CVLEACH: Coverage based energy efficient LEACH algorithm

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Abstract

Designing a protocol stack for wireless sensor network (WSN) is a challenging task due to energy, computational and storage constraints. Energy spent for communication between sensor nodes dominates the energy spent for the computation [10]. Multi-hop short range communication between wireless sensors nodes is energy efficient compared to single-hop long range communication. Hierarchical clustering is one of the possible solutions to save energy of wireless sensor nodes. Low-Energy Adaptive Clustering Hierarchy (LEACH), Centralized Low-Energy Adaptive Clustering Hierarchy (LEACH-C) and Advanced Low-Energy Adaptive Clustering Hierarchy (ALEACH) are energy efficient hierarchical clustering routing protocol. In this paper we proposed Coverage based Low-Energy Adaptive Clustering Hierarchy routing protocol – CVLEACH to make uniform distribution of Cluster Heads (CHs) by creating non-overlapped cluster regions using overhearing properties of the sensor nodes, which makes the routing protocol more energy efficient and prolongs life time of a wireless sensor network. Simulation results show that CVLEACH improves network life time compared to LEACH and ALEACH algorithms.

Keywords: Wireless sensor networks, Energy efficient LEACH, Coverage based LEACH, RSSI based LEACH, overhearing

1. Introduction

Wireless Sensor Network (WSN) is gaining popularity due to the reduction in cost and size and advancement in MEMS technology. Many challenges have been introduced to implement protocol stack of a WSN due to size, energy, computational and storage constraints. In most applications of a Sensor Network, sensor nodes are dropped from the helicopter in a hostile environment in unplanned manner. Sensor nodes will establish a network by communicating with the nodes within their radio range. In most application it is impossible to replace or recharge battery of sensor nodes. Energy expenditure of sensor nodes has to be done carefully in order to prolong life of a sensor network. Clustering with data aggregation is one of the solutions to increase lifetime of a sensor network. In cluster based algorithm, one of the nodes will work as a sink node which collects data from the cluster heads, aggregate them and send it to base station. Cluster heads will collect data from their member nodes, aggregate them and send it to sink node directly or through multi-hop communication. Energy is the most important parameter for sensor nodes because it is very difficult to replace or recharge battery of a node. Overhearing increases the energy expenditure of a node and it should be minimized to prolong life of a sensor network. A node can make a decision about its election as a cluster head by using overhearing property.

This paper is organized as follows: Section 2 describes the LEACH algorithm and few of its variants; CVLEACH algorithm is discussed in Section 3, Results and Concluding remarks are discussed and presented in Section 4 and Section 5 respectively.

2. Related Work

2.1 LEACH Algorithm

Low-Energy Adaptive Clustering Hierarchy (LEACH) is a hierarchical cluster based energy efficient routing algorithm. Network used in LEACH has following properties [1]:

– Base station is far from the network and it is immobile.

–All nodes are having equal energy, storage and computational capability.

– All the nodes are having limited amount of energy which imposes energy constraints on them.

The key features of LEACH algorithm is as follows:
– Coordination and control between the sensor nodes is implemented locally for cluster-set up phase.
– Role of the cluster head is randomly rotated among the nodes.
– Data is aggregated locally within the cluster.
– Decision of any node to join cluster head is based on minimum communication energy a node has to spend to communicate with the selected cluster head.

The following assumptions have been made in LEACH implementation.
– Each sensor node is sensing at fixed rate and it is having some data to send to the cluster head or base station.
– Energy consumption for Cluster Head is uniform.[6]
– Symmetric propagation channel.
– All nodes are able to reach Base Station.
– Cluster Heads are uniformly distributed.[8]

Working of LEACH is divided into rounds. Each node is able to become cluster head only once in a 1/p rounds, where p is the desired percentage of cluster heads during each round. A node will select a random number between 0 and 1. If value of selected random number is less than the threshold T (n), the node becomes a cluster head for the current round. The threshold value T (n) is given by the equation 1.

