# EECP-EI: Energy-Efficient Clustering Protocol based on Energy Intervals for Wireless Sensor Networks

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## ABSTRACT

Wireless Sensor Network is comprised of sensor nodes with a limited energy supply in the form of built-in batteries. Efficient utilization of limited energy supply of sensor nodes is one of the key design issues in wireless sensor networks. Hence, energy efficiency needs to be enhanced to prolong the stability and lifetime of WSN. In this paper, we propose Energy-Efficient Clustering Protocol based on Energy Intervals (EECP-EI) for multi-level WSN. EECP-EI associates sensor nodes to clusters based on energy intervals. The cluster heads are selected based on average energy of certain energy interval and the total estimated energy of network at a particular round. The role of cluster head is rotated within the cluster to evenly distribute the energy among sensor nodes inside the cluster. The sensed data is aggregated at the cluster head to reduce the amount of data that needs to be communicated to the base station. The sensed data is communicated to the base station using hierarchy of cluster heads that are in ten-meter distance to the sending cluster head. When the cluster formation no longer remains optimal, every sensor node in the network transmits data directly to the base station. Simulations show that EECP-EI shows the improved stability period of 37.08%, 36.37%, and 19.39%, and the improved network lifetime of 6.58%, 13.13%, and 32.15% as compared to LEACH, DEEC, and DDEEC respectively.

## CCS CONCEPTS

• **Networks → Network protocol design**.

## KEYWORDS

Wireless Sensor Network, Routing Protocols, Stability, Lifetime, EECP-EI

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## 1 INTRODUCTION

Wireless Sensor Network (WSN) is comprised of hundreds or thousands of sensor nodes having limited energy resources, communication bandwidth and computational capabilities. These nodes are designed to monitor environment using sensor subsystem in the sensor module of a sensor nodes. Whenever a WSN detects an event, the information is transmitted to the base station with the help of routing mechanisms. Hence, the routing mechanisms should minimize the energy consumption and maximize the lifetime of network. There are many military and commercial applications of WSN like battlefield surveillance and wildlife monitoring. Furthermore, WSN can be used to detect and diagnose faults in inaccessible areas like hazardous and rotating machinery. Sensor nodes consumes more energy during data transmission as compared to the computational operations [1] and [2]. Since the batteries in sensor nodes is difficult to replace in real time situations, there is an increased demand in routing mechanisms that can efficiently utilize the limited energy resources of sensor nodes [3] and [4]. Energy-efficient routing mechanisms need to ensure the minimum utilization of limited energy resources of sensor nodes, and hence extending the stability and lifetime of the network [5]. One of the main challenges with existing routing protocols is that they bring extra overhead because of their dynamic clustering technique.

One of the main challenges with existing routing protocols is that they bring extra overhead because of their dynamic clustering technique [6] have been proposed for WSNs. In DT mechanism, all sensor nodes directly transmit the sensed data to the base station. The sensor nodes that are far away from the base station will drain much faster in comparison to sensor nodes that are closer to the base station [7-10]. In a multi-hop MTE routing mechanism, the sensor nodes transmit data to the base station using intermediate nodes. Therefore, the sensor nodes closer to the base station drain quickly than those which are away from the base station [11]. Various energy-efficient routing mechanisms based on clustering are proposed in literature [12-15]. In clustering structure, the sensor nodes in WSN are organized in different clusters. The number of sensor nodes in each cluster is dependent on the underlying WSN protocol. The sensor node in a cluster with high residual energy takes the responsibility of performing the cluster-head (CH) operations. The data is aggregated at the CH in each cluster which in turn is transmitted to the base station through a hierarchy of cluster heads. However, the conventional clustering-based routing mechanisms requires the CH?s to be high energy nodes and assumes them to be fixed. Also, they do not optimally rotate the responsibility of CH among other sensor nodes in clusters. This results in uneven load distribution among sensor nodes in clusters, and hence does not prolong the network lifetime.

In this paper, we propose and evaluate an energy-efficient routing protocol that increases the stability, lifetime, and overall energy consumption of WSN. The protocol randomly organizes the sensor nodes in a hierarchy of clusters based on energy intervals. The energy intervals are defined based on calculated energy ranges. The formation of cluster heads is randomized and optimal. The optimal CH selection is based on the average energy of the energy interval and the total estimated energy of the network at particular round. The proposed protocol follows the hierarchical path using CHs that are near to the sending CH for routing the data to the base station. This path is followed if the clusters and CH formation is optimal. When the clusters and CHs formation is not optimal, all the sensor nodes use DT routing mechanism. The proposed protocol significantly improves the stability, network lifetime, and overall energy consumption of WSN. The simulation results show that the proposed protocol outperforms the existing clustering-based schemes such as LEACH [12], SEP [13], DEEC [14], and DDEEC [15].

