# MR-LEACH: Multi-hop Routing with Low Energy Adaptive Clustering Hierarchy

Muhammnmad Omer Farooq
Department of Computer Science
Virtual University of Pakistan
Email: omer.farooq@ymail.com

Abdul Basit Dogar
Department of Computer Science
Virtual University of Pakistan
Email: abasit126@yahoo.com

Ghalib Asadullah Shah
College of EME
NUST, Pakistan
Email: ghalib@ceme.nust.edu.pk

***Abstract* – In this paper, we present a Multi-hop Routing with Low Energy Adaptive Clustering Hierarchy (MR-LEACH) protocol. In order to prolong the lifetime of Wireless Sensor Network (WSN), MR-LEACH partitions the network into different layers of clusters. Cluster heads in each layer collaborates with the adjacent layers to transmit sensor's data to the base station. Ordinary sensor nodes join cluster heads based on the Received Signal Strength Indicator (RSSI). The transmission of nodes is controlled by a Base Station (BS) that defines the Time Division Multiple Access (TDMA) schedule for each cluster-head. BS selects the upper layers cluster heads to act as super cluster heads for lower layer cluster heads. Thus, MR-LEACH follows multi-hop routing from cluster-heads to a base station to conserve energy, unlike the LEACH protocol. Performance evaluation has shown that MR-LEACH achieves significant improvement in the LEACH protocol and provides energy efficient routing for WSN.**

***Keywords: Wireless Sensor Networks (WSN), Cluster Head (CH), Routing Protocol, Layered Sensor Network.***

## I. INTRODUCTION

Advances in Micro-Electro Mechanical system (MEMS)-based sensor technology has lead to the development of miniaturized and cheap sensor nodes, capable of wireless communication, sensing and performing computations. Dense deployment of sensor nodes enables us to achieve high quality and fault tolerant sensor network through distributive processing. These characteristics of micro-sensors have found sensor networks applicability in many smart environments such as battlefields, earthquake response system, smart hospitals, habitant monitoring [13], agriculture monitoring [14] and smart homes. Due to small size of a sensor node, sensor networks are constraint by limited power, limited communication capabilities, limited processing power and limited memory.

Sensor networks differ from wireless ad-hoc network because these networks are primarily data centric, unlike traditional networks where data is requested from a specific node, data is requested based on certain attributes, i.e., how many four leg animals were observed in a certain area? As we have already discussed sensors are densely deployed therefore; adjacent nodes may have similar data. Considering the limitations of resources in a sensor network it is not sagacious that every node transmits highly correlated data to the base station. Clustering algorithms [5, 6] have been developed to aggregate the data collected by the cluster heads. Sensor nodes within certain transmission range will formulate a cluster by choosing their common cluster head. Thereafter, each member node transmits its data to the cluster head which relays data to the base station (BS).

In cluster-based sensor networks configuration, cluster heads define the (TDMA) schedule for each member node transmission. Each member node turns on its transceiver only during its allocated time slot to save energy. Hence, sensor node lasts for longer time period. Secondly, each member node needs to transmit within a small distance therefore; lesser energy is consumed during the transmission phase. Thirdly, cluster heads perform computations on data collected from their member nodes and filter out the redundant data this will help to reduce the amount of data that needs to be conveyed to the BS. Consequently, lesser energy is consumed for transmission.

In this research, we design a Multi-hop Routing Algorithm with Low Energy Adaptive Clustering Hierarchy (MR-LEACH). The motivation behind this work is to reduce the energy consumption of sensor nodes by adaptively increasing the clustering hierarchy. In order to create the equal number of clusters, BS assists in defining the clustering hierarchy and issues a TDMA schedule for each layer of cluster heads. Based on this schedule, each cluster head issues its own TDMA schedule for member nodes. In MR-LEACH, cluster heads not only collect data from their member nodes but also act as relying nodes for cluster heads at lower-layers in-order to route data to the base station. Thus, cluster heads form a tree rooted at the base station, where the intermediate nodes are only the cluster-heads and leaves are the member nodes. This scheme yields longer network life time since transmission is based on multi-hop routing from lower-layers towards higher-layers. Similar, to the LEACH protocol, it operates in rounds and a new cluster head is selected in each round based on available energy of sensor nodes.

