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Improved Cluster Head Selection For Energy Efficiency In Wireless Sensor Networks

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ABSTRACT:- *Energy is one of the most important resources in wireless sensor networks (WSNs) that should be used as efficiently as possible. A number of clustering-based algorithms such as LEACH (Low-Energy Adaptive Clustering Hierarchy), DEEC (Distributed Energy Efficient Clustering), and SEP (Stable Election Protocol) are proposed to increase stability period of WSNs. Formation of clusters and selection of cluster heads are very crucial tasks in clustering-based schemes and this paper proposes energy saving improvements to these tasks. To do this, optimal number of clusters are used and cluster heads are selected based on residual energies and distances. It is shown via simulations that the proposed protocol has better network stability period, network lifetime, energy consumption, and throughput compared to other well-known protocols including LEACH, DEEC, and SEP.*

Keywords*:- Clustering, Energy efficiency, Residual energy, Routing protocol, Wireless sensor network.*

I. INTRODUCTION

Wireless sensor networks (WSNs) are spatially distributed autonomous sensors that are deployed for environmental sensing, health care monitoring, military surveillance, and so on. The WSN consists of sensors (nodes) that collect information from their surroundings and route them to a sink or base station (BS). One of the important challenges in the design of these networks is the limited energy of sensors. Therefore, prudent techniques should be investigated to use the available energy efficiently. No matter the application, it is always desirable to have a WSN that remains effective (alive) as long as possible. Typically, rechecking the batteries of sensor nodes is not feasible due to several reasons (too many nodes, hostile environment etc.).

To extend lifetime of WSNs, clustering-based approaches are adopted in previous studies in the literature. In these studies, cluster heads (CHs) are selected according to: random probability without considering energy consumptions of nodes; maximum residual energy; location of nodes and distance vectors. An optimal construction of clusters is very important issue. It is now well-known that if clusters are not constructed in an optimal way, the total consumed energy of the network per round increases exponentially.

In some of previous studies, energy consumption ofaWSN is calculated during the transmission of one frame only [1] or during a single round [2]. Thus, they do not reflect the true energy consumption of the network. Moreover, they do not consider effects of forming clusters and of the number of cluster heads in the energy consumption of a network. In order to determine the true energy consumption of a network, the long run of a network should be considered.

Moreover, establishing distance limits in WSNs is of great significance [3, 4]: *i*) If the distance is too low, then each node would be associated with a small number of neighbors. In this case, the node is more likely to be selected as a CH. This yields a large number of CHs in the network which may cause collisions and redundancy.*ii*) If the distance is too high, then each node would be associated with many neighborsand the probability of the node being a CH is very less. These arguments show that the optimal number of CHs is greatly influenced by the distance between nodes and the BS.

This paper takes the above mentioned aspects into consideration in the design of the proposed routing protocol. That is, we present a new clustering-based protocol that employs a cost function based on the residual energy, distance information between nodes and the base station, and the optimal number of cluster heads. We evaluate the effectiveness of the proposed protocol through simulations and show that the proposed protocol has better network stability period, network lifetime, energy consumption, and throughput compared to other well-known clustering-based protocols including LEACH (Low-Energy Adaptive Clustering Hierarchy), DEEC (Distributed Energy Efficient Clustering), and SEP (Stable Election Protocol).

The paper is organized as follows. In Section 2, the previous work on the subject is summarized. The system model is introduced and the proposed protocol is presented in Section 3. The performance of the proposed protocol is evaluated through simulations via MATLAB in Section 4. Some concluding remarks are given in Section 5.

II. RELATED WORK

Clustering in WSNs was first considered in [5] referred to as LEACH. This protocol uses a distributed cluster formation technique enabling self-organization of large numbers of nodes, algorithms for adapting clusters, and rotating cluster head positions to evenly distribute the energy load among all nodes in the network. Nonetheless this algorithm has some shortcomings: *i*) If network size increases, implementing the dynamic clustering may become prohibitively arduous. *ii*) The number of clusters to be formed is random. Sometimes a small number of and sometimes a large number of clusters are formed. In other words, LEACH does not guarantee that the optimal number of clusters are formed at each and every round. Modified Rumor [6], TEEN (Threshold Energy Efficient Network) [7], and PEGASIS (Power Efficient Gathering in Sensor Information Systems) [8] are other well-known clustering-based algorithms which also do not value the optimal number of clusters. On the other hand, [9] considers the optimal number of clusters in networks with mobile base station in which the BS travels very close to the CH resulting insignificant path loss. In LEACH-G [10], the optimal number of cluster heads is determined based on the energy model of LEACH algorithm. In OCEA (Optimal Cluster Energy Aware) [11], cluster heads are chosen based on their available energies. In [12], the optimal number of clusters is determined by means of a Fuzzy c-Means (FCM) clustering approach.