The remaining of the paper is organized as follows: In section 2, the related work in clustering-based routing protocols for WSNs is presented. In section 3, the detail of EECP-EI routing mechanism is presented. In section 4, performance evaluation of EECP-EI routing mechanism by simulations and its comparison to LEACH, SEP, DEEC, and DDEEC is presented. In section 5, the conclusion of this paper is presented.

## 2 RELATED WORK

ATo efficiently consume the limited energy resources of sensor nodes and to alleviate the deficiencies of classical clustering schemes, various adaptive energy-efficient clustering-based routing protocols are proposed. The Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol [12] is a self-organizing and adaptive clustering protocol. The LEACH protocol selects cluster heads periodically and based on probability. A fixed percentage of sensor nodes that are uniformly distributed inside the WSN field acts as cluster heads in each round. It randomly rotates the role of cluster head among sensor nodes in the network that uniformly drains the energy. Although the energy balancing problem is resolved in LEACH by CH rotation, the energy consumption issue in intra-clusters transmission is not addressed [16]. LEACH performs well in homogeneous WSN setting but performs very badly in heterogeneous WSN setting as depicted in [13].

PEGASIS) [17] is an optimal chain-based routing protocol. Each sensor node transmits its data to the nearest neighboring node that acts as relay nodes to transmit the data to the base station. PEGASIS is an improvement of LEACH routing protocol and is specially designed for homogeneous nodes which are randomly distributed in an area with fixed BS position. In PEGASIS, sensor nodes are organized in such a way that they form optimal chains for data transmission using greedy algorithm. The BS computes the chains and broadcasts it to all the sensor nodes. Chains are reconstructed when some sensor nodes die in the later rounds of the data transmission. The distances between sensor nodes is less in PEGASIS as compared to the distances between normal sensor nodes and CHs in LEACH. In PEGASIS, the aggregation of data is performed at each sensor node in the chain except the last node. However, each sensor node in PEGASIS must have the global knowledge of the network which results in more transmissions from sensor nodes and hence more energy depletion. Also, the reconstruction of chains is a time-consuming process and may not gather the complete information of the last node because data fusion is not performed at the last node of the chain.

The Stable Election Protocol (SEP) [13] is proposed for two-level heterogeneous network, which is composed of advance sensor nodes and normal sensor nodes. The advance sensor nodes are high energy nodes as compared to normal sensor nodes at the beginning. SEP uses dynamic clustering approach, and the cluster heads are selected based on weighted election probability. However, the selection of cluster heads between the two types of sensor nodes is not dynamic. Although SEP prolongs the stability period of the network, but it is not suitable for widely used multi-level heterogeneous networks.

The Distributed Energy-Efficient Clustering (DEEC) algorithm is proposed in [14] for multi-level heterogeneous network. The DEEC protocol selects the cluster heads by comparing the residual energy of the sensor node and the average energy of the network. Different epochs are used for CH selection and is based on the initial and residual energy of sensor nodes. The sensor node with high energy has greater chance to become CH as compared to sensor nodes with low energy. However, when the residual energy of advance sensor nodes and normal sensor nodes becomes same, the advanced sensor nodes die rapidly as compared to the normal sensor nodes because of the extra responsibility of acting as the cluster heads.

Developed distributed Energy-efficient clustering for heterogeneous WSNs developed in [15] uses dynamic CH selection probability to reduce the energy consumption of constrained sensor nodes in WSN. DDEEC is an improvement of DEEC routing protocol where the selection of cluster head is based on the ratio of residual energy of each node and average energy of the network. In DDEEC, sensor nodes are randomly distributed, and their position is static while base station is placed at the center of the network. CHs are selected based on residual energy of each node and estimated average energy of the network as in DEEC. However, there is no condition to control the number of CHs per rounds or restrict the number of CHs in a specific region.

## 3 ENERGY-EFFICIENT CLUSTERING PROTOCOL BASED ON ENERGY INTERVALS

The efficient energy utilization is directly related to the stability period and the lifetime of the network. The increase in stability period of a protocol for wireless sensor networks will make it more concrete and versatile, especially in critical environments such as energy, banking, and transport. The EECP-EI protocol is designed for use in multi-level heterogeneous WSN and includes the following modules: (3.1) network configuration, (3.2) the formation of energy range, (3.3) energy interval configuration, (3.4) the probability of election, (3.5) estimating the average energy of the network, (3.6) random selection of CHs, (3.7) optimal selection of CHs, (3.8) first order radio model, (3.9) the association of nodes with CHs and

(3.10) data transmission and scheduling. The detailed description of all the protocol modules are provided in detail as follows:

## 3.1 Network Configuration

The proposed protocol randomly assigns energies to the nodes in a close set $[Eo, Eo(1+a_i)]$, where $a_i$ is the randomly selected number between 1 and 0 for every node and ?Eo? is the initial energy. The sensor nodes also have a unique node ID which is used to differentiate one node from another and to keep record of individual information of a node. For example, we can access the distance between a node and BS or CH, the initial energy of a node, the residual energy of a node, and the probability of election of a node using the node ID.