The remainder of the paper is organized as follows. Section II presents related work. In Section III, motivation for this research is given. Section IV elaborates the network and radio model used for MR-LEACH. In Section V, we provide the details of MR-LEACH. Theoretical performance evaluation of MR-LEACH with other state of the art routing protocols is give in Section VI. Finally, this research is concluded in Section VII.

## II. RELATED WORK

In [1], communication protocol based on Low Energy Adaptive Clustering Hierarchy (LEACH) is presented. In LEACH, each node randomly decides to become a cluster head (CH). Once a node decides to become a cluster head it broadcasts advertisement (ADV) message. Upon reception of this ADV message each non cluster node will decide to join a certain CH depending on the Received Signal Strength (RSS). CH creates a TDMA based transmission schedule for each node in the cluster. CH aggregates

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the data received from various nodes inside the cluster and send it to the base station. This communication protocol works in rounds and a different node is selected as a cluster head according to the following formula in–order to distribute load among all participating nodes.

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

where, ***P*** is the percentage of nodes to be elected as cluster heads in the whole network, ***r*** is the current round, and ***G*** is the set of nodes that have not been cluster heads in the last ***1/P*** rounds. Nodes that are cluster heads in round r shall not be selected in the next ***1/P*** rounds. Major disadvantage associated with LEACH is CH has to reach the BS in a single hop. Secondly, to avoid interference among different clusters, it uses CDMA hence; each node should support CDMA and TDMA.

V. Loscri et al. [2] presents a two level hierarchy for LEACH (TL-LEACH). Authors have suggested the use of two levels of hierarchy to minimize the energy consumption. Cluster heads at first level are called level one cluster heads and they connect to their respective member nodes. Level two clusters heads form clusters from level one cluster heads. TL-LEACH implies more distributive algorithm therefore; network load is distributed that results is long lived sensor network.

In [3], Hybrid Energy Efficient Distributed Clustering is presented, it is a multi-hop clustering algorithm for wireless sensor networks. The main objectives of HEED are, distribute energy consumption to prolong network lifetime, minimize energy consumption during cluster head selection phase and to minimize the control overhead of the network. HEED determines cluster heads based upon two parameters namely, residual energy of each node and intra cluster communication cost. HEED can achieve uniform cluster head distribution across the network, but it needs iterations that incur high overhead.

Multi-path Routing Algorithm with Unequal Clustering for Wireless Sensor Networks was presented in [4]. This communication protocol partitions the sensor network into unequal clusters to provide multi-hop communication from source to the base station. Node with maximum energy level will advertise its willingness to become a cluster head afterwards, depending upon the transmission radius of a sensor node and received signal strength; node will select its cluster head from the list of available choices. Once, cluster heads are formed different cluster heads will choose their cluster head in-order to reach the base station and this process continues in a chain form till the base station is reached. The unequal size of clusters and varying level of cluster hierarchy in the same network yields difficulties for scheduling that result in wastage of energy due to absence of Time Division Multiple Access (TDMA) schedule at the network level.

In [5], Energy Efficient Clustering Scheme is discussed. EECS is primarily a clustering algorithm in which candidates broadcast their residual energy to neighboring nodes. If a node does not find any node having more energy than its own residual energy then the node will advertise itself as a cluster head node. EECS forms clusters based on the cluster's distance from the base station. EECS addresses the problem that clusters far away from the BS require more energy for transmission compared to those closer to the base station.

In [6], an Energy Efficient Unequal Clustering (EEUC) mechanism for wireless sensor networks is presented. EEUC partitions the wireless sensor network field into unequal clusters so that energy consumption is balanced. Drawback associated with this scheme is "isolated node" i.e., it is possible that some nodes may not have joined any cluster hence they are isolated inside the network.

