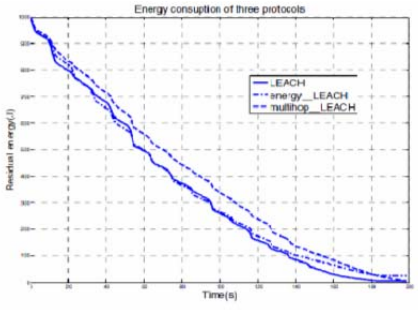

Fig.5. Comparison of residual energy [*7*].

E. LEACH-B

LEACH-B introduced in [*8*] had the purpose to find the cluster heads which are near optimal. It proposes a second stage for selecting the CH which is based on the residual energy of the nodes which are favorites for becoming CH. It makes sure the clusters are balanced. It proposes that the optimal range of number of CHs should be 3% to 5% of the total nodes in the network. The selection process of CHs is divided into two phases. First phase is same as that of LEACH means a random number between 0 and 1 is selected and then threshold value if counted, based on that value, some CHs are selected as a cluster head candidate. In the second phase, selected CHs are arranged in descending order based on their residual energy. Then n*p number of nodes, where n is the total number of nodes and p is the percentage of the CHs will become CH and others will be behave like normal nodes. Fig.6 shows the simulation results of the LEACH-B in comparison to LEACH.

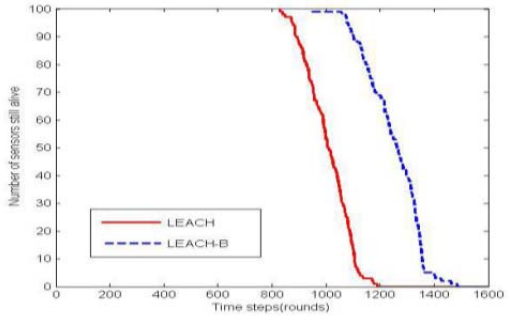

Fig.6. System lifetime using LEACH and LEACH-B [*8*].

F. LEACH-C

In LEACH, CH is selected by all the nodes in the network and the then form the cluster. In LEACH-C which is introduced in [*9*], the cluster head selection is done by the base station. All the nodes send their residual energy and location to the BS. BS then forms the clusters and selects the most appropriate CHs and sends this information to all the nodes. It resolves the problem of uncertainty in number of CHs to be selected.

It is compared with the LEACH, MTE and static clustering on the basis of first node die. Simulation results of LEACH, MTE and static clustering is shown in fig. 7

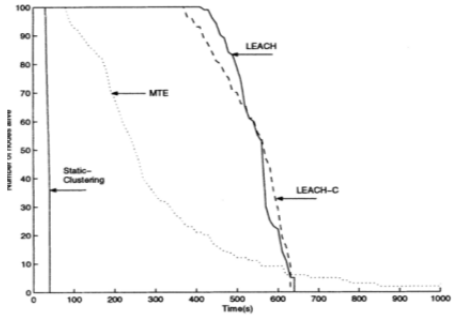

Fig.7. Number of nodes alive over time [*9*].

G. EWC

It is Energy Efficient Weight Clustering protocol introduced in [*10*]. Unlike LEACH it uses different parameters for selecting CH. Residual energy, node degree and distance, these are the factors used for the selection of CHs. Two channel modes are used. One is free space with d^2 power loss and multipath fading with d^4 power loss.

Different factors on which CH selection is performed:

1. Residual energy: Residual energy of every node is calculated and then node having higher values is selected as CHs.
2. Node degree: Nodes which are having more number of nodes surrounding them are more likely to become CH. As a result less energy is required for the transmission of messages.
3. Distance: Nodes having less distance from the other nodes, from BS and other CHs are more likely to become CH.

These factors help the network in saving energy and hence enhancing the lifetime although need some extra processing. Simulation result of this protocol compared with LEACH AND LEACH-C are shown in the Fig.8

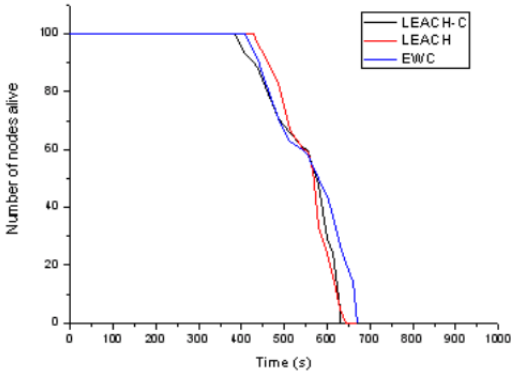

Fig.8 Number of nodes alive with time [*10*].

