Servant-ModLeach Energy Efficient Cluster Base Routing Protocol for Large Scale Wireless Sensor Network

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Abstract: *In wireless sensor networks, the sensor nodes are usually engaged in a number of activities making them lose energy very fast. Therefore, maximizing the lifetime of nodes during protocol design is of primary concern. In this paper, the MODLEACH protocol is studied and enhanced. In MODLEACH, it is observed that the Cluster Heads (CHs) are responsible for both data aggregation and routing of data to the Base Station (BS). This allows a faster depletion of the CHs energy and the energy of the entire network. Also, it has been observed that the residual energy of the nodes is not considered in selecting the Cluster Heads (CHs). This makes it possible for weaker nodes to be selected as CHs. In this research, a modified MODLEACH protocol called Servant-MODLEACH (S-MODLEACH) has been proposed to address the problem of residual energy and lessen the huge task placed on CHs in MODLEACH protocol. In the proposed protocol, Cluster CHs are selected based on the strength of their residual energy. In addition, servant nodes for data aggregation and routing of data to CHs are introduce in the network. Simulations have been conducted to evaluate the new clustering algorithm using MATLAB R2017a and the results showed that S-MODLEACH performs better than MODLEACH in heterogeneous settings in terms of throughputs, energy conservation and extension of the network lifetime*.

Keywords: Energy Consumption, MODLEACH Protocol, Network Lifetime, Servant-MODLEACH

1. Introduction

Sophistication in electronics due to advanced technology today, has enabled network protocol designers to develop low cost, low power and small size sensors [5, 6]. In fact, thousands of these sensors are deployed in Wireless Sensor Network (WSN) based on the requirement of network application. These devices are able to monitor physical environment, compute and transmit data among themselves to resource nodes called.

Base Station (BS) [8]. The over reliability of these sensor nodes on batteries for energy is a major issue because these batteries cannot be replaced or recharged easily once they are deployed. Therefore, protocols for these kinds of networks must be designed in such a way that they are energy efficient in order to prolong the lifetime of the network.

Low Energy Adaptive Clustering Hierarchy (LEACH) was the first hierarchical cluster-based routing Protocol with clusters in WSNs to have been developed [4].

The main objective of this protocol was to minimize the energy consumption in sensor networks [13]. In LEACH, there is a Cluster Head (CH) for each cluster responsible for receiving data from normal sensor nodes (NSN), aggregating the data and forwarding it to the BS.

Energy heterogeneity is another key issue that merits attention [14] in wireless sensor networks. This happens when there is energy difference to some threshold between a sensor node and its neighbors [1]. In the case of heterogeneous wireless sensor networks, [12], developed an energy-efficient service discovery protocol. Here, nodes are identified with hardware identifiers, which are unique, along with capability grades. The sensor node with the highest capability grade becomes cluster head and collects and aggregates data from all sensor nodes in the cluster. With this scheme, it is easy to construct and maintain and it can adapt quickly to topological changes in sensor networks. A delay-constrained energy-efficient routing scheme in heterogeneous WSNs was presented by [22]. In addition to static sensor nodes in their case, mobile and static supper nodes can be used to support periodic and event-based reporting applications. Various types of data messages are supported by the algorithm. From its routing table, the source sensor node selects the best relay super node and sends the message to it. Generally, Cluster Heads are selected using an advanced algorithm based on the amount of remaining energy on CHs and the distance they are from the base station. There are two multi-hoping criteria proposed in this algorithm: distance-based multi-hoping and load-balancing-based multi-hoping. This gives rise to different energy levels in the network. It is on the basis of this kind of network that a modified algorithm called Servant-MODLEACH (S-MODLEACH) has been proposed. It is an enhancement of MODLEACH protocol in heterogeneous settings. The algorithm operates in a WSN under three level energy heterogeneity. Simulation results showed that, the proposed algorithm outperforms that of the MODLEACH in terms of throughput and network lifetime.

The rest of the work is organized as follows: Section 2 looks at a review of related works; Section 3 presents problem definition, while Radio Energy and Network Model is described in Section 4. Simulation results and analysis are discussed in Section 5 and conclusion is drawn in Section 6.

2. Related Works

In 2001, [11] introduced a new energy efficient protocol called TEEN (Threshold sensitive Energy Efficient sensor Network protocol) for re-active networks. The performance of the protocol was evaluated and was found to be limited to a simple temperature sensing application. In terms of energy efficiency, the protocol was seen to have outperformed existing conventional sensor network protocols.