In [16], Directed Diffusion for Wireless Sensor Networks was proposed. In Directed Diffusion data is named using attribute value pairs. A node requests data by sending interests for named data. This data request is broadcasted throughout the network. Gradients are setup within the network designed to draw events i.e. data matching to query response. Whenever a sensor node senses data pertaining to a user query it will send back the sensed data to the node from which it has received the query. Every node that will receive the response will match it to the stored gradient and in this way data will be sent to the interested user. This approach is inappropriate for applications requiring continuous data delivery furthermore, attribute based naming is application dependent and it requires extra processing overhead at sensor nodes.

J. Kulik et al. [17] proposed Sensor Protocols for Information via Negotiation (SPIN). In this protocol if a node has some sensed data it will advertise to its neighbors about the kind of data it has. Any neighboring node interested in the data will send the request to the originating node for copy of data. In this way this process continues till there is no node in the network that requires this data. This approach does not guarantee delivery of data to every node in the network because if the node interested in the data is far away from the source then data will not be delivered. Secondly, this scheme is not good for applications requiring reliable data delivery.

In [12], Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks has been presented. It tries to reduce the communication overhead by defining the threshold levels on data that needs to be transmitted. If sensor reading remain below the defined threshold no network activity will be invoked in this case one can incorrectly assume that sensor network is not alive; this shortcoming has been addressed in [15].

Routing protocol in wireless sensor network has been an active area of research since last decade. A routing protocol that considers the real time requirements of applications has been given in [11]. An energy efficient routing protocol for wireless sensor networks has been presented in [7]. A power aware routing protocol for wireless sensor networks is presented in [8]. A survey of clustered based routing protocols for wireless sensor networks has been presented in [9].

## III. MOTIVATION

Clustering-based routing protocols for Wireless Sensor Networks have gained wide acceptance due to their characteristics of less energy consumption. Many state of the art routing protocols for wireless sensor networks use clustering at multiple levels to further reduce energy consumption. Some protocols introduce couple of clustering levels while others try to use resources efficiently by providing multi-hop routing with unequal clustering.

Defining multiple levels of clustering hierarchy suffers from following major drawbacks.

1. Cluster heads need to transmit data with higher power in-order to reach other cluster heads or the base station, this is particularly true if clustering is done at fewer levels.
2. As selection of the cluster head is done by the member nodes, it is possible that at higher level of clustering, cluster head close to base station will act as cluster head for majority of lower level cluster heads. Therefore, nodes close to the base station will die soon.

Another emerging approach for routing in WSN is multi-hop routing with unequal clustering. In this approach variable number of intermediate nodes will forward data to the base station, depending on the location of the sensed data. This approach has following shortcomings.

1. Since, there are unequal clusters inside the same network hence; scheduling becomes a difficult task. In some cases we may need to use Carrier Sense Multiple Access (CSMA), which is rather expensive compared with TDMA schedule.
2. Decision of joining upper level cluster head lies with the lower level cluster head this can result in hot spots.

In this research, our main aim is to develop a multi-hop routing algorithm for WSN with equal clustering to achieve the following objectives.

1. Reduce the average distance of each cluster head from its upper level cluster head so that in reaching the base station, the energy consumption is distributed among different cluster heads that will eventually result in longer network lifetime.
2. Selection of cluster heads at second and above level will be made by the base station thus; computational cost at sensor nodes will be reduced.
3. Equal number of clustering level will be used, this will enable us to use global TDM schedule hence; problem associated with multi-hop routing with unequal clustering will be alleviated.

It is a well established fact in wireless communication that energy of signal decays exponentially with respect to the distance it covers [18]. This phenomenon is referred as path loss. Path loss is measured in decibels (dB) and the following formula is used to compute it.

$$Path - Loss = 10 \times n \times \log(d) + C \qquad (2)$$

In above equation, $n$ is the path loss exponential and its value depends on the wireless channel condition as well as the distance between the transmitter and receiver. Following graph shows path loss in dB with different values of $n$. Following figure is generated through MATLAB simulation.