H. LEACH-P

LEACH-P was introduced in [*11*]which are based on Energy Aware Multipath Routing (EAMR) into LEACH so that enhanced clusters can be formed and better CHs can be selected. EAMR will make many different paths between the source and destination nodes and a probability is calculated for path which is based on having less communication cost and more residual energy of the nodes which will pass come through that path. Two types of energy saving are introduced. One is sleep control mechanism and other is data transmission control mechanism. Using these two mechanisms optimal energy solution is obtained. To select the next hop in the path some probability is defined by EAMR. This probability is defined as

$$P_{N_j,N_i} = \frac{1/C_{N_j,N_i}}{\sum_{k\in FT_j} C_{N_j,N_i}} \quad (3)$$

Where N_i is probability of be the next hop selected by node N_j and the cost of transmission between N_i and N_j is represented by CN_i and CN_j and FT represents optional nodes in the routing table. The threshold value of LEACH protocol is extended by this protocol with the probability of selection as given below.

$$T(n) = \begin{cases} \dfrac{p}{1 - p * \left(rmod\ {}^{1}/_{p}\right)} * \dfrac{\dfrac{1}{C_{N_j,N_i}}}{\sum_{k\in FT_j} C_{N_j,N_i}} & if\ n \in G \\ 0 & otherwise \end{cases} \quad (4)$$

Simulation results of LEACH-P are compared with LEACH in the fig. 9.

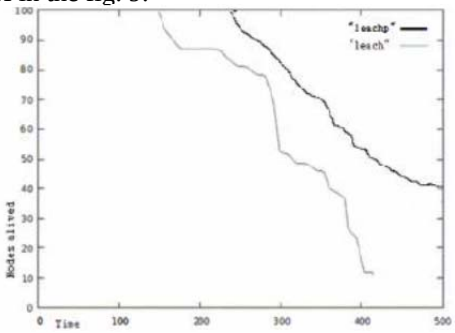

Fig 9. Network lifetime of LEACH-P compared with LEACH [*11*].

I. AN ADAPTIVE CLUSTER BASED ROUTING SCHEME FOR MOBILE WIRELESS SENSOR NETWORKS

Adaptive cluster based routing scheme is based on the phenomena of relative direction of node mobility as described in [*12*]. Like LEACH this scheme is divided into two phases. One is setup phase and other is steady state phase. During steady state phase, nodes are divided into two TDMA frames t1 and t2 and nodes broadcast their IDs in those frames twice. Using these frames every node estimates its distance with neighbor nodes on basis of received signal strength. If the Distance between d_{ij} (t1) and d_{ij} (t2) is negative, it means that the nodes (i and j) are moving away from each other. If positive, then nodes are moving towards each other or are stationary. Mobility factor Mi(t) which defines the relative direction of the nodes with its neighbors is given below.

$$M_i(t) = 1 - \frac{No\ of\ nodes\ moving\ away\ from\ i}{N} \quad (5)$$

N is the number of neighbor nodes of i.

If the value of Mi(t) >0.5, it means that the number of nodes moving towards *i* or are stationary are more than the number of nodes, then node will decide to be a CH or not.

CHs broadcast CH-adv message and that message is received by non-cluster head nodes. Every node will decide which CH they want to join by using this message.

$$\frac{d_i CH(t1) - d_i CH(t2)}{t2 - t1} \quad (6)$$

Then nodes send join request message to its CH and then CH forms the cluster send the TDMA schedule to its nodes. This protocol uses LEACH-M technique which has been discussed earlier in section A, which sends request to its members at the beginning of every TDMA slot and if it does not get any response in first two requests then the node is considered as out of reach node and removes it from the network.

This protocol is simulated and the results are compared with LEACH-M in fig.10 and 11.