[9], discussed a two-level (TL) hierarchy and realized a protocol that have a better energy consumption. TL-LEACH uses random rotation of local cluster base stations (primary cluster-heads and secondary cluster-heads). This allows better distribution of the energy load among the sensors in the network especially, when the density of network is higher. They evaluated the performances of their protocol with NS-2 and this protocol outperformed LEACH in terms of energy consumption and lifetime of the network.

[23], proposed the new Version LEACH (V-LEACH) protocol which improves the original LEACH protocol by selecting a backup-CH called the vice-CH which takes over the role of the CH in the event the CH dies/run out. When a CH dies/runs out, the cluster will become useless because all data gathered by sensors in the cluster will never reach the sink. So, in addition to electing CH, the vice-CH also chosen. By doing so, cluster nodes data will always reach the BS and therefore no need electing a new CH each time the CH runs out, and this will extend the life time of the network.

[17], proposed the modified R-LEACH protocol which allows an alternative node to get replaced in place of a node which loses its energy such that the entire network lifetime can be extended and avoid data loss. The Packet Delivery Ration (PDR) and energy levels have been found to be better than LEACH.

[21], presented the Stable Election Protocol (SEP) which gave a weighted probability that allowed each node the possibility of becoming a cluster head. [16], presented the Distributed Energy-Efficient Clustering scheme for heterogeneous wireless sensor networks called DEEC. In this scheme, the existing energy in the nodes is the election criteria for a node to become a cluster head. [1], proposed the Enhanced-SEP clustering algorithm in a three-tier node scenario to prolong the effective network life-time. Simulation results showed that the Enhanced-SEP achieves better performance in this respect, compared to other existing clustering algorithms in both heterogeneous and homogenous environments.

[19], described Leach-heterogeneous system which sought to compare the heterogeneous and homogeneous systems. They analyzed LEACH protocol which is a homogeneous system and then studied the impact of heterogeneity. Simulation results using MATLAB showed that the proposed Leach-heterogeneous system significantly reduced energy consumption and increased the total lifetime of the wireless sensor network.

[7], proposed Modified Enhanced Stable Election Based Routing Protocol for WSNs. The proposed protocol, which is an extension of the Enhanced Stable Election Protocol (ESEP), considered the residual energy and ensured maximum network lifetime.

[20], also evaluated some issues which have been left out in the field of WSNs and showed some comparison between homogeneous and heterogeneous protocols. In order to reduce the energy consumption of each clustering node and enhance the lifetime of the wireless sensor network, [18], proposed the LEACH protocol. In this case the base station chooses the cluster head directly. Tests results conducted showed that the proposed method proved to be more efficient than LEACH terms of lifetime of the network.[3], in their study, presented a model in which the selection procedure of cluster heads remains the same as in the case of ordinary Leach protocol. They however, divided the whole area of the network into a multiple rectangular distributed region. In each region, the authors applied the LEACH algorithm. As part of their study, [2], developed an intra-cluster multi-hop communication algorithm based on the LEACH protocol for multi-hop simulation of annealing (MhSA-LEACH). A Simulation Annealing (SA) algorithm was used to select intermediate nodes for multi-hop protocol using Traveling Salesman Problem (TSP). Based on the probability theory, multi-hop nodes are selected based on their shortest distance and can only be skipped once, resulting in a more optimal node path. In addition, the authors proposed an algorithm which was compared to the conventional LEACH protocol as well as the Multi-Hop Advanced Heterogeneity-aware Energy Efficient (MAHEE) clustering algorithm based on OMNeT++. The test results demonstrated that MHSA-LEACH can be optimized in terms of the number of packets received by BS or CH as well as the number of dead and alive nodes from LEACH and MAHEE protocols. A modified MODLEACH Protocol called Servant-MODLEACH in heterogeneous settings is presented in this paper. Three types of nodes are considered in this protocol with one node called the servant node assigned the responsibility of data aggregation to ease the work load of CHs. This idea is hatched in order to prolong the lifetime of the CHs and the network as a whole.