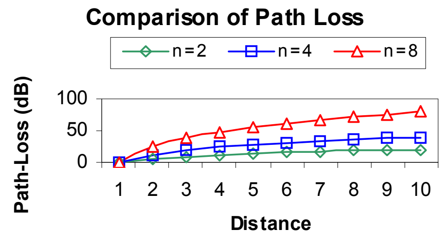


Figure 1: Comparison of Path Loss

It can be observed that greater the value of path loss exponential ‘n’ greater the path loss hence more energy is required to transmit a signal properly over the wireless medium. We must try to keep the value of path loss exponential as low as possible so that nodes consume less energy during transmission.

Following figure shows different existent routing schemes for wireless sensor networks.

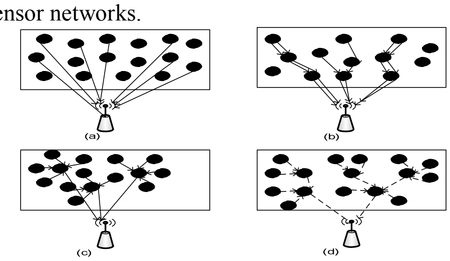


Figure 2: Sensor data forwarding with and without clustering.

Part (a) of above figure depicts the scenario of single hop communication without clustering i.e., each sensor node sends data directly to the BS. Part (b) of Figure 2 elaborates on multi-hop communication without clustering, i.e., intermediate sensor nodes relay data from source node to the BS. Part (c) of figure 2, depicts single hop clustering based communication i.e., member node transmits to Cluster Head and Cluster Head transmit data to BS. Part (d) of figure 2, depicts multi-hop routing scenario with clustering.

## IV. NETWORK AND RADIO MODEL

In this section, we shall explain our assumed network as well as radio model, assumptions made here will be used in the performance evaluation section.

### *A. Network Model*

In this research, we assume that set of sensor nodes are randomly deployed in the square field to continuously monitor the phenomenon under inspection. We assume that sensor network possess following properties.

1. Once, deployed all sensor nodes and BS are stationary.
2. Base Station can be placed any where inside the sensing field or away from it.
3. Nodes use power control to tune the amount of send power according to the transmission distance.

### *B. Radio Model*

Our radio model is similar to the one presented in [1]. Discussion of radio model is essential because assumptions about the radio characteristics including energy dissipation in transmit and receive mode will have an impact on the performance of a particular routing protocol. We further assume that path loss exponential is $d^2$ power loss in free space provided; transmitter and receivers are within certain threshold distance $d_0$.otherwise it is $d^4$. If a node wants to transmit '$k$' bits of data over a distance '$d$' then following equation will give us transmission energy requirements.

$$E_T(k,d) = \begin{Bmatrix} k.E_{elec} + k.\varepsilon_{amp}.d^2 & d < d_0 \\ k.E_{elec} + k.\varepsilon_{amp}.d^4 & d > d_0 \end{Bmatrix} \tag{3}$$

In above equation $E_{elec}$ is the electronic energy and $\varepsilon_{amp}$ is the amplifier energy required to maintain acceptable signal to noise ratio. Above equation was used in LEACH protocol.

Energy spent by the radio to receive '$k$' bits of data is calculated using the following equation.

$$E_r(k) = k.E_{elec} \tag{4}$$

Following table summarizes the values used for different parameters.

TABLE 1: RADIO CHARACTERISTICS

| Operation | Energy Dissipated |
|---|---|
| Transmitter Electronics ($E_{Tx\text{-}elec}$)<br>Receiver Electronics ($E_{Rx\text{-}elec}$) | 50 nJ/bit |
| Transmit Amplifier ($\varepsilon_{amp}$) | 100 pJ/bit/m$^2$ |

## V. MULTI-HOP ROUTING WITH LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY

MR-LEACH routing protocol works in three phases.