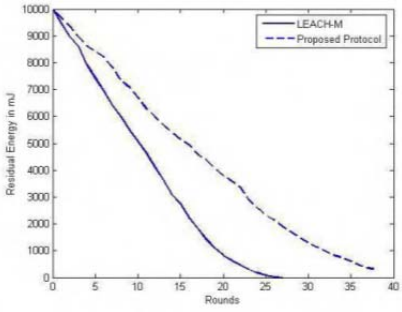

Fig 10. Average residual energy of nodes with mobility [*12*].

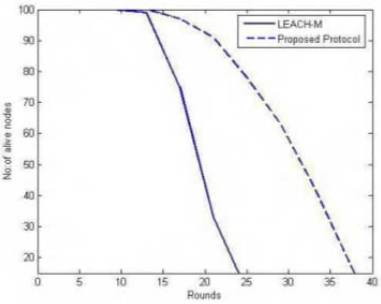

Fig 11. Network Lifetime Comparison with increased mobility [*12*].

J. *ENERGY EFFICIENT CLUSTER HEAD SELECTION(NECHS)*

This CH selection algorithm described in is based on the fuzzy logic and CH is selected using two criterions. One is neighbor nodes and other is remaining energy. The radio model is used to find the energy used in transmitting and receiving is shown below

This CH selection algorithm described in [*13*] is based on the fuzzy logic and CH is selected using two criterions. One is neighbor nodes and other is remaining energy. The radio model is used to find the energy used in transmitting and receiving is shown below.

$$E_{TX}(k,d) = E_{TX-elec}(k) + E_{TX-amp}(k,d)$$
$$= \begin{cases} E_{elec} * k + \varepsilon_{f_s} * d^2 d < d_0 d_0 = \sqrt{\frac{\varepsilon_{f_s}}{\varepsilon_{amp}}} \\ E_{elec} * k + \varepsilon_{f_s} * d^4 d \geq d_0 \end{cases} \quad (7)$$

$$E_{RK}(k) = E_{elec} * k \quad (8)$$

Where, k and d are message size and distance. Remaining energy and node degree is used as input is fuzzified and then output is de-fuzzified to get the clear output. On bases of remaining energy and node degree each node calculates its probability to become CH and then node having higher value of probability will be CH. Its simulation compared with LEACH is given below in fig 12.

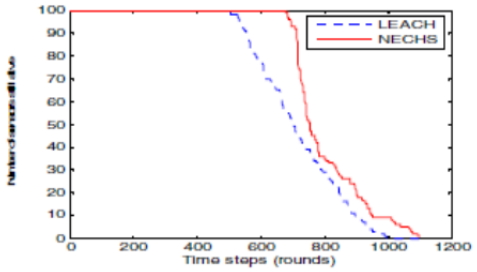

Fig.12. Number of nodes alive over time [*13*]

K. *ENERGY EFFIECIENT CLUSTERING ALGORITHM FOR EVENT DRIVEN(EECED)*

EECED is a clustering algorithm proposed in [*14*] which is used to balance the energy used in the network. It performs some assumptions in order to increase the network lifetime. Those assumptions are:

1. Location of BS at the center of the network and is configured with high storage and processing power
2. Nodes have power control capabilities.
3. Static network.
4. Event driven protocol architecture.

This protocol consist of number of rounds each having two phases similarly like LEACH which are named as clustering phase and transmission phase. In clustering phase clusters are made and CH are chosen. In transmission phase, data aggregation actions are performed.

Simulation of this protocol is performed by taking different number of nodes; 100 and then 300. For these simulations are compared with LEACH as shown in fig.13.

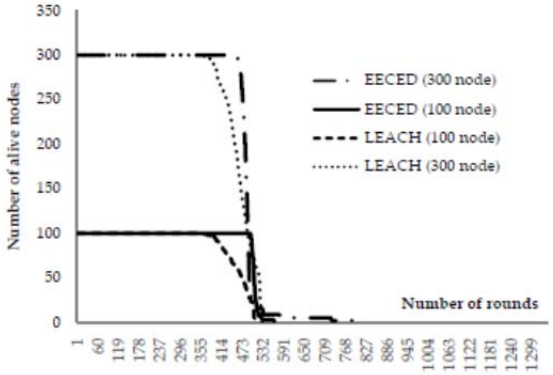

Fig.13. Comparison with LEACH by taking 100 and 300 nodes by using number of living nodes with same initial energy [*14*].