3. Problem Definition

LEACH forms the basis on which several cluster-based routing protocols have been developed. However, LEACH has some challenges; as a Single-hop communication used in this protocol design, and hence, cannot be deployed in networks that are spread over large distances. Also, Cluster Heads (CHs) are elected only on the basis of probability without taking into consideration the energy requirements and therefore LEACH tends not to provide the actual load balancing. In addition, CHs are elected in every round and this leads to re-clustering. The re-clustering process consumes a lot of energy. Finally, the same signals application is used in LEACH protocol irrespective of the type of communication and the given task.

MODLEACH is also a cluster-based algorithm that was proposed based on LEACH. It is a modification of LEACH build mainly on two points. Firstly, in MODLEACH, if the elected cluster head has more energy, it remains cluster head in the subsequence rounds [6]. Secondly, MODLEACH has not amplified all the signals to the same level as in the case of LEACH protocol. The signal amplification in this protocol depends on the type of communication such as inter cluster, intra cluster or cluster head to BS communications. This leads to reduction in energy consumption in the network. MODLEACH also has some challenges. Firstly, it allows the cluster heads alone to receive data from normal sensor nodes, aggregate the data and route it to the base station. These over burdens the cluster heads and as results deplete their energy at a faster rate. The CHs in the end die/run out leaving the data to be sent to BS wasted. Secondly, probability function is used in selecting the cluster head. This could allow weaker nodes to be selected as CHs which cannot transmit data successfully to BS.

4. S-MODLEACH: The Proposed Scheme

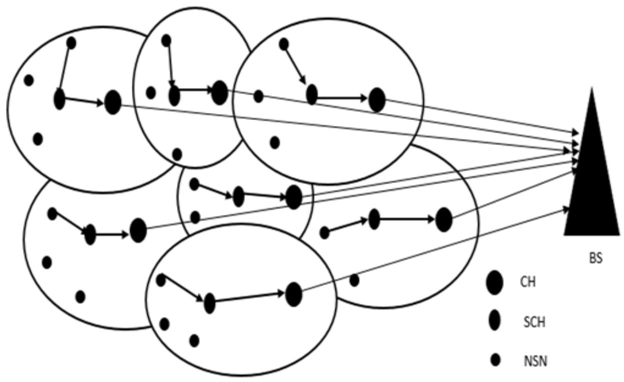

Figure 1. *S-MODLEACH Network.*

The proposed network model is made up of three types of nodes deployed uniformly in a square region, namely, normal nodes, servant nodes and advance nodes as shown in Figure 1. The selection probability of each node to become a CH is weighted by the initial energy of the node relative to that of the normal node in the network as explained by [1, 15]. It is assumed that each sensor node transmits sensing data to the BS through the selected servant nodes and selected cluster heads and all the CHs are selected periodically by different weighted probabilities.

MODLEACH challenges as explained in section 3 have been addressed by Servant–MODLEACH. Firstly, Servant-MODLEACH reduces the burden on the cluster heads by introducing special nodes called servant nodes. These special nodes are responsible for data aggregation. They receive data from the normal nodes, aggregate and transmit it to the CH.

The cluster heads then send the aggregated data straight to BS. This gives Servant-MODLEACH the advantage of being deployed in networks spread over long distance. Secondly, the proposed protocol selects CHs based on residual energy at all the three levels rather than relying on probability functions as in both LEACH and MODLEACH. In this case, the nodes with high residual energies are selected as cluster heads which are capable of sustaining the network energy requirement for a longer period. The servant nodes have their initial energies falling between the normal nodes and advance nodes; thus, making S-MODLEACH a suitable candidate for heterogeneous environment.

4. Cluster Formation

This is made up of the Setup Phase and Steady State Phase.

Setup Phase: The cluster heads selection process is similar to [1, 15]. Let m represent a percentage of the population of sensor nodes called advanced nodes which will be equipped with e times more energy resources than the normal sensor nodes in the network; and q is a fraction of the population of sensor nodes called servant nodes, which will be equipped with b times more energy resources than the normal sensor nodes in the network such that, the initial energy for normal nodes is E_0, advanced nodes, $E_{adv} = (1+e)E_0$ (1)

and servant nodes, $E_{svt} = (1+b)E_0$, (2)

where $b = a/2$. The total initial energy of the system is increased by the introduction of both advanced and servant nodes:

$$n.E_0\,(1-m-q)\ +n.m.E_0\,(1+e)\ +\ n.q.E_0\,(1+b) \quad (3)$$

Using the assumptions made by [1], the overall energy of the network is increased by a fraction of $1+am+bq$ and the new epoch of the system must be equaled to $1/P_{opt}\,(1+em+bq)$.