## 3.2 The Formation of Energy Range

After assigning the sensor nodes with initial energy, the base station finds the highest energy node in the network. The base station then randomly generates a set containing the random number of nodes with low energy in the network. The base station uses the high-energy node with low energy nodes in the set to find the energy ranges i.e., Erange. The energy range is defined as the difference between the high-energy node and low energy node. The energy ranges are calculated using eq. 1. The energy of sensor nodes reduces as the network proceeds, so the energy range will also reduce with the passage of time.

$$E_{range} = N_{HE} * N_{LE}\% \tag{1}$$

Where $N_{HE}$is high-energy resource in form of base station and therefore energy consumed by BS is not considered, whereas $N_{LE}$ is the number of low-energy nodes in a set generated by BS.

## 3.3 Energy Interval Configuration

After the calculation of Erange, energy interval configuration phase categorizes the whole network into equal energy intervals. The energy intervals are defined using eq. 2. These categorizations of nodes will drastically increase the life time and stability period of the network because of systematic monitoring of nodes.

$$E_{interval}(i) = [E_{range} * i, E_{range} * (i+1)] \tag{2}$$

Where $i$ is, the index used for creating required number of energy intervals.
residual energies of all sensor nodes for every energy interval. The total residual energy of every energy interval is considered as a reference energy for calculating the average energy of energy interval. Consider a sample scenario having an energy interval $E_{interval}(7) = [0.7to0.8]$ with $x$ number of nodes that have residual energy between 0.7 and 0.8. The BS will sum all the residual energies to find out the average residual energy for the given interval. The average residual energy of certain energy interval will be used to calculate the probability of election of all the nodes that are present in that particular interval. Hence, the greater the average residual energy of an energy interval, the higher is the chance for the sensor nodes in the energy interval to serve as CH.

## 3.4 The Probability of Election

Probability of election is the possibility of a node to elect itself as a CH. This module separately determines the probability for each node by taking the average residual energy of an interval instead of residual energy of a node as proposed in DEEC [13].

$$p(i,j) = \{\frac{P_{opt} N(1+a_i)\overline{E_{interval_j}}(r)}{(N + \sum_1^N a_i)\overline{E}(r)}\} \tag{3}$$

Equation 3 computes the probability for the $i^{th}$node lies in the $j^{th}$ energy interval, where $\overline{E_{interval_j}}$ is the average residual energy of the $j^{th}$ interval and $\overline{E}(r))$ is the estimated average energy of the $r^{th}$ round. $P_{opt}$ is the optimal probability which is taken as 0.1 and $a_i$ is the random number between 0 and 1 which tells us that a node gain $a_i$ times more energy than Eo.

## 3.5 Estimating the Average Energy of Network

It is challenging to develop a scheme in which each node knows the average energy of the network at each round. Equation. 4 demonstrate the need of $\overline{E}(r))$ for the calculation of probability of election, hence, by making an estimation we will determine the average energy at the $r_{th}$round using eq. 4. We assume that the energy of the network uniformly distributes, and by applying uniform probability distribution we will find out the average energy at each round.

$$\overline{E}(r) = \frac{E_t(1 - \frac{r}{R})}{N} \tag{4}$$

Where R is the total number of rounds for network lifetime, r is the rotating epoch, N is the number of sensor nodes in wireless sensor network, and $E_t$ is the total energy of the network.

## 3.6 Random Selection of CHs

In this phase the nodes elect themselves as a CH by choosing a random number (rnd) between (0, 1) and compare it with threshold value Th. Now there are two possibilities as follows:

(1) Possibility 1 ($rnd > Th$): Node cannot be selected as a CH and treated as a normal node.
(2) Possibility 2 ($rnd \leq Th$): Node is selected as a CH, and now it belongs to candidate set of CHs, after every $\frac{1}{p(i,j)}$ rounds it will be eligible again for the CH selection, where i is node number and j is the relevant interval.