- Cluster Formation at lowest level.
- Cluster Discovery at different levels by Base Station.
- Scheduling.

### *A. Cluster Formation at Lowest Level*

In the cluster setup phase, each node broadcasts the ***HELLO*** message to its neighboring nodes within its transmission radius $R_{Tx}$. Each node constructs a table in which it maintains the *N**ode ID***, ***Residual Energy Level*** and ***Node Status***. This table will be constructed at the start of each round, where the length of each round is set corresponding to decay in the energy level rather than fixed short period. This helps to minimize the reformation of clusters and controls overhead incurred in collecting clusters information at the BS. We assume that sensor Node ID comprises of 4 bytes, Residual Energy Level attribute will take 4 bytes and Node Status attribute is of one byte. One single record in this table is comprised of 9 bytes. Once cluster is formed sensor node will save the node ID of cluster head and all other data will be discarded.. Cluster head only needs to store the node ID's of its member nodes. Node Status has one of the three values i.e., unknown, cluster member, cluster head. If a certain node '***I***' has the largest residual energy among all its neighboring nodes, it will elect itself as a cluster head. Afterwards, cluster head node will broadcast the ***HEAD_MSG(ID, Energy, $R_{Tx}$)***. It is possible that a non cluster head node receives multiple ***HEAD_MSG*** from different cluster heads, in this scenario, node will select the cluster head whose ***HEAD_MSG*** has the highest Received Signal Strength (RSS). Once, a node selects the cluster head it will change the status of Cluster Head Node to "Cluster Head" and similarly cluster head will change the status of all its member nodes status to "Members".

Following is the algorithm for cluster formation.

TABLE 2: ALGORITHM FOR CLUSTER FORMATION

```
Node = Sensing Node
S= Set of all Sensing Nodes in the Network
NeighbouringNodes = Nill ; // No neighbours discovered
for ∀ Nodes ∈ S
    Broadcast_HELLO(nodeID, Energy)
for ∀ Nodes ∈ S
begin
    Recv_BroadCast_MSG(nodeID, energy)
    ID= NeighbouringNode.searchNodeID(nodeID)
    if (ID≠ nodeID)
        NeighbouringNode.insert(nodeID, energy)
end
for ∀ Nodes ∈ S
begin
    nodeWithHigestEnergy = neighbouringNodes.getHighestEnergy()
    if (nodeWithHighestEnergy < nodesEnergy)
        BROADCAST_HEAD_MSG(nodeID)
end
for ∀ Nodes ∈ S
begin
    Rev_Head_MSG(ID)
    Cluster_Head.insert(ID, ReceivedSignalStrength)
end
for ∀ Nodes ∈ S
begin
    Select Cluster Head with Higest Received Signal Strength
    Send_Cluster_Join_MSG(ID);
end
for ∀ ClusterHeads ∈ S
    Recv_Join_MSG(ID)
```

### *B. Cluster Discovery at different Levels by Base Station*

Using its broadcast capability base station will discover cluster heads at different levels. We assume that the BS can reach all nodes in one hop over a common control channel. The BS will broadcast its Identifier (ID) over the common control channel. All cluster heads which hear this broadcast will record the BS ID. Afterwards, all cluster heads send a beacon signal with their own ID's to the BS using their default low power level. Cluster heads which are near to the BS form layer one since they are at single hop distance from the BS. Now, BS will broadcast a control packet with all layer one cluster heads ID's in it. All cluster heads in the network will reply to this message at default low power level with their own ID's as well as ID's of layer one cluster heads (Layer one cluster heads will not respond to this message, since their ID's are present in the control packet). Since, nodes will broadcast at lower power level therefore; this reply will not get to the BS directly. Layer one cluster heads are one hop away from layer two cluster heads therefore; this reply will get to layer one cluster heads. Layer one cluster heads whose ID's are present in the reply message will relay this message to the BS. BS will record the ID's of cluster heads, level of the cluster head and ID of the forwarding cluster head (at immediate upper level, of the node) in its internal data structure. Similarly, BS will again broadcast control message with ID's of all cluster heads it has discovered. All undiscovered cluster heads will reply to this message and the processing will be done as described above. This process continues till no new cluster head is discovered.