If we choose P_{nrm}, P_{svt} and P_{adv} for probabilities of becoming normal, servant and advanced nodes respectively, then we have them in Equations 4-6. Their respective thresholds are also given in Equations 7-9.

$$P_{nrm}) = \left(\frac{P_{opt}}{1+e*m}\right)*\frac{E_{(i)}}{E_0} \quad (4)$$

$$P_{svt}) = \left(\frac{P_{opt}(1+b)}{1+e*m}\right)*\frac{E_{(i)}}{E_0} \quad (5)$$

$$P_{adv}) = \left(\frac{P_{opt}(1+e)}{1+e*m}\right)*\frac{E_{(i)}}{E_0} \quad (6)$$

$E_{(i)}$: residua energy

$$T(n_{nrm}) = \begin{cases} \frac{P_{nrm}}{1-P_{nrm}(r \bmod (\frac{1}{P_{nrm}})} & if\ n_{nrm} \in G \\ 0\ otherwise \end{cases} \quad (7)$$

where G is the set of normal nodes that have not become cluster heads in the past $\frac{1}{P_{nrm}}$ round r

$$T(n_{svt}) = \begin{cases} \frac{P_{svt}}{1-P_{svt}(r \bmod (\frac{1}{P_{svt}})} & if\ n_{svt} \in G^1 \\ 0\ otherwise \end{cases} \quad (8)$$

where G^1 is the set of servant nodes that has not become cluster head in the past $\frac{1}{P_{svt}}$ round r

$$T(n_{adv}) = \begin{cases} \frac{P_{adv}}{1-P_{adv}(r \bmod (\frac{1}{P_{adv}})} & if\ n_{adv} \in G^{11} \\ 0\ otherwise \end{cases} \quad (9)$$

where G^{11} is the set of advanced nodes that have not become cluster heads in the past $\frac{1}{P_{adv}}$ round r.

Cluster heads follow a Time Division Multiple Access (TDMA) schedule to assign time slots for the sensor nodes inside the cluster as explained by [6].

Steady Phase

The sensor nodes send the sensed data to the corresponding Servant Cluster Heads (SCHs). The SCHs aggregate the data, remove redundancies and forward the data to their respective Cluster Heads (CHs), which then transmit the aggregated data to the base station.

The total energy dissipated by each cluster head is given by Equation (10);

$$E_{CH} = kE_{elect}(c1) + E_{TX}(k, d_{to\ BS}) \quad (10)$$

where $d_{to\ BS}$ is the distance from the cluster head to BS and $c1$ is the number of SCHs. As regards to the servant cluster head, the energy dissipated will be aggregated and transmitted as k bits of data to the respective cluster heads. So, the total energy dissipated by each Servant Cluster Head is given by Equation (11).

$$E_{SCH} = kE_{elect}\left(\frac{n}{c}-2\right) + \left(\frac{n}{c}-1\right)kE_{DA} + E_{TX}(k, d_{to\ CH}) \quad (11)$$

Where, $d_{to\ CH}$ is the distance from the Servant Cluster Head to cluster head.

The total energy dissipated by each non-cluster head is given by Equation (12)

$$E_{non-CH} = E_{TX}(k, d_{to\ SCH}) \quad (12)$$

The energy dissipated in a cluster per round can be calculated as in (13).

$$E_{cluster} \approx E_{CH} + E_{SCH} + \left(\frac{n}{c}\right)E_{non-CH} \quad (13)$$

Thus, the overall energy of the network is given in Equation (14).

$$E_{total} = c\,E_{cluster} \quad (14)$$

$$E_{total} = c(kE_{elect}\left(\frac{n}{c}-2\right) + \left(\frac{n}{c}-1\right)kE_{DA} + E_{TX}(k, d_{to\ CH}) + kE_{elect}(c) + E_{TX}(k, d_{to\ BS}) \quad (14)$$

The different amplification energies proposed by [10] for intra, inter and cluster head communication to BS have been implemented in this work and is given in Equation (15)

$$\begin{cases} kE_{elect} + k\frac{\epsilon_{sf}}{10}d^2, if\ d > d_1 \\ kE_{elect} + k\frac{\epsilon_{mp}}{10}d^4, if\ d \le d_1 \end{cases} \quad (15)$$

Simulation Results and Analysis

The S-MODLEACH algorithm is simulated using MATLAB R2017a. This is to set up a comparative analysis for MODLEACH and S-MODLEACH proposed in this work. In this experiment, 200 nodes are deployed in 200*200 region and the BS is placed (100, 250) away from the centre. Let us initialize the P_{opt} = 0.5 and assume that 20% of sensor nodes will be advanced nodes (m=0.2) and 20% servant nodes (q=0.2). Other parameters used are shown in Table 1.