L. TL-LEACH (TWO-LEVEL)

This leach based protocol is named as TWO-LEVEL LEACH which is proposed in [*15*]. In this protocol, the CH is further divided into two categories one is primary CH and other is secondary. The secondary CH collects data from the nodes and aggregate it to primary CH and then primary CH further send it to BS. This protocol has four phases. First is Advertisement phase, in which every node has to decide whether it wants to be primary CH (CH_i), secondary CH (CH_{ij}) or a simple node (SN). Second phase is cluster setup phase in which every node decides which secondary CH it want to join and every secondary CH decides which primary CH it want to join. Third phase is Schedule creation in which TDMA schedule for the nodes is created. In fourth phase that is data transmission, the data aggregation is performed. Topology network for cluster setup phase is shown in fig. 14

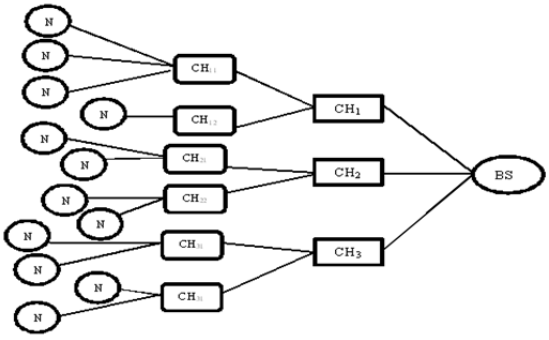

Fig.14. Topology network after the setup cluster phase [*15*].

Simulation results of TL- LEACH compared with LEACH is shown in fig 15 and 16. Fig 15 shows the energy dissipation over time and fig 16 shows number of nodes alive over time.

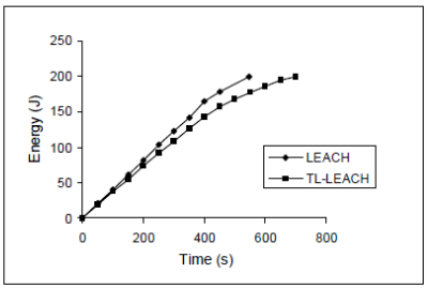

Fig.15. The total amount of energy dissipated in the system over time [*15*].

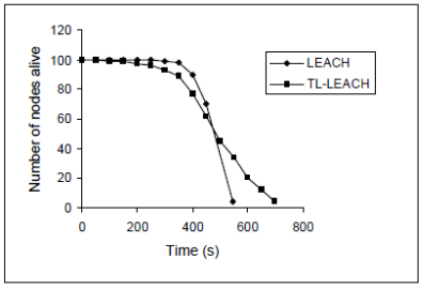

Fig.16. Number of nodes alive over time [*15*].

M. EFFICIENT CLUSTER HEAD SELECTION SCHEME FOR DATA AGGREGATION IN WIRELESS SENSOR NETWORK

ECHSSDA is a LEACH based protocol proposed in [*16*]. This protocol consists of two types of CHs. One is associate CH and other is normal CH. Associate CH will come into action when the normal cluster energy decreases and become less than the average energy. So the associate CH will become CH in the very next round if the energy of main CH has less than average energy. It is very useful for the dense and large scale networks.

Simulation results of this protocol have been compared with LEACH and LEACH-C protocols on the bases of network lifetime as shown in fig 17.

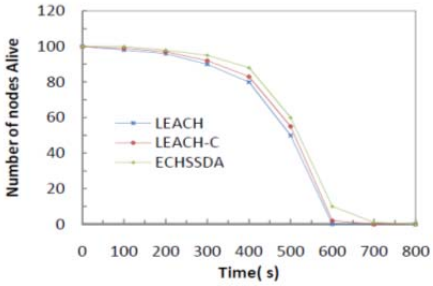

Fig.17. Network lifetime of ECHSSDA [*16*].