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

where G is the set of nodes which are not elected as cluster head in last r rounds. LEACH algorithm is distributed. It does not ensure that during each round only p% of total nodes will be elected as cluster head. Placement of cluster heads is also not guaranteed by LEACH algorithm. [2]

2.2 LEACH-C Algorithm

In LEACH-C algorithm, each node is required to send its location and energy information to the base station. The base station will calculate average of the energy level received from all the nodes. Nodes which are having energy level higher than the average energy calculated will be the probable cluster heads for the current round. Base station will find the cluster head from the set of probable cluster heads using simulated annealing algorithm [9] to find k optimal clusters which is NP-hard problem [4]. This algorithm attempts to minimize the amount of energy for the non-cluster head nodes to transmit their data to the cluster head, by minimizing the total sum of squared distances between all the non-cluster head nodes and the closest cluster head. Once all cluster heads and their associated clusters are identified, base station will broadcast cluster head ID for each node. A node will declare itself as cluster head if its own ID matches with the cluster head ID broadcast by base station. If any node does not become a cluster head it will find out its TDMA schedule during which it can transmit its data to cluster head or base station. Nodes will go to sleep state upon reception of the TDMA schedule, until their turn comes. It helps to save energy of nodes.

The problem with LEACH and LEACH-C is that it assumes that cluster heads are uniformly distributed [11]. This is shown in Figure 1 which is redrawn from [1]

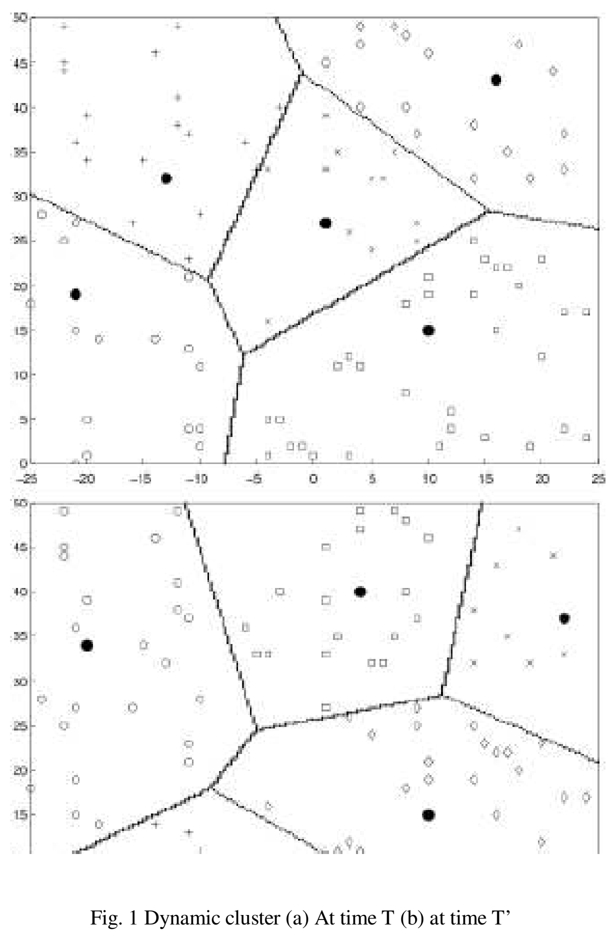

Fig. 1 Dynamic cluster (a) At time T (b) at time T'

2.3 ALEACH Algorithm

Advanced LEACH (ALEACH) [5] is proven energy efficient routing protocol compared to LEACH. Like LEACH, ALEACH also works in two phases (a) Cluster Setup Phase and (b) Steady Set Phase. The major difference between LEACH and ALEACH is ALEACH considers both stochastic value as given by equation 1 and energy level of a node to calculate threshold value T (n) of a particular node, where T (n) is given by equation 2.

$$T(n) = G_p + CS_p \qquad (2)$$

where Gp and CSp is given by equation 3 and 4 respectively. Gp and CSp refer to general probability and current state probability.

$$G_p = \frac{k}{N - k * (\text{r mod } \frac{N}{k})} \qquad (3)$$

$$CS_p = \frac{E_{current}}{E_{max}} X \frac{k}{N} \qquad (4)$$

where k/N refers to the desired percentage of cluster heads during each round and $E_{current}$ and E_{max} is remaining energy and maximum energy of a node respectively.

In subsections 2.1, 2.2 and 2.3, we have discussed LEACH, LEACH-C and ALEACH. These routing protocols are designed by considering various parameters and proven energy efficient. But the main drawback of these algorithms is their assumption about uniform distribution of cluster heads. It can be possible that overlapping clusters can be formed by these algorithms because selected cluster heads may sit nearby during the same round.