Table I compares several clustering-based schemes proposed for homogenous and heterogeneous WSNs with respect to their cluster head selection process. As seen from the table, most of the studies take at most two parameters into account in the CH selection.

TABLE I. Comparison of CH selection in WSN protocols

Clustering approach	**Clustering metho**	**CH selection based on**		
		Initial Energy	**Residual Energy**	**Average Energy of Network**
EEHC [16]	Distributed	☐	√	☐
DEBC [16]	Distributed	☐	√	√
WEP [16]	Distributed	√	☐	☐
DEEC [16]	Distributed	☐	√	√
DDEEC [16]	Distributed	√	√	☐
SDEEC [16]	Distributed	√	√	☐
TDEEC [16]	Distributed	☐	√	☐
DCHE [16]	Distributed	√	☐	☐
LEACH [5]	Prob/random	☐	☐	☐
SEP [14]	Distributed	☐	√	√

III. SYSTEM MODEL

In this study, we use a radio energy dissipation model given in Figure 1. Here, L-bit data packets are transmitted to a receiver (Rx) located at a distance d from the transmitter (Tx). E_{elec} is the amount of energy needed in Tx or Rx hardware to send or receive data. Due to path loss and multipath fading phenomena that occur in wireless channels, Tx is equipped with an amplifier. The amplifier has a gain of $\varepsilon L d^{\alpha}$ where α denotes the path loss exponent, ε is the amplifier energy, and L denotes the packet size. Note that the value of the path loss exponent is between 2 and 4 in general.

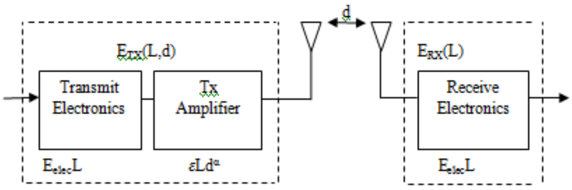

Figure 1. Radio Energy Dissipation Model [5].

To transmit L-bit message to a distance d, the energy dissipated at the Tx is given by

$$E_{Tx}(L,d)=\begin{cases} LE_{elec}+L\varepsilon_{fs}d^{2}, & d\le d_{0} \\ LE_{elec}+L\varepsilon_{mp}d^{4}, & d\ge d_{0} \end{cases} \quad (1)$$

where ε_{fs} is the amplifier energy per bit per square meter (m^2) when free space model is used for the channel $(d_0 \le d)$ and ε_{mp} is the amplifier energy per bit per m^4 when multipath propagation model is used $(d_0 \ge d)$ for the channel. The threshold distance d_0 determining whether the free space model or the multipath propagation model is used for the channel is given by [5]:

$$d_{0}=\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \quad (2)$$

and is set to 87m in this study. Similarly, the energy needed to receive L-bit data packet at the Rx:

$$E_{Rx}=LE_{elec} \quad (3)$$

Since transmitting and receiving messages are costly operations in wireless channels, protocols used in WSNs should try to minimize not only the transmit distances but also the number of transmit and receive operations for each message. In the following, we first present optimal clustering approach and then introduce our proposed protocol.