N. ENERGY EFFIECIENT CLUSTER HEAD SELECTION FOR WIRELESS SENSOR NETWORK

This protocol proposed in [*17*] performs the cluster head selection process by considering the probability of each node to become a CH. This probability is counted on the basis of remaining energy of the node and initial energy of the node. Both of these energies are used in calculating the threshold value *T(n)*

$$T(n) = \left(\frac{p}{1 - p(r \bmod {}^{1}/_{p}} . \frac{E_{residual}}{E_{initial}} \right) . k_{opt} \quad (9)$$

$$k_{opt} = \sqrt{\frac{N}{2\pi}} . \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp}}} . \frac{M}{d^2 toBS} \quad (10)$$

Where, $E_{residual}$ is the residual energy and $E_{initial}$ is the initial energy and k_{opt} is the optimal number of CHs.

Result of the simulation are compared with LEACH on the basis of the network lifetime are shown in fig.18.

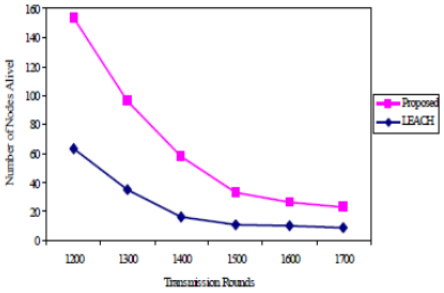

Fig.18. No of nodes alive in different transmission rounds [*17*].

O. V-LEACH

This version of LEACH protocol proposed in [*18*] contains two types of CHs. CH and vice CH, CH which sends and receives data form the nodes and forwards it to BS and vice CH which will act as a CH when the CH dies. In LEACH, when CH in any cluster dies due to over use of its energy or by any other reason, the data aggregation operation in that particular cluster stops and cluster becomes isolated. To resolve this kind of problem vice CH will play a vital role. It will replace the dead CH and starts performing as a CH. Instead of electing a new CH every time the CH dies, selecting a vice CH on the time of CH selection helps in increasing the network lifetime. However, if the vice CH dies there is no concept of replacing it with a new node. In this protocol, the selection of CH and vice CH is done on the basis of the distance, residual energy and total energy.

Simulation results of this protocol compared with the LEACH on the bases of network lifetime is shown in fig.19.

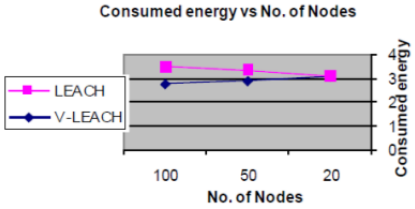

Fig.19. Network energy consumed [*18*].

P. MR-LEACH

Multi-hop routing with LEACH which is introduced in [*19*] consists of multiple layers of clusters. Every outer layer transmits the data to its inner layers and inner one sends to its adjacent inner layer and so on and finally data reaches at Base station. This protocol is based on three phases. First phase is cluster formation phase in which every node holds the information of node's ID, its residual energy and its status. Node's status states that whether the node is unknown, cluster member or CH. All this information is stored in a table which is updated in the beginning of every round and CH saves the entire node IDs of its associated member nodes. Next phase is cluster discovery at different levels by the BS, in this process the BS ID is broadcasted by the BS to all the member nodes and then every node save that ID. Layer-one is formed by the CHs which are nearest to the BS. Then using these IDs BS broadcast the control message to all the CHs then every CH except layer-one CHs directly reply to the BS. In third phase, is Scheduling in which TDMA scheduling is done.

Comparison with LEACH on the basis of energy efficiency is shown in fig.20.

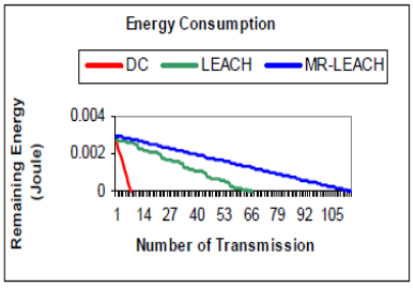

Fig.20. Remaining energy with number of transmissions [*19*].