We have slightly changed the threshold function of LEACH protocol [12] by introducing the residual energy of sensor node i.e., E(i) in the threshold function in eq. 5.

$$Th(i,j) = \frac{p(i,j)}{1 - E(i)(r \mod \frac{1}{p(i,j)})} \tag{5}$$

Each node has its own threshold value based upon its probability of election p(i,j) and residual energy. The modified threshold function results into a positive increase in the stability period of the network up to few hundred rounds.

## 3.7 First Order Radio Model

3.7 First Order Radio Model The proposed protocol follows the first order radio model to find out the energy dissipated while sending a b bit message over a distance d. The transmitter and receiver energy consumption of radio resource is computed using eq. 6 and eq. 7. Eelec is the energy consumed per bit during transmitting or receiving process, $\epsilon fs$ and $\epsilon mp$ are two types of amplifier types, d is the distance between the transmitter and receiver while do is known as reference or threshold distance ($do = \sqrt{\frac{\epsilon fs}{\epsilon mp}}$)

$$Etx(k,d) = \begin{cases} k.Eelec + b.\epsilon fs.d^2 & \text{if } d < \text{do} \\ k.Eelec + b.\epsilon mp.d^4 & \text{if } d \geq \text{ do} \end{cases} \quad (6)$$

$$Erx = b.Eelec \quad (7)$$

Where Etx is the transmission energy and Erx is the receiving energy.

### 3.8 Optimal Selection of CHs

The random selection of CHs based on the threshold that is used in [11-14] cannot effectively monitor and cover the whole network field. Therefore, we must include the signal strength factor during the optimal CH selection. Signal strength between sender and receiver is directly related to the distance between them. It is observed that better lifetime, stability and throughput can be achieved when CHs selected inside the network belongs to different energy intervals. All the CHs lie at a distance of 10 meters or more from other CHs as shown in Fig. 1. In other words, there will be no other CH under the area of $\pi 10^2$ meter square of a particular CH. Moreover, each CH will provide coverage to an area of approximately $\pi(CRadius)^2$, where CRadius is the radius of a cluster as shown in Fig. 2. The optimal selection of CHs results into a high stability period because excess use of CHs may increase the burden on the energy resource of the network.

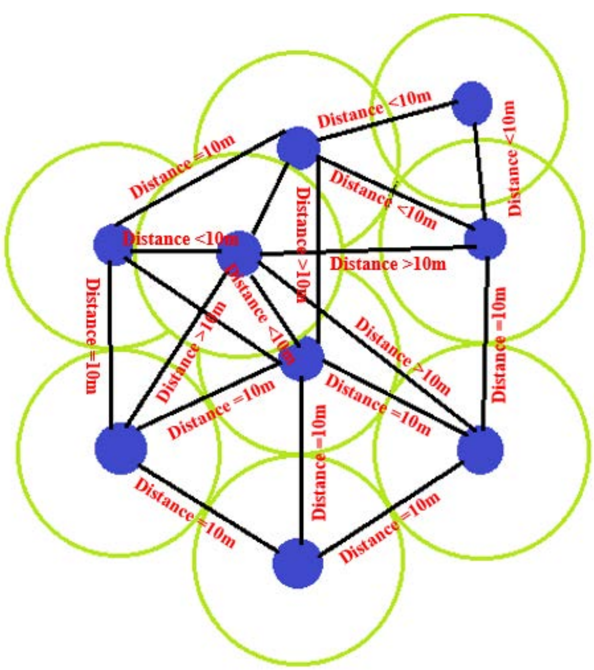


**Figure 1: Random Selection of CHs**

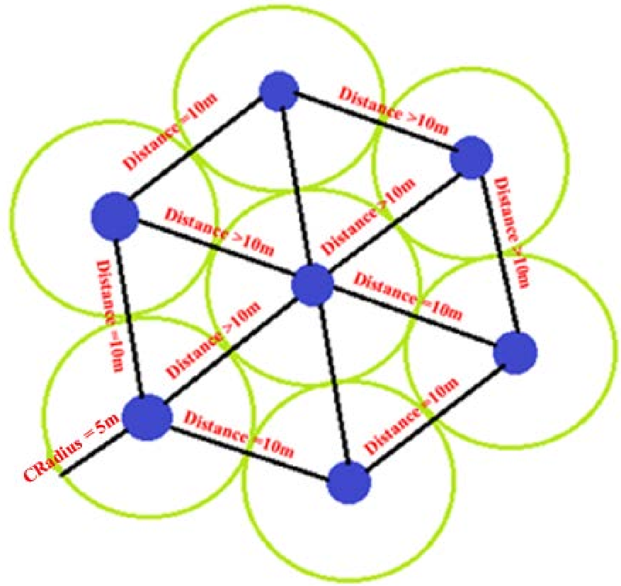


**Figure 2: Final Selection of CHs**

### 3.9 The Association of Nodes with CHs

After the optimal selection of CHs, cluster setup phase starts in which nodes are associated with the CHs based on the received signal strength. All the CHs will broadcast a message to all the nodes through BS to inform them that they are CHs for a particular round. The received signal strength from CH is directly proportional to the distance between a node and CH. Each node will find out the CH with the strongest signal strength, then it will send a message to that CH to associate itself. This process is repeated for all active nodes in every round.

