OCEA-LEACH: An Optimal Cluster Energy Aware Centralized LEACH for Routing in Wireless Sensor Networks

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Abstract

Wireless Sensor Networks (WSNs) are the networks consisting of wireless sensors which transmit and receive information among each other. Such networks are useful in various fields like civil and military applications for security systems, fault detections, etc. Energy optimization is one of the major issues of WSNs to extend the lifetime of these networks. A number of clustering based algorithms like LEACH and SEP are already well known and are used to increase stability of the network. In this paper an effort has been done to propose a protocol, OCEA-LEACH, which is an improvement over LEACH in heterogeneous environment in which the randomized selection of clusters is tried to be centralized and to avoid the redundancy cluster heads tried to be kept well separated with in the region. So, unlike LEACH, cluster heads are chosen based on their available energies which results in better distribution of cluster heads within the region. Simulations results on MATLAB shows that OCEA-LEACH depicts better results than the existing protocols like LEACH and SEP.

Keywords

Wireless Sensor Networks, Stability Period, LEACH Protocol, SEP Protocol, OCEA-LEACH Protocol

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Introduction

Wireless sensor networks are the networks with wireless sensors distributed in a region which sense various types of information and then transmit this information to the other nodes or to the final destination. These nodes sense by the change in the physical parameters like – temperature, pressure, etc. The data sensed by these nodes are then passed to the Base Station (BS) for evaluation. WSNs are used for the variety of purposes like military surveillances, habitat monitoring, forest fire detections, landslide detections, etc. These nodes are small and wireless; they can be deployed with ease even in remote and hilly areas[6]. However, the monitoring of these nodes time by time is not an easy task because such nodes are deployed in high numbers and their sizes are also small[9]. The nodes have some battery life and the energy of the nodes keep on dissipating whenever they transmit or receive the information.

A number of routing protocols are already exists which guarantees the minimization of the energy dissipation in the wireless systems[7]. Since the nodes sense data and if they are present too near to each other than redundant data is transferred to the base station. Hence, the algorithms try to minimize the energy by avoiding transmission of the redundant information. To avoid such types of redundancies, clustering algorithms were proposed and LEACH[1] is one of the famous clustering algorithm. In clustering algorithms, the nodes present in the network are grouped into clusters and a cluster head is being assigned to each cluster. The main purpose of the cluster head is to aggregate the information send by its cluster nodes, and then transmit this aggregated information to the base station. Such types of clustering protocols can also be referred to as the hierarchical protocols. So, clustering helps in increasing the overall lifetime of the network[8]. In the propose protocol OCEA-LEACH, an effort has been done to make an improvement over the existing LEACH[1] protocol by centralizing the network in such a way that the network stability is improved. Simulation results on MATLAB shows that OCEA-LEACH give far more better results than the existing protocols like LEACH[1] and SEP[2]. Numbers of experiment have been performed on MATLAB and comparison has been done on the basis of stability period and energy utilization of the system.

The rest of the paper is organized as follows: Section 2 describes the related works in the field of wireless sensor routing protocols. Section 3 will show the energy model that has been used in the proposed protocol. Section 4, explains the OCEA-LEACH protocol and its two phases. Section 5 compares simulation results of the proposed OCEA-LEACH protocol with the existing LEACH and SEP routing protocol. Finally, section 6 depicts the conclusion and the future works for further improvement in the proposed protocol.

Related Work

A lot of research has been done for better utilization of the energy of the wireless system. The main motive of all the existing protocols is to minimize the energy dissipation during routing. The various protocols are proposed and which could be classified as hierarchical, data centric, location based and Network flow protocols. In this paper, work has been done on the hierarchical protocols. In such protocols, the clusters are formed and the cluster heads are assigned. The cluster heads aggregate the data from their respective clusters and then transmit this data to the Base Station either directly or through the hierarchy of other cluster heads.

The existing hierarchy protocols are:

1. Low Energy Adaptive Clustering Hierarchy (LEACH)

It is one the most popular hierarchical algorithm. In leach, the clusters are formed on the basis of the signal strength of the sensors. In LEACH, out of the total number of existing nodes, some of the nodes are randomly chosen as the cluster heads. A node is chosen to be the cluster head if its random value comes out to be less than the threshold value T(n) where T(n) is given by –

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

P is the percentage of cluster heads, r is the r^{th} round, and G is the set of nodes which are not cluster heads in the last 1/P rounds.

Whenever, a cluster head is chosen, the CH broadcasts its advertisement to in the entire region and the nodes which are receiving better signal strength will associate themselves to be with this Cluster Head. In such a way, the clusters are formed and organized.