A. Optimal Clustering

Suppose that N nodes are uniformly distributed over a square field (D x D). The square field has an area of D^2 square meters and the BS is located at the center of the field for simplicity. The field is divided into K sub regions, clusters. For each cluster, one node is assigned as the cluster head. During transmission, each non-cluster head (non-CH) node sends L-bit data to the CH node within its cluster. Thus, the energy used by a non-CH node is [13]:

$$E_{non-CH}=LE_{elec}+L\varepsilon_{fs}d_{CH}^{2} \quad (4)$$

where d_{CH} is the average distance between a cluster member and its corresponding CH given by [14]:

$$d_{CH}^{2}=\frac{D^{2}}{2\pi K} \quad (5)$$

In (4), the free space model is used for the channel due to the intra-cluster communication.Similarly, the energy dissipated in a CH is given by

$$E_{CH}=\left(\frac{N}{K}-1\right)LE_{elec}+\frac{N}{K}LE_{DA}+LE_{elec}+L\varepsilon_{fs}d_{BS}^{2} \quad (6)$$

where E_{DA} is the data aggregation processing cost and d_{BS} is the average distance between a CH and the BS given by [13]:

$$d_{BS}=0.765\frac{D}{2} \quad (7)$$

The total energy dissipated during one round is:

$$E_{round}=L(2NE_{elec}+NE_{DA}+\varepsilon_{fs}(Kd_{BS}^{2}+Nd_{CH}^{2})) \quad (8)$$

If E_{round} is known, the average residual energy at the r^{th} round is estimated as

$$\bar{E}_r = \frac{E_{total} - rE_{round}}{N} \tag{9}$$

where $E_{total} = \sum_{i=1}^{N} E_i$ is the initial energy of the network and E_i is the energy of node *i*. By differentiating E_{round} with respect to K and equating to zero, the optimal number of clusters is found to be [13], [14]:

$$K_{opt} = \sqrt{\frac{N}{2\pi}}\frac{D}{d_{BS}} = \sqrt{\frac{N}{2\pi}}\frac{2}{0.765} \tag{10}$$

If a significant percentage of nodes are farther away from the BS (a distance greater than d_0), then the optimal number of clusters is given by

$$K_{opt} = \sqrt{\frac{N}{2\pi}}\sqrt{\frac{\varepsilon_{fs}D}{\varepsilon_{mp}d_{BS}^2}} \tag{11}$$

B. Proposed Protocol

Like LEACH, our proposed protocol also consists of two phases (1) Setup Phase and (2) Steady Phase. During the Setup Phase, the BS broadcasts a message at a certain power containing its identification information. This message makes each node aware of the BS. The BS decides the number of and optimal size of clusters depending upon the size of a network area and density of nodes. The BS then sends control packets to each node informing about the protocol to be used. These control packets consist of all necessary information required for steady state workings of the protocol including threshold energy value for a CH change, TDMA slots for intra-cluster communication, CDMA code for communication with the BS along with node identities. This also makes eachnode aware of the other members of its cluster, current round CH, CH rotation sequence, sleep and wake-up patterns to reduce collision and to save energy. Threshold energy is defined as the least amount of energy of a CH node.LEACH is an iterative algorithm and each iteration in the algorithm is called a round. In LEACH, during the Setup Phase, each node generates a random number between 0 and 1. If this random number is less than a specific value, the threshold value T(s), then the node becomes a CH for that round. The threshold value is chosen as:

$$T(s) = \begin{cases} \dfrac{p}{1 - p\left[r \bmod \left(\dfrac{1}{p}\right)\right]}, & \text{if } s \in G \\ 0 \quad , & \text{otherwise} \end{cases} \tag{12}$$

where p is the desired percentage of CHs among all nodes, r is the current round number, G is a set of sensor nodes that have not been selected as CHs in the last (1/p) rounds, and s is the current CH node.

The cluster head selection strategy of LEACH ignores the residual energy information, distance from the base station and does not guarantee the optimal number of clusters. This paper takes these aspects into consideration to ensure an even energy load distribution over the network by means of improving the cluster head selection process. Specifically, we adjust the threshold T(s) in (12) to include residual energy, distance information and to enforce the expected number of clusters per round to be K_{opt}.

Energy dissipation due to transmission through the channel is remarkably affected by the distance and the network lifetime is strongly related to nodes' residual energy levels. Besides, cluster heads consume more energy than other nodes in the network. To prolong the lifetime of a network, energy consumptions of all nodes must be balanced. Thus, we employ the following cost function

$$C(i) = \frac{d(i)}{E(i)}K_{opt} \tag{13}$$

The motivations of the new cost function (13) are given in the following:

- $d(i)$ is the distance from node *i* to the BS. This factor checks whether the node to be selected as cluster head belongs to the density popular area as well as the distance from the node to the BS is minimum.
- $E(i)$ is the residual energy accounting for whether the node to be selected as cluster head has maximum residual energy.
- K_{opt} is the optimal number of cluster heads. This factor guarantees the selection of cluster heads of each round is optimal.