If we assume that energy expenditure of a node to communicate with cluster head and base station is E_{CH} and E_{BS} respectively, where $E_{CH} <<< E_{BS}$. Further we can assume that there can be C nodes which can be elected as cluster head during each round and each node can be elected as cluster head only once in 1/p rounds, where p is desired percentage of cluster heads during each round. For LEACH and ALEACH algorithms, energy consumption per round E_{round} is given by Equation 5.

$$E_{round} = M * E_{CH} + (N - M) * E_{BS} \qquad (5)$$

where M is the total member nodes of the clusters during the round and N is the total number of nodes deployed in a region to be monitored.

A node becomes a cluster head or not is decided using stochastic values in LEACH, ALEACH and LEACH-C algorithm. It is also possible that two cluster heads can be in the nearby region. In this case, the number of nodes covered by the cluster head is reduced. Hence from equation 5, E_{round} increases. We have designed Coverage based energy efficient LEACH (CVLEACH) algorithm using the overhearing properties of the sensor nodes to create non-overlapping cluster regions.

3. CVLEACH: Coverage based energy efficient LEACH algorithm

Energy required to communicate with the cluster head by the member nodes is very less compared to energy required by the cluster heads or non member nodes to communicate with the base station. From equation 5, if we will increase number of member nodes, with desired number of cluster heads–C, then overall energy expenditure during a round is reduced. This can be possible by creating non-overlapping clusters. CVLEACH is the coverage based energy efficient LEACH algorithm which increases the number of member nodes of a cluster by creating non overlapping clusters. CVLEACH also works in round – which is fixed amount of time during which selected node can act as a cluster head. Like LEACH, at the beginning of each round each node selects a random number between 0 and 1 and calculates threshold value T(n), where T(n) is given by equation 1. If selected random number is less than the threshold value T(n), node elects itself as a cluster head. However, before a node can announce itself as a cluster head to other nodes, if it receives cluster head announcement from other cluster head then the node withdraws itself as a cluster head during that round and decides to join to one of the clusters. A node will join to one of the clusters, from where it has received cluster head announcement. A node will send join message to one of the clusters for which minimum energy is required for communication with the cluster head. This algorithm also ensures that a node can becomes a cluster head only once in 1/p rounds. Each round begins with the cluster set up phase which is followed by steady state phase. Nodes are elected as cluster heads during cluster set up phase. Cluster set up phase is shown in Algorithm 1. Steady Set up phase is used by member nodes to send data to their cluster heads or by cluster heads to send data to the base station and is shown in Algorithm 2.

Algorithm 1 Cluster Set up Phase

```
Require: Total Round Time > 0 and Round Duration > 0 and Total Round Time ≥ Round Duration and N > 0 and 0 ≤ P < 1
for all i ∈ G do
  ClusterHeadInLastRound = false
end for
rounds = ⌈ (SimulationTime/RoundTime)⌉
for r = 0 to rounds − 1 do
  CHAdvReceived = false
  for all i ∈ N do
    if ClusterHeadInLastRound or CHAdvReceived then
      T(i) = 0
      if NotCHAdvReceived and NotTimeOut then
        Wait For CH Adv(t)
      end if
      if TimeOut and NotCHAdvReceived then
        Wait For Steady State Phase
      end if
      Send Join Request(i)
      Wait For TDMA Schedule(t)
    else
      if T(i) > random(0, 1) then
        ClusterHeadInLastRound = true
        Do Cluster Head Announcement(i)
        Wait For Join Request(t)
        for all j ∈ Members do
          Send TDMA Schedule(j)
        end for
      else
        if NotCHAdvReceived and NotTimeOut then
          Wait For CH Adv(t)
        end if
        if TimeOut and NotCHAdvReceived then
          Wait For Steady State Phase
        end if
        Send Join Request(i)
        Wait For TDMA Schedule(t)
      end if
    end if
    CallStedy State Algorithm(i)
  end for
  if (round + 1) = ⌈ N/(P * 100)⌉ then
    ClusterHeadInLastRound = false
  end if
end for
```

Algorithm 2 Steady-State Phase

```
Require: i
if t < RoundTime then
  if i ∈ CH then
    for all j ∈ Members(i) do
      Collect Data From Member Nodes(j)
    end for
    Send Aggregate Data To Sink By CH(i)
  else
    if t < Scheduled Start Time or t > Scheduled End Time then
      Sleep Node(i)
    else
      Send Data To CH By Member(i)
    end if
  end if
end if
```