Q. LEACH-GA

This LEACH protocol which is introduced in [*20*] is based on the genetic algorithm which obtains the optimal value of CH percentage. It consist of three rounds first is preparation round which will occur only once and then setup phase and steady state phase will take place. In preparation phase, first of all every node will decide whether it wants to be a CH candidate or not same as of LEACH and then send it's ID along with location to BS. Then BS applies genetic algorithm to find out the P_{opt} i.e. optimal probability and then send this optimal value to all the nodes. Setup phase and steady state phase works same as in LEACH.

LEACH-GA uses the same radio model which is used by LEACH. These equations 11 and 12 show the energy consumptions per round.

$$E_{CH}(l,d) = \begin{cases} l \times \left[E_{elec}\left(\frac{n}{k}-1\right) + E_{DA}\frac{n}{k} + E_{elec} + \varepsilon_{fs} \times d_{toBS}^2\right] \\ if\, d_{toBS} < d_0 \\ l \times \left[E_{elec}\left(\frac{n}{k}-1\right) + E_{DA}\frac{n}{k} + E_{elec} + \varepsilon_{mp} \times d_{toBS}^4\right] \\ if\, d_{toBS} \geq d_0 \end{cases} \quad (11)$$

where, k is number of clusters, n is the number of nodes, l is message size, d is distance and $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$.

Energy consumption of non-CH node is shown in equation (11)

$$E_{non-CH}(l,d) = l \times E_{elec} + l \times \varepsilon_{fs} \times d_{toCH}^2 \quad (12)$$

R. MOD-LEACH

In this LEACH based algorithm introduced in [*21*], CH selection is not done on the basis of a chance for every node to become a CH in every 1/*p* rounds (like LEACH), but by using efficient cluster head replacement scheme. According to this scheme if the CH has not spent much energy and its energy value is more than the threshold value then that node will remain CH for the next round also. In this way, energy for the broadcasting information regarding the new CH can be saved and if it has less energy than threshold then it will be replaced by a new one as done in LEACH. Three modes of transmission have been introduced in the protocol.

1. Inter Cluster Transmission.
2. Intra Cluster Transmission.
3. CH to BS Transmission.

Inter Cluster Transmission means the transmission between the two CHs, Intra Cluster states about the transmission of data by nodes to CHs and in CH to BS transmission, the communication is done between Cluster Head and Base station. Two types of energy levels are used; low level for intra cluster transmissions and more energy for inter cluster and CH to BS transmission.

S. CELL LEACH

This protocol which is introduced in [*22*] is based on the network which is divided into different sections known as cells. These cells consist of many sensors and out of

those one is selected as cell head. A cluster is formed by seven nearby cells and one sensor node is selected as a cluster head. These CHs and cell heads will change in every round although clusters will remain same. In the first round, all the cell heads and CHs are selected dynamically, since all nodes having same energy level. In the next round, old cell-head will select a new cell head dynamically to replace itself with it. Sensor node send the data to its cell head at its assigned time which is assigned using time division multiplexing and then cell head further send it to CH using same approach. The cell head delete all the duplicate data and send the original data received to the destination.

T. *EE-RRT (A novel energy efficient redundant routing tree for WSNs)*

This protocol introduced in [*23*] is based on the idea of dividing every cluster into square area (M*N). From that area a working node is selected which reduce redundant information and save energy. After selecting the redundant node phase, a redundant routing tree is built which handles the information exchange between the cluster head and base station to reduce the energy consumption of the network. After that the data is sensed and then sent to the base station through that redundant routing tree. The less energy dissipation by this protocol as compared to the LEACH and RNTA are shown by the simulation results of these protocols in the fig 21.

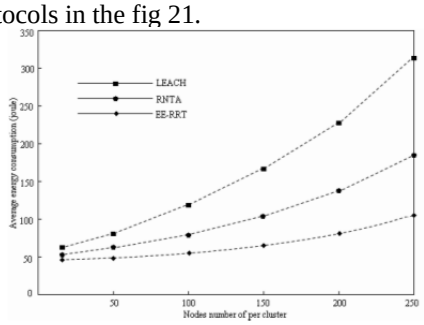

Fig.21. Average energy dissipation of different nodes number in each cluster [*23*].

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

It is Power Efficient Communication Protocol introduced in [*24*] for Data gathering on Mobile Sensor Networks. It was developed to solve the problem of power efficient communication. It works on some assumptions:-

1. BS is far away located and is fixed.
2. Homogeneous nodes and have limited power.
3. Nodes are movable and have GPS device.