With this new cost function, we claim that cluster head selection process is done in a very energy efficient manner. Considering all three factors, the modified threshold T(n) becomes:

$$T(n) = \begin{cases} \dfrac{p}{1 - p\left(r \bmod \left(\dfrac{1}{p}\right)\right)} C(i) & \text{, if } n \in G \\ 0 & \text{, otherwise} \end{cases} \qquad (14)$$

where p is the cluster head probability, r is the current round number and G is the set of nodes that have not been cluster heads in the last 1/p rounds. In order to select cluster heads, each node n determines a random number between 0 and 1. If the number is less than the threshold T(n), the node becomes a cluster head for the current round. Using this threshold, each node will get a chance to be cluster head that have not been cluster-heads in the last 1/p rounds. Thus, the new approach selects the optimized node as cluster head node which has minimal cost function in terms of the above mentioned three factors.

IV. SIMULATION RESULTS

The performance of the proposed clustering-based protocol is evaluated using MATLAB for heterogeneous networks. In the network, 100 nodes are randomly deployed in a 100m x 100m region where the BS is located at the center as illustrated in Figure 2.

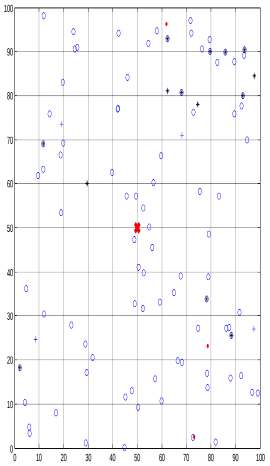

Figure2. An illustration of the network

The performance evaluation of the proposed network is done with respect to the following parameters:

Stability period**:** The time interval between the start of the network operation and the death of the first sensor node also known as stable region.

Instability period**:** The time interval between the death of the first sensor node and of the last sensor node.

Network lifetime**:** The time interval between the start of the network operation and the death of the last sensor node.

Number of alive nodes**:** The number of sensor nodes that have not yet depleted their energy.

Number of dead nodes**:** The number of sensor nodes that have consumed all of their energy and are not able to do any kind of functionality.

Throughput**:** The rate of data sent from cluster heads to the base station.

The proposed algorithm is compared with LEACH, DEEC, and SEP in terms of dead and alive nodes per round, energy consumption of the network, and overall throughput. The total number of rounds used in our experiments is 5000 and network model parameters are summarized in Table II.

TABLEII: Network model parameters

Parameter name	**Value**
E_0	0.5 J
Packet size	4000 bits
Number of nodes	100
$E_{tx} = E_{rx}$	50 nJ/bit
E_{fs}	10 pJ/bits/m^2
E_{mp}	0.0013 pJ/bits/m^2
E_{DA}	5 nJ
Area of network	100*100

Here all nodes have different amount of initial energies. The initial energies are uniformly distributed on [0.5, 1] resulting the average initial energy of 0.75 J. Several experiments are conducted and the average stability periods are calculated. Figure 3 and Figure 4 show the number of dead nodes per round indicating stability time of the networks. The death of the first node occurs at the round 1869 in the proposed protocol whereas the death of the first node occurs at rounds 1036, 1382, 1482 in LEACH, DEEC, and SEP respectively.The death of the last node occurs at the round 3707 in the proposed protocol whereas the death of the last node occurs at rounds 2626, 2691, 2047in LEACH, DEEC and SEP respectively. Hence, the proposed protocol has better stability time and network lifetime as compared to the other protocols considered.