Cluster heads (CH) perform a lot more work and dissipate energy more quickly than the non-CH nodes. So, instead of assigning the role of the CH to the same node always, the role of the CHs is equally distributed among all the nodes present in the network. Hence, CHs keep on rotating with each round. A node which had become the CH in the current round will not get an opportunity to become the CH again before a set interval of time.

Figure 1 below shows how clusters are formed in 100*100 region in one round. The same cluster can be identified with nodes having same symbol. The cluster heads are shown in red. Base Station (or sink) is situated at (50, 50) and is shown by X.

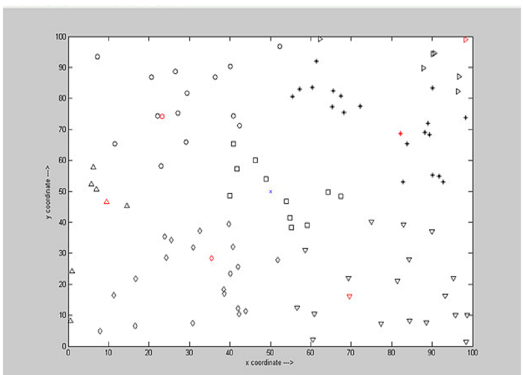

Figure 1. Distribution of nodes and formation of clusters

When LEACH is compared to the direct transmission, it yields 7 times more reduction in energy dissipation. It also gives 4-8 times reduction than in energy dissipation when compared to existing MTE routing protocol. However, instead of better stability period and efficient utilization of energy, LEACH has some drawbacks[1]. One of the drawbacks is that the LEACH is single hop routing protocol. Each node transmits data to one node only. Each normal node transmits information to either CH or BS directly.

Moreover, if network size is increased, the dynamic clustering may become overhead because of energy dissipations due to advertisements of CHs at every round. In LEACH, the number of clusters formed is random. Sometimes, very small number of clusters and sometimes very large number of clusters is obtained. The results have shown that the energy is most efficiently utilized at a particular number of clusters only. LEACH does not guarantee that the optimum number of clusters is formed at each and every round.

2. SEP (Stable Election Protocol)

SEP[2] was an improvement over LEACH in such a way that it took into account the heterogeneity of the networks. In SEP, two types of nodes are assumed - normal nodes and advanced nodes. Advanced nodes are considered to have more energies than the normal nodes. So, SEP improves the protocol by assigning high probability to the advanced nodes to become the cluster heads. SEP is a two –tier clustering protocol.

3. LEACH-C protocol

LEACH-C[3,4] is the modification of LEACH and is a centralized protocol. In LEACH-C, BS has the right to select the clusters upon the annealing algorithm to find k optimal number of clusters. BS also selects CHs for a particular round. The protocol results in optimal clusters but there is an extra overhead of sending information about the current location and residual energy to the sink during the set up phase.

4. LEACH-F protocol

LEACH-F is fixed cluster LEACH. In LEACH-F, once the optimal clusters are identified, the clusters formed are fixed and not changed with rounds. However, the role of CHs is distributed in each round within the same cluster. No set-up overhead is required in each round in LEACH-F. The centralized cluster algorithm is same as LEACH-C but unlike LEACH-C, this algorithm runs only once before the commencement of first round. However, the disadvantage is that the algorithm is static. The protocol does not allow change in the network size because if the network size is varied, the fixed clusters would be required to change. Moreover, adding new nodes in the existing network also requires change in the fixed clusters.

5. PEGASIS

PEGASIS[5], which is an extension of LEACH, does not allow formation of multiple clusters. It only allow sensor nodes to transmit and receive nodes to their neighbor nodes only. Hence, the information is passed to the base station by the formation of the chain. Only one node that is near to the BS is selected to pass the data to the BS. The chain is selected based upon the annealing algorithm. It is the near chain optimal cluster. There are also further developments in PEGASIS like Hierarchical PEGASIS and Energy Balancing PEGASIS.

Energy Model Analysis

The energy dissipation model as used in the proposed protocol is shown below. Each sensor node consists of a transmitter and receiver having some transmitter and receiver electronics. Energy is dissipated when nodes transmit and receive data.