It mainly consists of three phases. First phase is for cluster head selection, second for the organization of clusters and third is for the transmission of the messages. In this protocol nodes are divided into three categories. First is valid round, in which some CHs are elected, second is invalid round(CM-IR), in which there are no CHs are elected, as a result energy in these rounds used are of no use and third is super round, which consists of some valid rounds and some invalid rounds.

Simulation of LEACH with CM and CM-IR is compared in the fig 22.

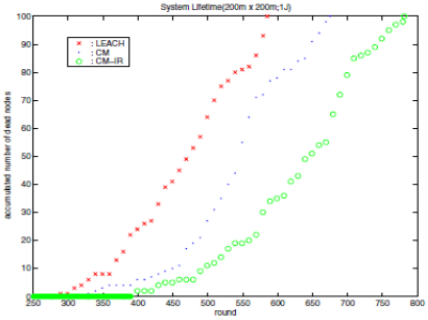

Fig.22. System lifetime of a wireless sensor network [*24*].

V. *K-LEACH*

This leach based algorithm introduced in [*25*] has two main ideas. First is to obtain highly uniform clusters by using K-medoids clustering algorithm and to have better cluster head selection. Second idea is to obtain the CH contenders on the bases of least distance from the center of the cluster. There are two phases in this protocol, first is cluster formation phase and other is steady state phase. In cluster formation phase, in the first round, the cluster formation is done by using K-medoids cluster formation algorithm and CH is done by using Euclidian distance and for the other rounds the node nearest to the first round CH is selected. In the steady state phase, -CHs receive and aggregate the data to the BS.

Some assumptions are made in its system model:-

1. BS is far away from the sensing network.
2. Nodes are GPS equipped for the location awareness.
3. Symmetric communication channel.
4. Nodes are homogeneous and immobile.
5. No Battery recharge.

Simulation results of this protocol are compared with LEACH in the table 1.

TABLE 1.

Protocol	FND (First Node dies)	HND (Half nodes Die)	LND(Last node dies)/(5% alive nodes)
LEACH	1	25	35
K-LEACH	15	27	35
Improvement	41.17%	5.88%	0%

Table 1. Network lifetime improvemet [*25*].

W. *EELEACH-C*

The protocol Energy Efficient LEACH-C introduced in [*26*] prolongs the network lifetime by exploiting residual energy of the network. It calculates nodes eligibility to become cluster head. It discovers the nodes which are in the path of the BS and other sensor nodes. Then these nodes will be the cluster coordinates for the protocol. This protocol assigns the weight(w_i) which is the probability of a node to become a CH. Weight is calculated by dividing initial energy of the node by residual energy. Nodes having highest value of w_i will become CH in the next round. The probability of the already chosen CH to die is more than the probability of other nodes to die.

Simulation results show the comparison between LEACH, LEACH-C and EELEACH working in the fig 23.

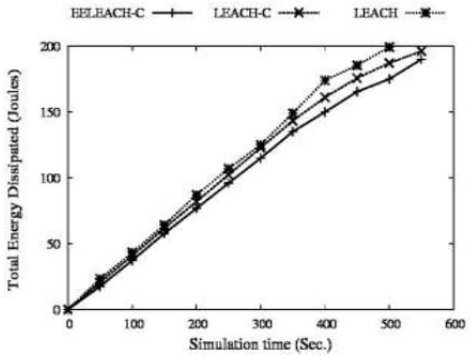

Fig.23. Total energy Dissipated by all the nodes over time [*26*].

X. Maximizing the Network Lifetime of Clustered-based WSN Using Probability of Residual Energy

In this protocol which was introduced in [*27*], threshold value residual energy of every member in every round and the optimum cluster head probability are considered for the CH selection process.

