Low Energy Adaptive Clustering Hierarchy – Redundancy Aware protocol (LEACH-RA)

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INTRODUCTION

Wireless Sensor networks (WSN) present new challenges due to their unique characteristics, one of them being their distributed, multi-hop, dynamic nature. (Gnanambigai et al., 2012). The WSN is applied in wide range of areas like weather monitoring, military surveillance, wild life monitoring, agriculture, industrial applications, medical examination etc. In WSN, all sensor nodes are small in size and battery operated.

The main functionality of sensors is sensing the environment and communicates the sensed information to the sink either directly or through its neighbors. To prolong the lifetime of the network, an effective mean of energy conservation technique is essential both in the node level and network level.

In WSN, improper placement of sensor nodes, lack of efficient data aggregation method, inefficient routing methodology, insecure data transmission are some of the reasons for the depletion of energy of nodes. There are various parameters such as placement of nodes, connectivity, coverage, energy consumption, life time, reliability etc., which influence the performance of the wireless sensor network. It is not possible to improve all these parameters to attain greater efficiency which may in turn increase the complexity. It is advisable to consider certain specific parameters depending on the area of application.

In WSN, the sensor nodes are either scattered or placed in a regular pattern within the area of interest (AOI). Random deployment of sensor nodes are used in the hostile environment where human involvement is not possible. There may be some possibility of placement of extra sensors which will result in spatial redundancy, temporal redundancy or information redundancy (Daniel-Ioan et al., 2009).

The structure of WSN may take different forms as flat or hierarchical. In flat structure, all nodes are having same power and functionality. In hierarchical structure, we have sensor nodes, aggregator nodes and sink node. Each category may have different power capability. Clustering is the efficient way of organizing the hierarchical network.

In the proposed work, a popularly known hierarchy protocol LEACH is used. Also we include an efficient method of reducing redundant sensors by sleep and utilizing those sensors by wakeup method without affecting the normal functioning of the network.

The rest of the paper is organized as follows. Section II describes about the research work carried out as an enhancement of LEACH protocol. The preliminaries of clustering are described in section III. The section IV explains about the working principle of LEACH. Section V describes the architecture of the proposed protocol LEACH_RA. The simulation work and results are discussed in section VI. Finally, section VII concludes the work.
2. Related work:
The involvement of sensor increases because of Technology advancement. An extensive study about
the working of LEACH and its extended versions are
carried out. Some of the reviews are discussed here.
In (Gnanambigai et al., 2012)(Usha et al.,2014),
the authors highlighted the working of LEACH and
some of its derivatives are LEACH-C(Centralized
Low Energy Adaptive Clustering Hierarchy),
MULTITHOP LEACH, LEACH-F Fixed no of
clusters, Low Energy Adaptive Clustering Hierarchy
LEACH-L (Energy Balanced Low Energy Adaptive
Clustering Hierarchy), LEACH-B(Balanced Low
Energy Adaptive Clustering Hierarchy), LEACH-
M(Mobile - Low Energy Adaptive Clustering
Hierarchy), LEACH-S(SOLAR AWARE
CENTRALIZED LEACH), LEACH-S(SOLAR
AWARE DISTRIBUTED LEACH) and
LEACH-
(Advanced Low Energy Adaptive).
This clearly illustrates the various parameters
that can be considered for cluster formation and for
data communication. Some of the prominent factors
are the distance to the sink, relative position of
nodes, residual energy, fixed number of clusters, load
balancing technique, introducing solar driven
sensors, multihop communication within the cluster,
optimal path selection for data transmission based on
distance and energy.
An analytical comparison for energy efficiency of
LEACH and its derivatives are explained in (M.
Aslam et al., 2015). Various available clustering
techniques and their pros and cons are listed in
(Xuxun Liu 2012).
In the proposed work, the redundancy as a key
factor is considered to reduce energy consumption to
prolong the network lifetime.
3. Clustering:
WSN may be used for sensing either small scale
environment or large scale environment involving
less or more number of sensors respectively.
Clustering is one of the efficient techniques used to
organize the nodes in a hierarchical manner. The
Cluster based approach segment of the nodes into
different groups are called clusters. A cluster
includes Cluster Head and Cluster Members. Within
a cluster, the Cluster Head will be selected either
randomly or through fixed constraints. The Cluster
Head is entirely responsible for collecting and
transmitting the sensed information either directly
towards the sink or through other Cluster Heads.
The number of clusters, size of the clusters and
data processing technique will be based on the
underlying application.
Advantages of clustering over different classes of
algorithms are (Alakesh Braman et al., 2013):
• Minimization of energy consumption of intra
cluster and as well as inter cluster network.
• Scalability of the network.