Following figure depicts the whole process.

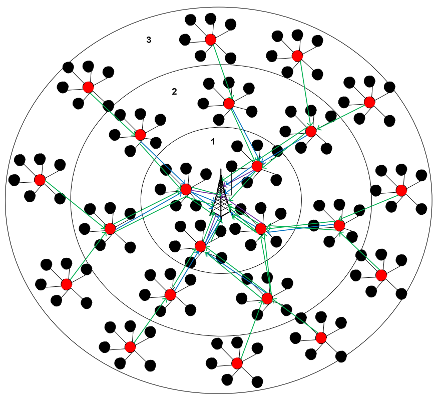


Figure: 3 Partitioning of Network into layers and cluster head discovery at multiple layers by the BS.

Once the cluster heads at different levels have been discovered, the BS will use the information, i.e., cluster head ID, Cluster Head Level and immediate Cluster Head ID to form cluster of cluster heads. The BS will use the following simple algorithm to setup clusters of different cluster heads.

- Repeat the following for all clusters belonging to layer 2 and above till all layers are processed.
- For all clusters belong to a particular level say '***i***' do the following.
- Set each cluster at level '***i***' as a cluster head of all those clusters at level '***i+1***' who has used this cluster head as its immediate forwarding cluster head (Cluster head at level 1, which has forwarded the control message at setup phase for cluster head at level 2 is immediate forwarding cluster head for layer 2 cluster head). If there are multiple immediate forwarding cluster heads for a particular cluster head, select only one cluster head for that particular cluster head.
- Remove the cluster from the pending cluster heads list.

Following figure shows different clusters formed for the network shown in Figure 3.

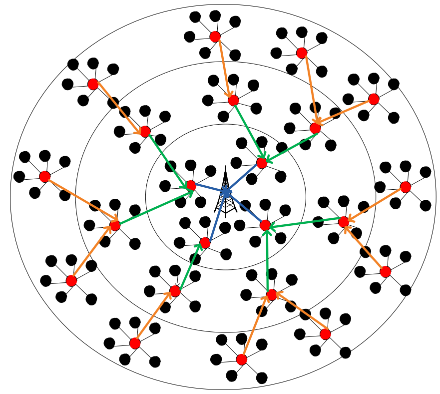

Figure 4: Clustering at Different Layers

To distribute network load evenly among the nodes present in the network this protocol will work in rounds and in every round different node will be selected as a cluster head for each cluster.

*C. Control Messages Overhead*

**Lemma 1:** Control Message Complexity for Making Clusters is O(N), where N is total number of nodes in the network.

**Proof:** During cluster setup phase each node will broadcast *HELLO* message for neighbor discovery. We assume total number of '*P*' nodes will act as cluster heads. Therefore, there will be *P* HEAD_MSG. Afterwards; *N-P* nodes will send *JOIN_MSG* to join a particular cluster head. Total messages exchanged are $N+P+(N-P)$ hence $O(N)$.

**Lemma 2:** Control Message Complexity across network for Forming Cluster Hierarchy is O(*P*), where P is total number of cluster heads in the network and *L* is total layers in which the network is divided.

**Proof:** We have assumed that in each layer there are equal numbers of cluster heads, i.e., (*P/L*).
Initially, layer 1 Cluster Heads will reply to the BS afterwards, layer 2 and layer 1 Cluster Heads will reply and this process continues till no new cluster head is discovered.

*Complexity* $= (P/L) + 2(P/L) + \ldots + L(P/L)$ hence, $O(P)$.