In Algorithm 1, G is the number of nodes which are not elected as a cluster head in last r round. If a node is elected as a cluster head during last q round where q < r or it has received cluster head announcement from the neighboring nodes during a particular round, a node will withdraws its participation to be elected as a cluster head during that round and decide to join one of the cluster heads from which it has received cluster head announcement and having highest RSSI (Received Signal Strength Indicator) amongst all received cluster head announcements. If a node which is neither a cluster head nor a member node will send data directly to the base station. Steady state phase is shown in Algorithm 2. If a node is a cluster head it will collect data from the member nodes, aggregate them and send it to base station. Member nodes will be activated and send its data to cluster head as per the TDMA schedule sent by the cluster head. For the rest of the time member nodes will remain into SLEEP state to save energy and reactivated at the end of the round time.

4. Results

We have investigated performance of CVLEACH against ALEACH and LEACH algorithm using Castalia simulator [7]. Castalia can be used for simulation of Wireless Sensor Networks (WSN), Body Area Networks (BAN) and networks of low-power embedded devices. It is used to test distributed algorithms and/or protocols in realistic wireless channel and radio models, with a realistic node behavior especially relating to access of the radio [7]. A network of size 250m x 250m is created with randomly distributed 100 sensor nodes to test performance of CVLEACH against LEACH and ALEACH. Each node has CC2420 as transceiver. Each node constantly draws 6mW and sensing device within the node draws 0.02mW. The transceiver energy parameters are set as: ETx = 46.2mW to do cluster head announcement, to send cluster join message and to send data by member nodes to their respective cluster heads; ETx = 57.42mW to send data by the non cluster member nodes and cluster heads to Base Station. A transceiver of node can be in one of the three states: RX (receive), TX (transmit) or SLEEP, if node is alive. Transceiver takes the 194µsec to change from SLEEP state to either RX or TX, 10µsec to change between TX and RX states and 50µsec to enter the SLEEP state [7]. Transition to SLEEP state from RX or TX consumes 1.4mW while any other transition consumes 62mW [7].

Size of control and data messages is set to 30 bytes. Every 2-seconds sensor will report sensed data to the node itself. Round time is fixed to 20-seconds. Each node has given 18720 Joules of initial energy which is equivalent to energy of two AA batteries [7]. p is set to 5% in equation 1.

We have run simulation for 1000 seconds to investigate following performance metrics: Packet Reception Rate: It represents the ratio of number of packets received over number of packets transmitted; Energy Consumption: It represents total energy consumption of all nodes; Average Energy Consumption per Node: It represents the average energy expenditure of a node; Coverage: Average number of members covered by all cluster heads per round; Fitness of Cluster Head: It represents average number of cluster heads; Application Level Latency: It represents end to end delay experienced by the packet; Network Life Time: Network life time can be measured in terms of First Node Dies (FND), Half of the Nodes Alive (HNA) and Last Node Dies (LND).

Table 1: Simulation Parameters

Node Deployment Area	250m x 250m
Number of Nodes	100
Initial Energy	18720 Joules
Energy to do CH announcement Energy to transmit data to CH Energy to send CH Join Message	46.2mW
Energy to transmit BS	57.42mW
Rate of Sensory Data generation	Every 2 seconds
Round Duration	20 Seconds
Simulation Time	1000 Seconds
Operating power of a Node	6mW
Operating power of a sensing device	0.02mW
Size of Control and Data messages	30 Bytes
Expected percentage of CH per round	5%
Initial Energy (for FND,HND,LND)	6 Joules

Total number of packets received and transmitted is shown in figure 2 and 3 respectively. Total packets received for ALEACH, CVLEACH and LEACH are 1274, 1406, 1255 and total packets transmitted for ALEACH, CVLEACH and LEACH are 1476, 1614 and 1420 respectively. Packet reception rate for ALEACH, CVLEACH and LEACH is found 86.31%, 87.11% and 88.38% respectively.

Total energy consumption of all nodes and average energy consumption per node for ALEACH, CVLEACH and LEACH is shown in figures 4 and 5 respectively. Total energy consumption of all nodes is 6344.872 Joules, 6301.75 Joules and 6357.801 Joules and average energy consumption per node is 63.449 Joules, 63.017 Joules and 63.578 Joules recorded for ALEACH, CVLEACH and LEACH algorithm respectively.