4. Leach architecture:
LEACH is one of the most popular distributed
cluster-based routing protocols in WSNs. The cluster
formation is a random process and the basic
architecture is depicted in Fig 1 (Alakesh Braman1 et.
al., 2014). In LEACH protocol, all the nodes are
grouped into the clusters, and in each cluster one of
the nodes is assigned as a Cluster Head (CH). The
base station (Sink) is the central component where
the sensed information is stored and it is fixed. 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 (Raed
et al., 2013). CH collects the data from the
surrounding nodes and passes it to the base station
(Annu Ghotra et al.,2015). It’s overall operation is
based on rounds (Sangita Vishwakarma 2015).
LEACH performs self-organizing and re-clustering
functions for every round. (Alakesh Braman1 et al.,
2014).
A node n is selected as a CH in next round based
on the following formula.
\[
T(n) = \begin{cases} 
1 - p & \text{if } n \in G \\
0 & \text{otherwise}
\end{cases}
\]
(1)

If T(n) is 1, then the node n will be the CH in
next round where p is the probability of node n
being selected as a CH, r represents the current round
number and G is the set of nodes that are not selected
as a CH in the last 1/p rounds. (Annu Ghotra et
al.,2015).
Cluster Head collects the data from all the
nodes, aggregate the data and route all meaningful
compressed information to Sink. Because of these
additional responsibilities Cluster-Head dissipates
more energy and if it remains as Cluster Head
permanently for long duration, it will die quickly as
happened in case of static clustering. LEACH tackles
this problem by randomized rotation of Cluster Head
to save the battery of individual node. (Alakesh
Braman1 et al., 2014).

Data aggregation is performed by the Cluster
Head. The Cluster Head create a Time-Division
Multiple Access (TDMA) based schedule whereby
each node of the cluster is assigned a time slot which
can be used for transmission. The Cluster Head
advertises the schedule to its Cluster Members
through broadcasting. To reduce the likelihood of
collisions among sensors within and outside the
cluster, LEACH nodes use a Code-Division Multiple
Access (CDMA) based scheme for communication
(Bhakti Parmar et al., 2014). Most of the wireless
sensor networks use heterogeneous devices and the
remaining power of these nodes may differ. Based on simple random rotation, if any node with low remaining energy is selected as a CH, its energy evaporates soon. Therefore, many number of LEACH routing with some enhancements were used by many researchers. (Annu Ghotra et al., 2015).

The LEACH operation is classified into different rounds and each of these rounds are having mainly two phases and these are

![Fig. 1: The basic architecture of LEACH.](image)

**a) Setup phase:**
- For the process of organizing the whole network into different intra-clusters
- Advertisements of the Cluster Heads to its different individual cluster members
- Transmission of the schedule that has been created during the setup phase only

**b) Steady state:**
- The process of data aggregation within the different clusters of the network
- Compression of the sensed information that is being sensed by the sensor node into its different Cluster Head within the cluster only
- Transmission of the compressed data to the sink via different Cluster Heads (Alakesh Braman1 et al., 2014).

The duration of the setup is assumed to be relatively shorter than the steady-state phase to minimize the protocol overhead. (Bhakti Parmar et al., 2014).

**Advantages of LEACH Protocol:**
Cluster based routing protocols have a variety of advantages, such as more scalability, less load, less energy consumption and more robustness.