When the sensor node transmit k-bit data by its transmitter, the energy dissipation is –

$$E_T(k,d) = \begin{cases} (E_{elec} * k) + (E_{fs} * k * d^2) & \text{if } d \leq d_0 \\ (E_{elec} * k) + (E_{mp} * k * d^4) & \text{if } d > d_0 \end{cases} \tag{2}$$

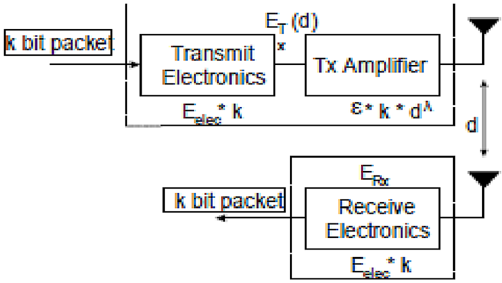

Figure 2. Energy dissipation diagram

- Eelec is the energy dissipated to run the electronics circuits
- k is the packet size
- Efs and Emp are the characteristics of the transmitter amplifier
- d is the distance between the two communicating ends.

When the sensor node receives k-bit data packet, the energy dissipation is –

$$E_R(k) = E_{elec} * k \tag{3}$$

The radio characteristics and energy due to electronics are –

$$E_{elec} = 50 \text{ nJ/bit}$$
$$E_{fs} = 10 \text{ pJ/bit/m}^2$$
$$E_{mp} = 0.0013 \text{ pJ/bit/m}^4$$

In addition to above energy dissipations, CHs also dissipates energy in data aggregation. The data aggregation energy EDA has the value of 5nJ/bit/signal.

An Optimal Cluster Energy Aware Centralized LEACH (OCEA-LEACH)

LEACH does not guarantee formation of optimal number of clusters at each round. The cluster heads and hence, clusters formed in LEACH protocol are randomly chosen. Neither very less nor very large number of clusters are required to have a stable network. The number of clusters always has an optimal value at which the network is most stable. It is found from the study of[3] that the optimal value of clusters is given by –

$$k_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}} \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \frac{M}{d^2_{toBS}}. \tag{4}$$

Where, N is the number of nodes, M is the length of the region.

LEACH does not allow that optimum clusters are formed at each round and is not centralized. In OCEA-LEACH, an effort has been done to centralize the LEACH protocol in such a way that in every round more or less optimal numbers of clusters are formed.

In addition to this, in the proposed protocol the criterion of selection of cluster heads at each round has been changed. In OCEA-LEACH, BS has the authority to select the optimum number of CHs. Unlike LEACH, The CHs selected are not random but are chosen depending upon the available energies of the nodes. In other words, out of the total number of nodes, those nodes which have maximum energies available have a higher priority to become the CHs. So, the CHs are chosen as evenly as possible which can only be achieved if at each round BS is aware of the available energy of each and every node. Moreover, in OCEA-LEACH, whenever the CHs are chosen by the BS, it is also verified that no two CHs lie too close to each other. The CHs have to be separated by a certain favorable distance d.

In OCEA-LEACH, we have assumed three phases –

A. Pre-setup phase

This phase takes place at the start of the system before the commencement of the first round. In this phase, all the nodes send their respective energies, positions and ID directly to the base station. In addition to this it has been assumed that each node is capable of calculating its own position using modern GPS systems. After receiving the information from each node, BS broadcasts positions and IDs of all the nodes in the entire system. Each node now has the information about other nodes of the system.

B. Setup Phase

The setup phase takes place at the beginning of each round. At the start of the each round, BS has the knowledge of available energies of all the nodes. So, BS sorts the available energies of the nodes present in the system and then choose ‘k’ number of nodes to become the cluster heads. The nodes chosen are the nodes with maximum available energies. k can be chosen in such a way that the minimum energy is dissipated(in that case, k=kopt). The value of k may vary depending upon the network size and degree of heterogeneity of the nodes. It can also be noted here that an increase in the value of k results in better data quality and a decrease in value of k results in better energy optimization with the expense of some data quality. Hence, the proposed protocol is flexible enough to maintain a tradeoff between the data quality and energy optimization depending upon the type of application in which the protocol is used. The BS advertises the cluster head IDs in whole network and the nodes whose own ID matches with the ID sent by the BS, that node elects itself to be the cluster head. Now, each node has the information about the CHs selected and the distance with these CHs. Now, each node selects its CH by choosing that CH which is at the minimum distance from it. Hence, there is no need of the advertisement of CH ids by the CHs.

In addition of above criteria of selection of CHs, BS does not allow CHs to lie too close to each other. BS assures that two CHs must be separated by a favorable distance d to eliminate further redundancy of the information. It is found from the experiments that the optimal value of d depends upon the network size and the total number of nodes. A large value of d also results in reduction of the number of clusters formed.