In equation 1 p is set to 5% for the simulation. Number of nodes which is covered by the cluster heads and average number of cluster heads is shown in Figure 6 and Figure 7 respectively. Average members of all clusters during each round are shown in Figure 6 and it is 9.98, 10.9 and 9.7 for ALEACH, CVLEACH and LEACH algorithm. It can be seen from Figure 7 that average number of cluster heads per round for ALEACH, CVLEACH and LEACH is 5.52, 5.06 and 5.04. From Figures 4 – 7, we can conclude that CVLEACH maintains the desired number of cluster heads and more number of members is to be covered by these cluster heads. Energy required to communicate with cluster heads is very less compared to energy required to communicate with base station. Hence, energy conservation for CVLEACH is better than ALEACH and LEACH algorithms. End to end latency felt by packets is shown in Figure 8. In Figure 8, latency felt by the packets in CVLEACH algorithm is higher than the latency felt by the packets of ALEACH or LEACH algorithm because of packets transmitted by member nodes of a cluster can reach to base station through cluster heads and large number of nodes is covered by the cluster heads in CVLEACH compared to ALEACH and LEACH.

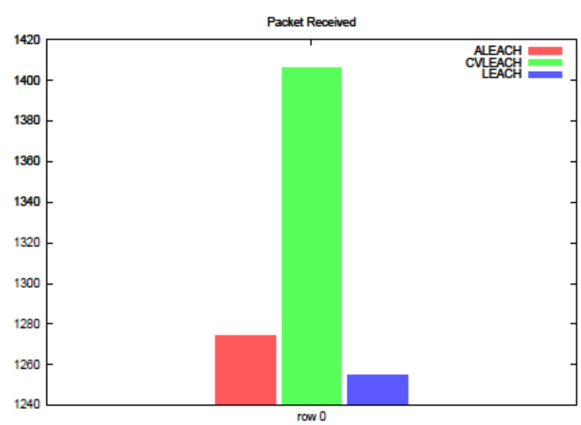

Fig. 2 Number of Packets Received

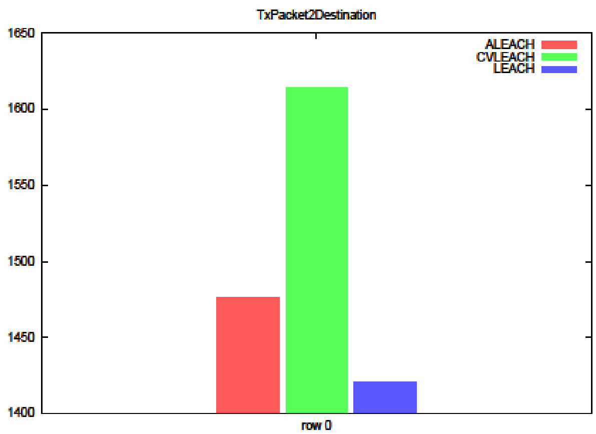

Fig. 3 Number of Packets Transmitted

There are three major matrices which can be used to measure lifetime of sensor nodes: First Node Dies – FND, Half of the Nodes Alive - HNA, and Last Node Dies – LND [3]. To test these matrices, 6 Joules of initial energy is given to each node and FND, HNA and LND recorded for ALEACH, CVLEACH and ALEACH, which is shown

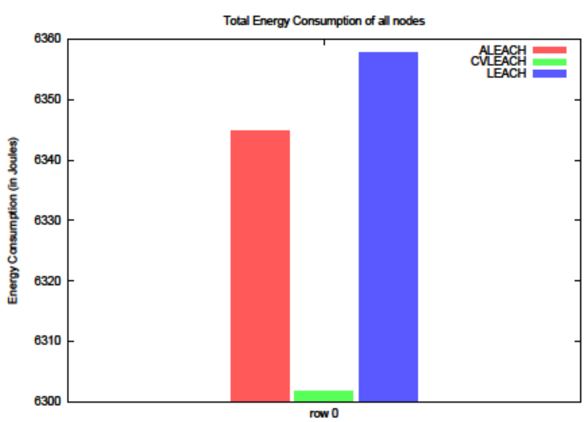

Fig. 4 Total Energy Consumption (in Joules)