There are three phases introduced in this protocol, first is set-up phase, second is steady state phase and third is pre set-up next round phase. In the set-up phase, at the beginning of every round, threshold value *T(n)* is calculated by producing a random probability function(p_n). In the first round, the node is selected as a CH if $p_n < p_{opt}$, because in the beginning every node has the same energy. In the steady state phase, every node will send its current energy and IDs at the end of every round to the CH and CH aggregates it to BS. Third round is next round set-up phase, in which BS receives the residual energies and calculates the total residual energy (E_{total}) of the network and then again sends to CH for the computation of next threshold value *T(n).*

Simulation of this protocol has been done on the basis of FND and LND on different values of network area and different number of TDMA frames. Comparison between the LEACH and this protocol for FND and LND is shown in the table 2 and 3.

TABLE 2.

	Modified Algorithm Improvement					
Area(m^2)	**500*500**			**1500*1500**		
BS Distance(m)	**100**	**150**	**200**	**100**	**150**	**200**
5 frames (%)	133	145	122	81	111	56
25 frames (%)	85	109	77	83	67	86

Table 2. Network lifetime improvement in % modified algorithm to LEACH (FND) [*27*].

TABLE 3.

	Modified Algorithm Improvement					
Area(m^2)	**500*500**			**1500*1500**		
BS Distance(m)	**100**	**150**	**200**	**100**	**150**	**200**
5 frames(%)	67	65	71	43	60	50
25 frames(%)	9	6	4	12	17	10

Table 3. Network lifetime improvement in %age modified algorithm to LEACH (HND) [27].

IV. COMPARISON

TABLE 4.COMPARISON OF LEACH BASED PROTOCOLS [*28*]

PROTOCOL	**BASES OF CH SELECTION**	**ADVANTAGES OVER LEACH**	**DISADVANTAGE**
LEACH-M	Residual energy	Support mobility, less packet loss	Packet loss in case of CH movement and is less energy efficient
LEACH-ME	Residual energy	Support communication even if the node is in motion	More overhead
Multi-hop Leach	Random	Provide energy efficiency using multi-hop	Data lost sometimes
E-Leach	Residual energy	Improve cluster head selection	More overhead in CH selection
Leach-b	Residual energy	Better network lifetime and CH selection	More overhead in CH selection
Leach-c	Residual energy	More rounds in a small area	More overhead to BS and less efficient for large networks
EWC	Residual energy	Better network lifetime	More overhead in CH selection
Leach-p	EMAR probability	Better network lifetime	More overhead in CH selection
An adaptive cluster based routing scheme for mobile WSN	Neighbor's direction with mobility	Better network lifetime over LEACH-M	More overhead in calculating the direction of node
NECHS	Residual energy	More energy efficient	Does not provide surety of Cluster member's membership.
EECED	Residual energy	Better network lifetime and consumes less energy	More overhead to BS
TL-LEACH	Using primary and secondary CH	Better utilization of energy using two levels of transmission	More overhead for secondary CH selection
ECHSSDA	Residual energy	Less energy utilization and overload	More overhead and processing in CH selection
Energy efficient CH selection for WSN	Residual energy	Better network lifetime	More overhead in CH selection
V-LEACH	Random	Vice CH act as CH on CH death	More overhead in vice CH selection
MR-LEACH	Residual energy	Concept of equal number of hops of data transmission to CH	More overhead in CH selection and routing in multi-hop can fail
LEACH-GA	Residual energy using GA	Concept of optimal probability for selection of CH	More overhead in CH selection
MOD-LEACH	Residual energy	CH replacement only when its energy level degrades to certain extent and better energy efficiency	More overhead in CH selection and data to BS

PROTOCOL	BASES OF CH SELECTION	ADVANTAGES OVER LEACH	DISADVANTAGE
Cell Leach	Residual energy	Concept of cell head is introduced and hence improved network efficiency.	More overhead in CH and cell head selection
EE-RRT	Residual energy	Better network lifetime and energy efficiency	More overhead in CH selection
Power Efficient Communication Protocols for Data Gathering on Mobile Sensor Networks	Same as LEACH using valid and invalid rounds	Better energy efficiency and provide solution for the case of where there is no CH.	More overhead in CH selection
K-Leach	Using Euclidian distance	Better network lifetime using uniform clustering	More overhead to BS
EELEACH-c	Residual energy and distance	Better network lifetime and energy efficiency	More overhead in CH selection
Maximizing the network lifetime of clustered based WSN using probability of residual energy	Residual energy	Provide better network lifetime	More overhead in CH selection and less improvement as network size increases

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