Calculation of d: Consider a square region of dimension M and suppose k number of clusters is to be formed in the region. Then –

$$(M * M)/k = \pi * d * d \tag{5}$$

From the above equation, r comes out to be –

$$d = \sqrt{(M * M)/(k * \pi)} \tag{6}$$

As an example, if we consider M=100 and k=kopt=2, then d comes out to be 39. It means that if the cluster separation, d =39, then an average two clusters are formed in the region, which results in minimum energy dissipation.

C. Steady State Phase

In this phase, actual dissipation of energy takes place. The data is transmitted, received and aggregated by various nodes. The data sensed by the nodes is transferred to the CHs or to the BS, whichever is close. The duration of this phase is more as compared to the steady state phase to minimize overhead. The energy dissipation [1] due to CH is given by

$$E(CH) = E_T(k, d_{to\,BS}) + E_R(k) + E_{DA} \tag{7}$$

here k is the packet size. The energy dissipation due to non-CH node is given by –

$$E(non\text{-}CH) = E_T(k, d_{to\,CH}) + E_R(k) \tag{8}$$

In OCEA-LEACH, it has been considered that BS has the knowledge of the available energy of each and every node. However, transmission of the energy by a node directly to the BS is not feasible. So, whenever a node transmits data to the CH, it also transmits its available energy to the CH. Now, CH transmits the aggregated data of its cluster nodes and ID and available energy of all the nodes (without aggregation) to the BS. In the proposed protocol additional bits have been appended which represents the available energy of the nodes.

BS is considered to have infinitesimal energy and never runs out of energy. So, no energy is dissipated when BS transmits or receives data.

NOTE: The energies received by the BS in the r^{th} round are the energies of the nodes at the starting of $r\text{-}1^{th}$ round hence in r^{th} round the BS sorts the energies of $r\text{-}1^{th}$ round.

Simulation Results

Numbers of Experiments have been carried out on MATLAB and comparison of OCEA-LEACH has been done with the existing protocols like LEACH and SEP with the same experimental setup. Simulation results depict that OCEA-LEACH has more stability period and higher energy utilization than the existing LEACH and SEP protocol.

A. Network Settings

For Simulation, a 100*100 region has been used for the deployment of 100 nodes. The fraction of advanced nodes are taken to be 0.2, hence number of advanced nodes is 20. The parameter values used for simulation are shown in table 1.

The performance is compared on the basis of following parameters –

(i) Stability Period is the period (or round) up to which all nodes are alive. This period lies from first round up to the round of first dead node.

(ii) Amount of data received at the BS.

(iii) Energy dissipation of the system.

Figure 3 shows how clusters are formed for minimum energy dissipation in 100*100 network. The red node symbolizes the CH for the respective cluster. The nodes with square shape do not belong to any cluster and are sending their data directly to the BS. This is due to the fact that their distance from the BS is less as compare to any of the CHs.

Table 1. Values of parameters for simulation

Parameter	Value
Eelec	50 nJ/bit
Efs	10 pJ/bit/m^2
Emp	0.0013 pJ/bit/m^4
EDA	5 nJ/bit/packet
E0	0.5 J
No. of bits	4000 bits (LEACH,SEP) 4100 bits (OCEA-LEACH)
Kopt	2
N	100
A	1
M	0.2
D	40
Network size	100*100
Base Station Location	(50,50)

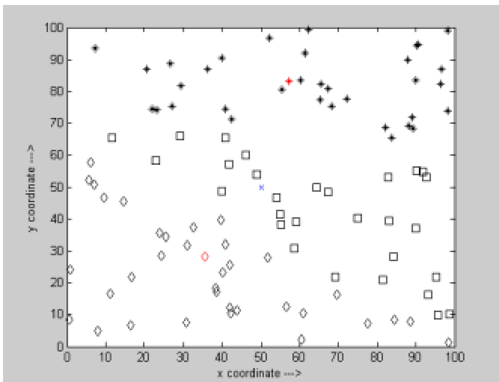

Figure 3. Formation of cluster in OCEA-LEACH in which minimum energy is dissipated.

Figure 4 below shows the improvement in the stability period of OCEA-LEACH when compared to LEACH and SEP. The percentage improvement of OCEA—LEACH over LEACH is 48.3% and that over SEP is 38.9%.