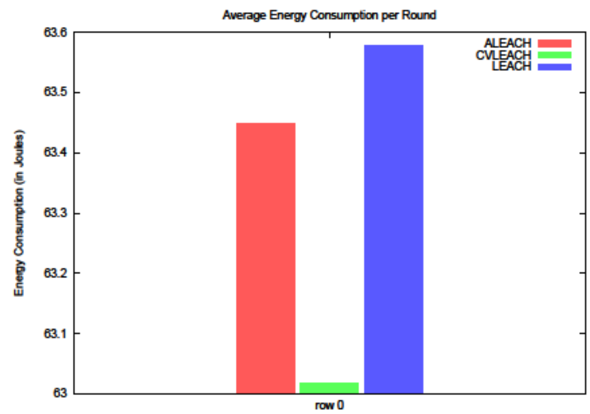

Fig. 5 Average Energy Consumption per node (in Joules)

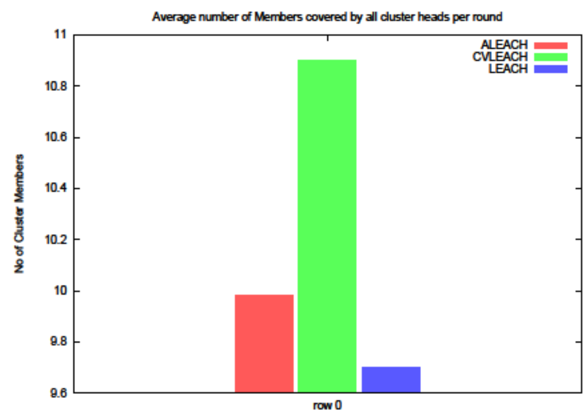

Fig.6 Average number of member nodes covered by all cluster heads per round

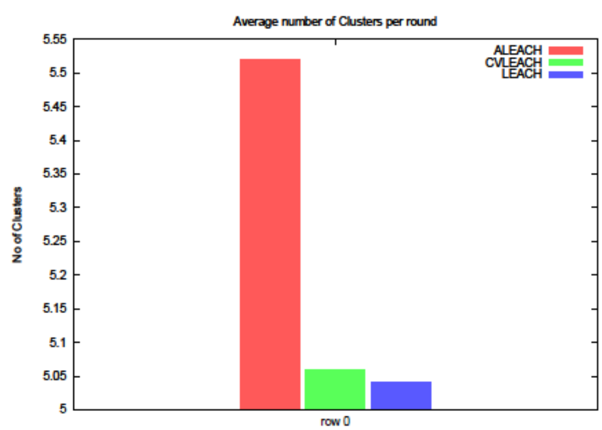

Fig. 7 Average number of cluster heads per round

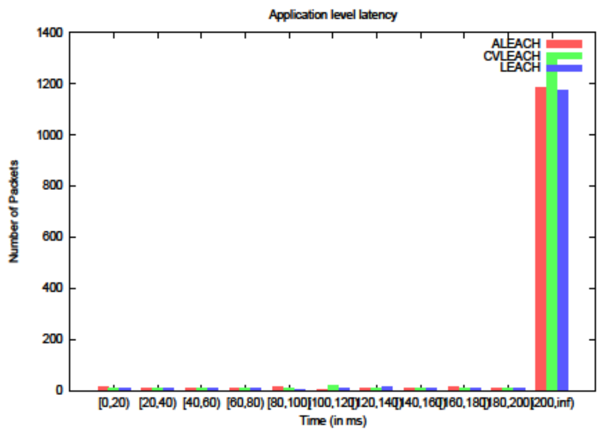

Fig. 8 End to end delay felt by packets

Table 2: FND, HNA and LND for ALEACH, CVLEACH and LEACH (6 Joules as initial Energy)

Algorithm	FND (in seconds)	HNA (in seconds)	LND (in seconds)
ALEACH	29.426	**33.726**	58.206
CVLEACH	**29.432**	33.702	**64.130**
LEACH	29.414	29.742	58.717

in Table 2. It can be seen from the Table 2 that CVLEACH is better than ALEACH and LEACH algorithms in terms of FND and LND and ALEACH is better than CVLEACH and LEACH in terms of HNA. Comparative of performance matrices simulated for ALEACH, CVLEACH and LEACH is shown in Table 3.

5. Conclusions

CVLEACH is distributed, energy efficient algorithm compared to LEACH and ALEACH. It also ensures that a node can becomes a cluster head only once in 1/p rounds, where p is the desired percentage of cluster heads. It also increases the lifetime of a sensor network which we have verified using FND, HNA and LND matrices. LEACH is better than CVLEACH and CVLEACH is better than ALEACH in terms of packet reception rate.