*D. Scheduling*

After forming cluster heads at different levels, member nodes scheduling needs to be done. Time Division Multiple Access (TDMA) is the preferred scheduling scheme in sensor networks because it saves lot of energy compared to contemporary medium access tetchiness for wireless networks. One thing must be noticed here that whenever a cluster head needs to communicate with its upper cluster head in the cluster hierarchy it must use higher power in-order to guarantee data delivery. Upper level cluster heads will allocate longer time slots to their member low level cluster heads because they have more data to send compared to simple members.

Following figure shows the time slot issued by a cluster head having five simple member nodes and two lower cluster heads as member nodes. We assume 60% of data collected by a cluster head is highly correlated therefore; time slot for lower level cluster heads will be twice as large as that to simple member nodes.

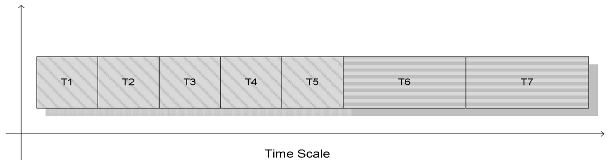


Figure 5: TDMA Schedule

Time slots T1 to T5 are allocated to simple member nodes and time slots T6 and T7 are allocated to lower level member cluster heads.

## VI. PERFORMANCE EVALUATION

There have been many routing protocols proposed for wireless sensor networks. In our research, we examine two such protocols along with MR-LEACH. First protocol that we have examined is direct communication protocol and the second one is LEACH.

Using direct communication protocol, each sensor node sends data directly to the BS. If the base station is far away from the transmitting node, direct communication will require large amount of transmission power. This will quickly drain the battery of the nodes hence; reduce the network life time.

The following table summarizes the assumptions we have made in evaluating different routing protocols.

TABLE 3: SYSTEM PARAMETERS

| | |
|---|---|
| Distance Between Member Node and Cluster Head = $\lambda$ | r |
| Average distance between two successive Cluster Heads = $\lambda_{CH}$ | 1.5r |
| Total Sensing Field | $200m^2$ |
| For Direct Communication, average distance Between node and BS = d | 135m |
| Total Number of layers in network | N |
| When message is relayed using clustering hierarchy, Message will go through to BS on average in | $\left\lceil \frac{N}{2} \right\rceil$ hops |
| In LEACH average distance between cluster head and BS = $\lambda_L$ | $110m^2$ |
| Data Packet Size = $K$ | 200 bits |
| Transmitter Electronics ($E_{Tx\text{-}elec}$) Receiver Electronics ($E_{Rx\text{-}elec}$ | 50 nJ/bit |
| Transmit Amplifier ( $\varepsilon_{amp}$ ) | 100 pJ/bit/$m^2$ |

For direct communication, energy required to transmit a message to the base station is given by the following equation.

$$E_{direct} = E_{Tx}(K, d)$$

$$E_{direct} = E_{Tx}(200, 135)$$

$$E_{direct} = E_{elec} \times 200 + \varepsilon_{amp} \times 200 \times d^2 \qquad (5)$$

Instead of direct communication in LEACH there is a cluster head that relays data to the base station. Therefore; there will be two transmits and one receive operation in LEACH. Following equations summarize total energy requirement of two transmits and one receive operation.

$$E_{Tx} = 2(E_{elec} \times 200 + \varepsilon_{amp} \times 200 \times d^2)$$

$$E_{Rx} = K.E_{elec}$$

$$E_{Leach} = E_{Tx} + E_{Rx}$$

$$E_{Leach} = 2(E_{elec} \times 200 + \varepsilon_{amp} \times 200 \times d^2) + K.E_{elec} \qquad (6)$$

In above equation we have assumed that distance between the member nodes to cluster head and distance between cluster head to BS is same.