Table 1. *Simulation Parameters.*

Parameter	Values
E_{elect}	50nJ/bit
E_{fs}	10pJ/bit/m²
E_{fs1}	$E_{fs}/10$
E_{mp}	0.0013pJ/bit/m²
E_{mp1}	$E_{mp}/10$
E_0	0.5J
k	4000
n	100
p_{out}	0.1
E_{DA}	5nJ/bit/message

Performance Criteria Used

The performance metrics used to study and evaluate the cluster-based routing protocols are:

Number of the alive/live nodes, number of the dead nodes, packet to the BS and packet to the CH.

These metrics can allow us to draw conclusion about the stability period of the network which is the time interval from the start of network operation until the death/run out of the first node; and the unstable period of the network is also defined as: the time interval from the death/run out of first node until the death of the last node. The Lifetime of the network is also the number of rounds made until the first node dies [21].

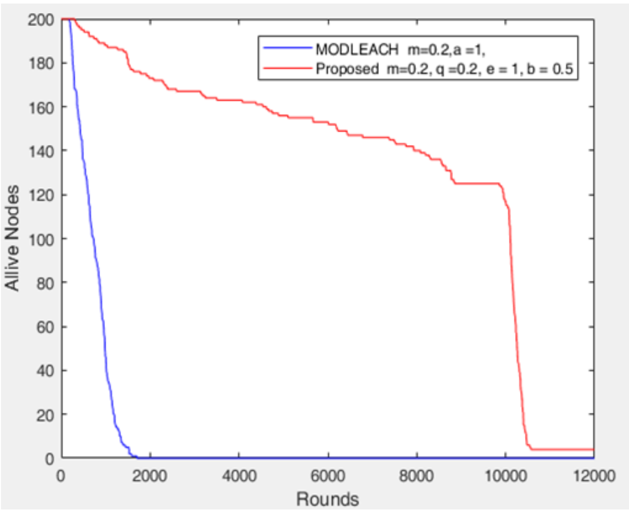

Figure 2. *Number of the Alive Nodes per Round.*

Figure 2 represents the simulation dynamics of the number of alive/live nodes during the lifetime of the network. Between 0 to 500 rounds, both MODLEACH and S-MODLEACH showed high number of alive nodes with S-MODLEACH showing slightly better stability. When the number of rounds increased slightly above 2000, no node was alive in MODLEACH protocol. S-MODLEACH on the other hand, has more than 160 alive nodes in 2000 rounds. Though the number of alive nodes decreases slightly as the rounds increase, it is able to maintain more than 120 alive nodes up to 9000 rounds and then eventually, ends up between 10000 and 12000 rounds. This clearly shows that by introducing the servant node concept into MODLEACH, it reduces the distance between the normal and advanced nodes; hence, more energy is conserved to sustain the nodes and the network.

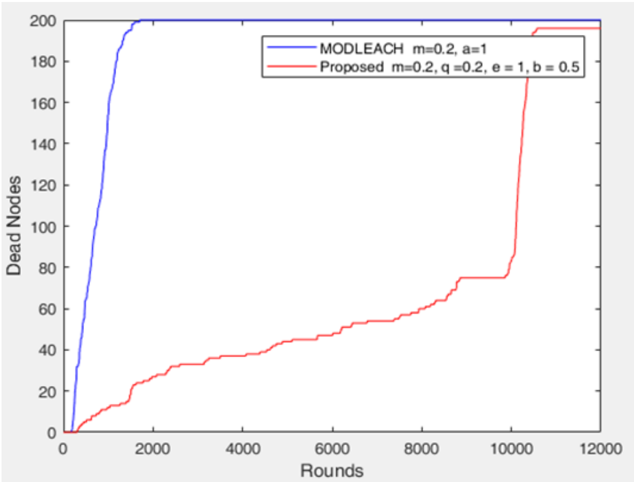

Figure 3. *Number of the Dead Nodes per Round.*

Figure 3 shows the number of dead nodes per rounds of the protocols. It is important for any energy efficient cluster-based routing to have low dead nodes per round as dead nodes mean loss of information from that region. In MODLEACH, the number of dead nodes increased at a faster rate and no surviving nodes existed after 2000 rounds. S-MODLEACH, on the other hand, reduces the death rate of the nodes until the last node died between 10000 and 12000 rounds.