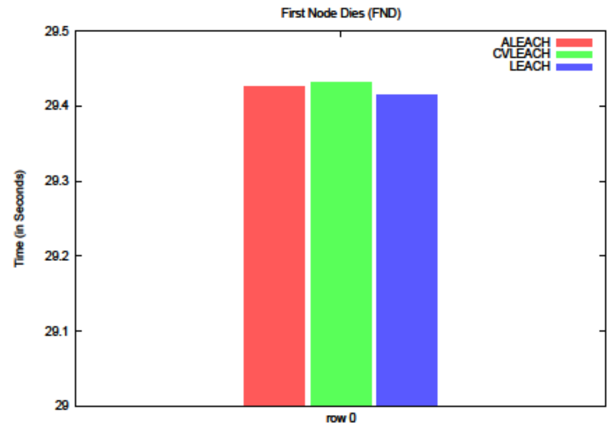

Fig. 9 First Node Dies (FND)

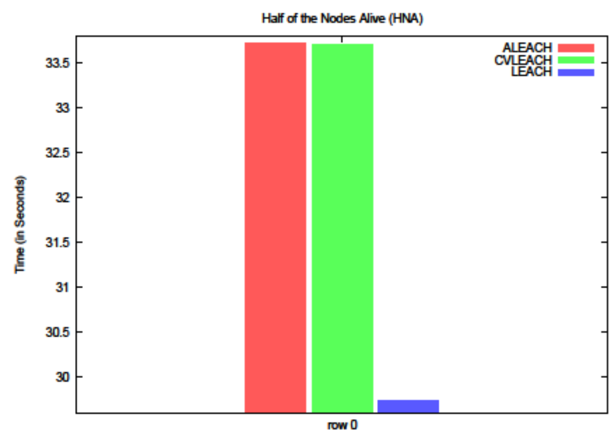

Fig. 10 Half of the Nodes Alive (HNA)

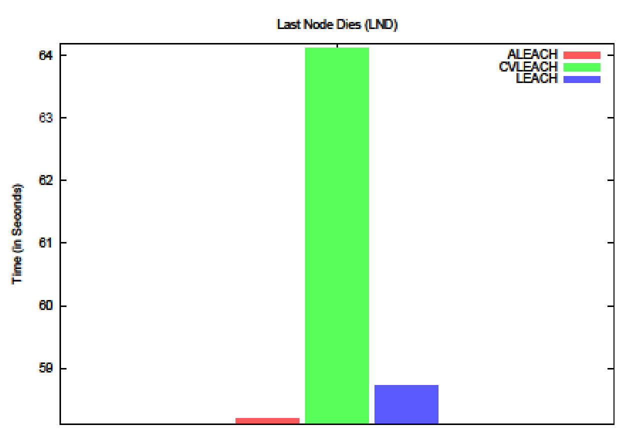

Fig. 11 Last Node Dies (LND)

Table 3: Comparative of performance matrices simulated for ALEACH, CVLEACH and LEACH

Performance Matrix	ALEACH	CVLEACH	LEACH
Packet Reception Rate	86.31%	87.11%	**88.38%**
Total Energy Consumption	6344.872 Joules	**6301.75 Joules**	6357.801 Joules
Average Energy Consumption per Node	63.449 Joules	**63.017 Joules**	63.578 Joules
Average number of Cluster Heads	5.52	5.06	**5.04**
Average number of Member nodes covered by Cluster Heads	9.98	**10.90**	9.70
End to end latency [0,20)(No of packets)	**15**	11	10
End to end latency [20,40)(No of packets)	8	9	**10**
End to end latency [40,60)(No of packets)	8	**10**	6
End to end latency [60,80)(No of packets)	6	**8**	7
End to end latency [80,100)(No of packets)	**13**	11	5
End to end latency [100,120)(No of packets)	5	**17**	9
End to end latency [120,140)(No of packets)	10	11	**12**
End to end latency [140,160) (No of packets)	6	6	**10**
End to end latency [160,180)(No of packets)	**14**	11	6
End to end latency [180,200)(No of packets)	7	**8**	**8**
End to end latency $[200,\infty)$ (No of packets)	1182	1304	**1172**

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