Since the data transmission is only within the cluster, the routing information is minimum when compared to flat topology. It is highly scalable based on the underlying application.

The nodes in LEACH may play the role of Cluster Head or Cluster Member. The probability of being a Cluster Head is evenly distributed among the nodes. Cluster Member will sense the environment and Cluster Head will aggregate the non-redundant information and forward it to the sink. Thus, the Cluster Head reduces the amount of data need to be processed and transmitted to the sink. It also reduces the distance of data transmission path.

Wireless sensors are dynamic and the nodes are mobile in nature. Since LEACH follows compact cluster structure, it easily manages the node or link failure.

The bandwidth utilization is efficient because CDMA based scheme is used for communication. LEACH reduces communication energy by 8 times as compare to direct transmission and minimum transmission energy routing. (Tripti Sharma et al., 2012).

**Drawbacks of LEACH Protocol:**
Some of the problems that may occur while implementing LEACH protocol are:
- The Cluster Head selection is random based on the threshold Tn, so after some rounds the chances of each node to become a Cluster Head node is same. Also, the nodes of different energy levels have the same chances of becoming Cluster Head node. These issues will degrade the network lifetime.
- In a large area of network there may be a possibility of Cluster Head to be placed further away from the sink. Since Cluster Head is responsible for fusing and sending, the sensed data to the sink and the amount of energy consumption will be high.
- In LEACH, there is no well established recovery or preventive mechanism for both link and node failure.
5. Leach-RA protocol:
In LEACH, there is a lack of control over the number and size of clusters. The Cluster Head selection and cluster formation are a random process. It will result in an uneven distribution of clusters i.e. the number of clusters will be more in one place and less in other place. Also, the Cluster Heads are very close to each other in one place and far away in some other places.

This uneven distribution of nodes will cause some serious effects such as redundancy and coverage hole. It is necessary to frame a mechanism to identify the redundant (extra) sensors and reuse the same. In this paper, LEACH-RA protocol is introduced to identify and efficiently use the redundant sensors.

The algorithm is executed in round. Round is a time slot fixed based on the underlying duplication.

System Description:
Some of the basic assumptions about the system are as follows:
- Nodes are randomly distributed in the two dimensional area of interest.
- Nodes are homogeneous in nature i.e. having same computing power
- The communication range (RC) and Sensing range (RS) are same.
- Base station is fixed at the centre.
- All the sensed information is forwarded to the sink in single hop manner.

Energy Model:
In the proposed work, for measuring the energy consumption, the energy model is used as in LEACH. It is described below:
The energy per bit spent in transmission is given by
\[ e_{tx(d)} = e_t + e_d * d^n \] (2)
\( e_t \) is the energy dissipated per bit in the transmitter circuitry and \( e_d * d^n \) is the energy dissipated for transmission of a single bit over a distance \( d \), \( n \) being the path loss exponent (usually 2.0≤\( n \)≤4.0). \( n = 2 \) is assumed in the first order model for the purpose of simulation.

Thus the total energy dissipated for transmitting a K-bit packet is
\[ E_{tx(k, d)} = (e_t + e_d * d^2) * K \] (3)
If \( e_r \) be the energy required per bit for successful reception then the energy dissipated for receiving a K-bit packet is
\[ E_{rx(k)} = e_r * K \] (4)

LEACH-RA consists of three phases, namely, Setup Phase, Redundancy Check Phase and Steady State Phase. Both Setup phase and Steady State Phase are same as LEACH. It is a centralized process in which all the nodes should undergo all three phases in each round.

Setup Phase:
In this phase, Cluster Head selection and cluster formation are performed. In simulation, the probability of Cluster Head is fixed as 0.2. For each round, the Cluster Head will be elected and the Cluster Head in the current round will not be elected as Cluster Head for the next further rounds. The node which is in least distance to any of the Cluster Head when compared to the sink is selected as Cluster Member for that particular Cluster Head. If the node is not close to any of the Cluster Head, it will act as individual member and transmit all the information directly to the sink.