In MR-LEACH we divide the network into 'N' layers and at worst message will get to the base station in 'N' number of transmits and (N-1) number of receives therefore; in worst case total energy requirement to transmit a message is given by the following equation.

$$E_{Leach} = N(E_{elec} \times 200 + \varepsilon_{amp} \times 200 \times \left(\frac{d}{N}\right)^2) + (N-1)K.E_{elec} \qquad (7)$$

The following graph shows total energy consumption in-order to relay message to the BS w.r.t. increase in clustering hierarchy. In equation 7 'N' is the total number of layers in which we have divided the network. We have incrementally increased 'N' from 1 to 20. 'd' is the distance of the sensing node from the base BS and we have assumed value of d = 135 meters. N = 1 is the case for direct communication and total energy consumption in this case was 0.000375 joules. We can observe that energy consumption drastically decreases when we divide network into different layer in-order to from clustering hierarchy. With four levels of clustering hierarchy, energy requirement gets to minimum thereafter consumption of energy slowly increase till we reach a threshold point where energy consumption gets higher than direct communication. This shows that clustering hierarchy should be done to a level where over all energy consumption gets to minimum.

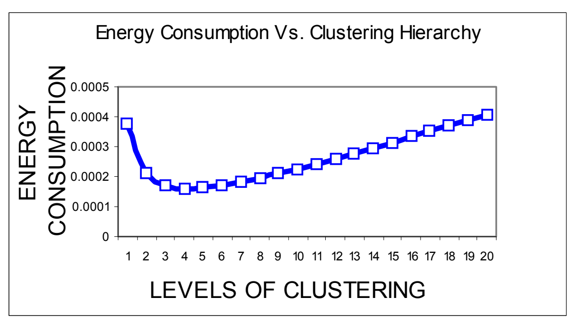


Figure 6: Energy Consumption vs. Levels of Clustering

Figure 7 shows energy consumption of a node using Direct Communication, LEACH and MR-LEACH. We have assumed that a node has 0.003 joule of energy available. In case of MR-LEACH we have divided the sensor network into four layers as in our stated assumptions it yields minimum energy consumption. Figure 7 clearly depicts that MR-LEACH outperforms direct communication as well as LEACH routing protocol in terms of energy consumption.

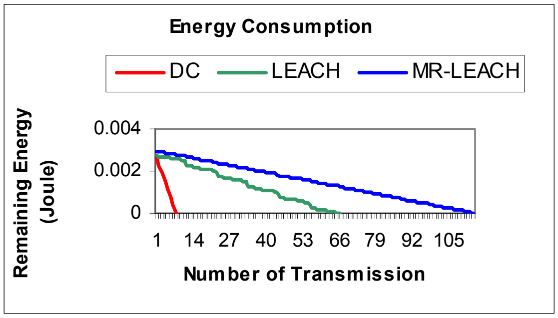


Figure 7: Energy Consumption vs. No. of Transmissions

Figure 8 shows number of transmissions done by a node using different protocols as node energy level varies. We can easily observe that MR-LEACH performance is far better compared to direct communication and LEACH routing protocol. This show's that lifetime of WSN using MR-LEACH is longer as compared to contemporary routing protocols for WSN.

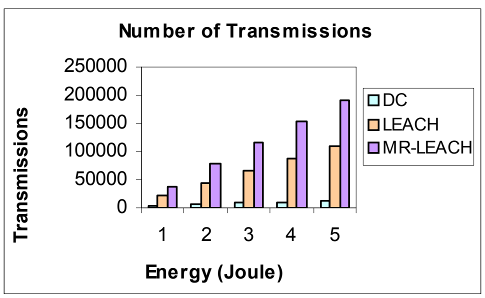


Figure 8: Number of Transmissions with varying energy levels

## VII. CONCLUSION

In this paper, we proposed a multi-hop routing protocol with low energy adaptive cluster hierarchy to minimize the energy consumption of sensor nodes. 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. Simple sensing nodes will join the cluster head afterwards, the BS will choose the cluster heads for lower layer cluster heads from its immediate upper layer cluster heads. In this way clustering hierarchy will be formed till we reach the base station. Performance evaluation section has shown that MR-LEACH performs well compared to similar approaches given that network is divided into optimal number of layers.

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