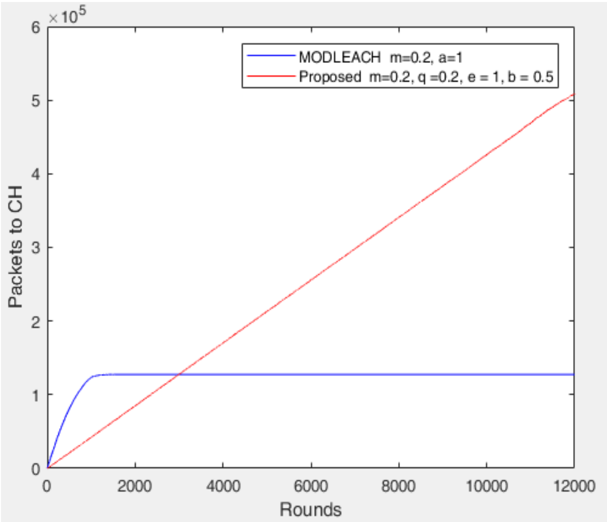

Figure 4. *Number of Packets to the BS per Round.*

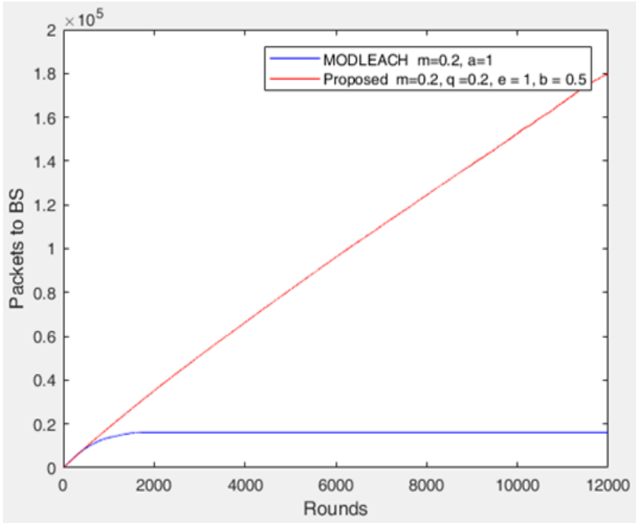

Figure 5. *Number of packets to the Cluster head.*

Figures 4 and 5 show the comparison between MODLEACH and S-MODLEACH in terms of number of data packets sent to the BS and cluster heads. The results showed that, after 1800 rounds, the MODLEACH protocol maintains the same amount/number of packets sent to the BS and also maintains the same amount/number of packets sent to the cluster heads. S-MODLEACH, on the other hand, increases lineally and moves beyond 10000 rounds for both the BS and the cluster head. It is clear that, S-MODLEACH sent more data to the BS and cluster heads than MODLEACH. This is due to the presence of servant nodes which have reduced the work load of CHs; and hence, CHs have enough energy to transmit and also implement different amplification energies.

5. Conclusion

In this paper, an improved MODLEACH algorithm in heterogeneous settings called S-MODLEACH has been proposed. Three levels of nodes were used in formulating the algorithm. In each level, nodes elected themselves as cluster heads based on their energy levels. Simulations were carried out and the results showed that S-MODLEACH outperformed MODLEACH in terms of throughputs and network lifetime. The proposed algorithm tended to reduce network energy consumption using active servant nodes. These nodes were assigned the responsibility of aggregating the data received. From normal nodes, which are mostly, assigned to cluster heads. This really gave cluster heads longer lifetime and the network as a whole. Also from the experiment, the position of the BS was moved far away from the field (100, 250) compared to that of MODLEACH (100,100) and this makes S-MODLEACH suitable for networks spread over a large coverage area. Further, dual transmitting power levels for inter, intra and cluster head to base station communications were implemented this really minimized the energy used within these clusters. Results further showed that there is optimisation of data packets received and reduction in dead notes and data loss.

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