Redundancy Check Phase:
After cluster formation was completed, Redundancy Check Phase was initiated. This phase identifies the extra sensors if any, based on the following assumptions:
- The Cluster Heads with cluster size less than the \( C_{thres} \) was selected for redundancy check.
- The selected Cluster Heads are marked as redundant if their distance to the sink is more than 2*RC (P. Santi et al., 2003) and the number of neighboring Cluster Members are more than \( T_{neigh} \) (F. Xue et al., 2004).
- The Cluster Member is considered as redundant if its distance to the sink is less than RC and its number of neighboring Cluster Members are more than \( T_{neigh} \).

The values for threshold parameters \( T_{neigh} \), \( C_{thres} \) are mentioned in the next section.

The identified redundant sensors are turned OFF and are not allowed to participate in that round. They will be revoked again to ON state for next forthcoming round.

Steady State Phase:
In this phase LEACH-RA will behave similar to LEACH and the Cluster Head will aggregate the data received through its Cluster Members. After that the compressed data are forwarded to the base station.

Highlights:
- By turning the extra sensors to ON and OFF mode, we can increase the residual energy of the node.
- Extra sensors are identified based on the threshold which will guarantee better coverage and connectivity (F. Xue et al., 2004).
6. Experiment and results:
The proposed protocol was implemented using MATLAB- R2013a. The results are compared with the standard LEACH protocol.

Assumptions:
- Sensor nodes are randomly distributed in a square.
- The sink is fixed at the centre.
- The communication is direct.
- The communication range is same for all the nodes.

Simulation Parameters:
The following table lists the parameters and its corresponding values which are used in simulation work.

<table>
<thead>
<tr>
<th>Simulation Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>100 m × 100 m</td>
</tr>
<tr>
<td>Number of nodes (n)</td>
<td>200</td>
</tr>
<tr>
<td>Probability of being Cluster Head (P)</td>
<td>0.2</td>
</tr>
<tr>
<td>Position of Base Station (BS)</td>
<td>50, 50</td>
</tr>
<tr>
<td>Initial Energy (E0)</td>
<td>0.1</td>
</tr>
<tr>
<td>Number of rounds (r)</td>
<td>100</td>
</tr>
<tr>
<td>Communication Range</td>
<td>12 m</td>
</tr>
<tr>
<td>Cmax</td>
<td>10</td>
</tr>
<tr>
<td>T_{targ}</td>
<td>&gt; 0.074 log n &amp; &lt; 5.1774 log n</td>
</tr>
<tr>
<td>Packet Size</td>
<td>4000 bits</td>
</tr>
<tr>
<td>Protocols</td>
<td>LEACH &amp; LEACH-RA</td>
</tr>
</tbody>
</table>

In the simulation scenario, 100 rounds are executed and the results are shown in the following figures. The simulation result concludes that the number of nodes becoming obsolete is less in LEACH-RA than LEACH protocol. The simulation graph representing the rate of occurrence of dead nodes is given below.

It is also clear that the average energy consumption in the proposed protocol is less when compared to the LEACH protocol which will enhance the network life time. The following figure shows the average remaining energy of nodes at each round for both LEACH and LEACH-RA protocol.

In the proposed protocol, the Cluster Heads which are not so active are turned to OFF state. The
following graph shows the number of Cluster Heads in each round for both LEACH and LEACH-RA protocol.

7. Conclusion:
The main aim of the proposed work is to reduce the redundancy effect. Redundancy is an alley and enemy. There are different categories of Redundancy such as Spatial Redundancy, Temporal Redundancy and Information Redundancy. In the proposed work, the physical Redundancy is considered. From the simulation results, it is concluded that the proposed LEACH-RA protocol will perform well in reducing the number of dead nodes, increasing the average energy of node and decreasing the number of Cluster Heads in different rounds when compared to LEACH. In future work, we will investigate the approach which will efficiently reallocate the cluster members belong to the inactive Cluster Head to other cluster group as well as to handle the extra sensor in fruitful way.

REFERENCES