The Table 1 compares the first dead node of each of the protocols:

Table 2. Improvement of stable region

	LEACH	SEP	OCEA-LEACH	Improvement over SEP
First Node Dies	1042	1113	1546	38.9%

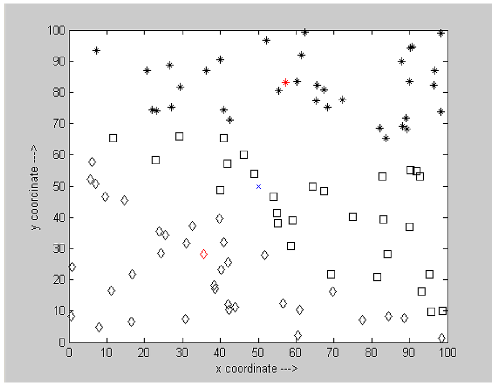

Figure 4. Plot of stability period for m=0.2 and a=1. Blue (LEACH), Red (SEP), Green (OCEA-LEACH)

Figure 5 shows the number of clusters formed by the BS vs length of stable region. From the figure, it is clear that the system is more stable when kopt=2 .

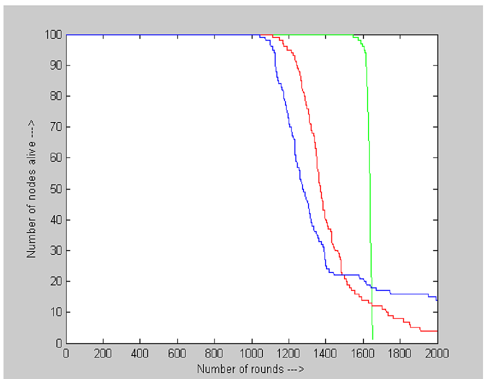

Figure 5. Change in stable region as the number of clusters varies

Figure 6 shows the comparison on the basis of the total energy remaining in the system with the number of rounds. From the figure, it is clear that after a given number of rounds, OCEA-LEACH has more energy of the system as compared to LEACH and SEP.

Figure 7 shows the information received at the base station with time. It can be concluded from the graph that after a given number of rounds, in OCEA-LEACH, BS receives a large number of packets as compared to LEACH and SEP. This large improvement is mainly due to the fact that in this protocol nodes closer to each other can send their data directly.

From the simulation, following results are obtained:

(i) The stability period shows a major improvement over the existing protocols.

(ii) Cluster Heads are chosen as evenly as possible and clusters are formed in such a way that the energy utilization is higher.

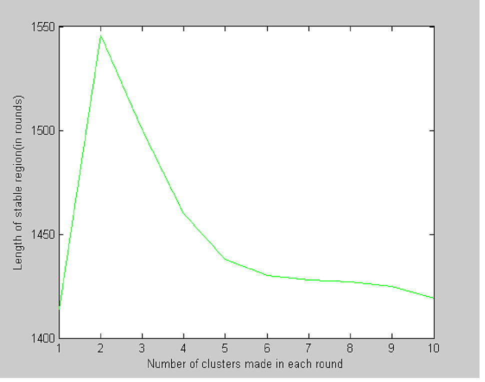

Figure 6. Dissipation of total energy of the system with the number of rounds. Blue (LEACH), Red (SEP), Green (OCEA-LEACH)

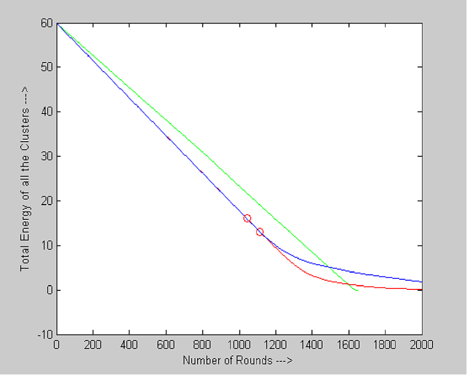

Figure 7. Packets received at the base station with time

(iii) The information received at the BS is increased considerably with time.

Conclusion and Future Works

OCEA-LEACH is a hierarchical cluster based technique in which random selection of cluster heads is ruled out. The concept of threshold T(n) is not present in this protocol. Instead, the CHs are chosen by BS based upon the available energies of the nodes in the network. The protocol ensures best possible way in which the CHs can be chosen in a given network. There is an extra overhead in OCEA-LEACH to aware the BS about the available energies of the nodes at each round, however, even after considering this extra overhead; OCEA-LEACH is able to give best results as proved in simulations.

In this paper, experiments have been carried out in a fixed network size with the same level of heterogeneity. In future work, we will try to change the level of the heterogeneity and the number of clusters formed in the network and then examines the change in stability period.

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