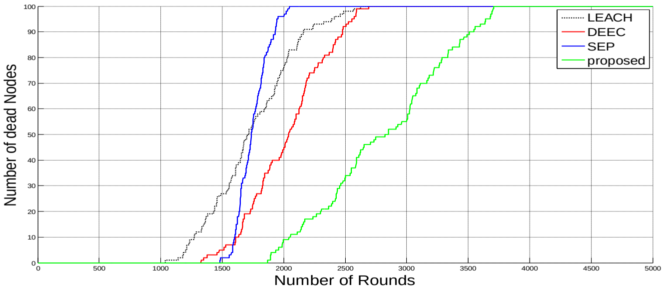

Figure 3. Number of dead nodes per round

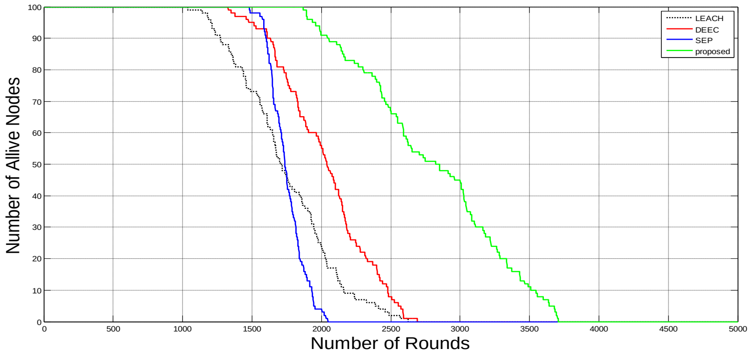

Figure 4.Total number of live nodes in each round

The proposed protocol has also better energy consumption and higher throughput than the other protocols considered which can be seen from the Figure 5 and Figure 6. Initial energy E_0 of the network is consumed at the round 3600 in the proposed protocol whereas the initial energy E_0 of the network is consumed at rounds 2300, 2350, 2100 in LEACH, DEEC and SEP respectively (Figure 5). Similarly, Figure 6 shows the superiority of the proposed algorithm in terms of the throughput thanks to the wiser selection of CHs.

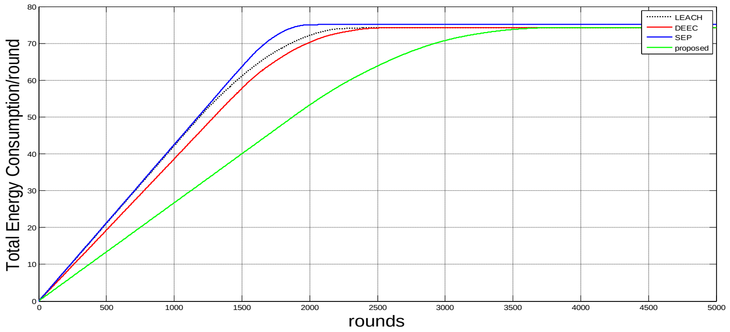

Figure 5. Energy consumption

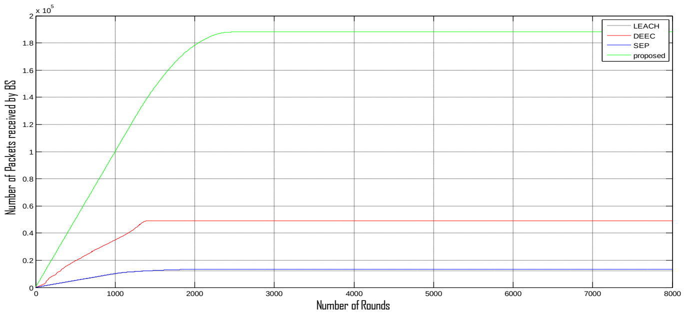

Figure 6. Throughput

V. Conclusions

This paper presents a new clustering-based protocol for heterogeneous WSNs. Heterogeneity of the network comes from nodes with different energy levels. The lifetime and reliability of the network can be improved by heterogeneity. Further, a single-hop transmission approach is adopted for intra-cluster and inter-cluster communication.

Formation of clusters and selection of cluster heads are very important tasks in clustering-based schemes affecting energy efficiency of the network. CHs require more energy than other nodes in the network because they perform processing, sensing, communication and aggregation. Hence, they die earlier and if so, the entire network becomes useless. We propose an optimized routing scheme where the main focus is to enhance cluster head selection process. CHs are selected in each cluster on the basis of residual node energy and the distance with respect to the optimal number of cluster heads. From the conducted experiments, it is seen that:
Stability period of the network is enhanced compared to the other well-known clustering-based protocols including LEACH, DEEC and SEP. Superior network lifetime is obtained for different scenarios. Last but not least, the throughput of the proposed protocol is significantly better than the other protocols considered. Thus, the proposed protocol improves energy efficiency of the network and prolongs the network lifetime.

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