### 3.10 Data Transmission and Scheduling

Both BS and CHs should receive a lot of packets from cluster heads and non-cluster heads, all this type of transmission cannot be carried out without any proper scheduling scheme. In real time scenarios, we assume that all non-cluster heads and cluster heads always have data to send. The proposed protocol uses Time Division Multiple Access (TDMA) scheduling technique in which each CH and BS transmit their sensed data in their allocated time slots. BS will receive data from CHs and nodes and CHs will receive data only from non-CHs. These transmissions minimize the energy consumption by clustering and data scheduling. The sensor nodes only transmit in their allocated TDMA slot while CH is always assumed to be ready for receiving the data from non-CHs. After collecting all the data, CH will further process the data to transform it into a single composite signal, called as data fusion or aggregation. These high energies fused signals are then sent to BS. When all the transmissions end then the next round starts from the network configuration phase.

# 4 PERFORMANCE EVALUATION

The performance of proposed protocols in compared with the other well-known routing protocols such as LEACH [12], SEP [13], DEEC [14], and DDEEC [15]. We consider static nodes and the two-dimensional plane. There are 100 nodes that are randomly deployed in an area of $(100x100)m^2$ with randomly allocated limited energy resource, i.e. based on random number $a_i$ in a range of $[Eo, Eo(1 + ai)]$ for EECP-EI, LEACH [12], DEEC [14] and DDEEC [15] while for SEP [13] we use $m = 0.2$ and $a = 1$ (initially m fraction of total number of nodes having 'a' times more energy than normal nodes with Eo initial energy). When nodes use all their initial energy, then they are considered as dead and are unable to take part in any operation. During packets propagation, the effect of channel intrusion is ignored. Some of the packets can?t reach the destination due to broken communication links. To compensate such packet drops, we used uniform random distribution. The uniform random distribution approach gives a probability of 0.3 for each packet to drop. Hence, the communication link status is 30% bad and 70% good. The radio parameters used in our protocol are given in Table 1. The energy efficient Protocols in WSNs are evaluated based on following metrics:

- Stability Period of Network: It is the duration for which the network continues its operation until the depletion of the first sensor node in the network.
- Network Life-Time: It is the duration for which the network continues its operation until the depletion of the last sensor node in the network.
- The Number of Packets sent to BS: It is the number of packets sent to the BS either from CHs or normal sensor nodes.
- The Number of Packets dropped: It is the number of packets that don?t reach BS and are dropped somewhere during transmission.
- Throughput: It is the number of packets that successfully reach BS in per unit time.

This section has the following modules: (4.1) The number of alive nodes per round, (4.2) Energy consumed per round, (4.3) The number of packets sent to BS, (4.4) The number of CHs per round, and (4.5) The number of packets dropped. The detailed description of each module is presented as follows:

**Table 1: Radio Parameters**

| Symbol | Operation | Energy Dissipated |
|---|---|---|
| Etx | Transmitting Energy | 50nJ/bit |
| Erx | Receiving Energy | 50nJ/bit |
| EDA | Data Aggregation | 05nJ/bit /message |
| Efs | Transmit Amplifier | 10pJ/bit/m2 |
| Emp | | 0.0013pJ/bit/m4 |
| Msg | Message Size | 4000bits |

## 4.1 The Number of Alive Nodes per Round

The simulation results of the number of alive nodes per rounds evaluates three basic metrics of a protocol i.e., stability period, unstability period, and network life-time. Figure 3 shows that the stability period and network life-time of EECP-EI protocol is increased by 37.08% and 6.58%, 36.37% and 13.13%, and 19.39% and 32.15%, as compared to LEACH [12], DEEC [14], and DEEC [15] respectively. Furthermore, the creation of energy intervals and optimal selection of cluster heads in EECP-EI has significantly increased stability and life-time of the network compared to SEP [13]. This means that EECP-EI treats all the nodes with discrimination taking in to consideration the difference in their initial energies. Also, EECP-EI considers the residual energy pertaining to certain energy interval and the total estimated energy of the network at particular round instead of initial energy and the residual energy used by the techniques evaluated here.

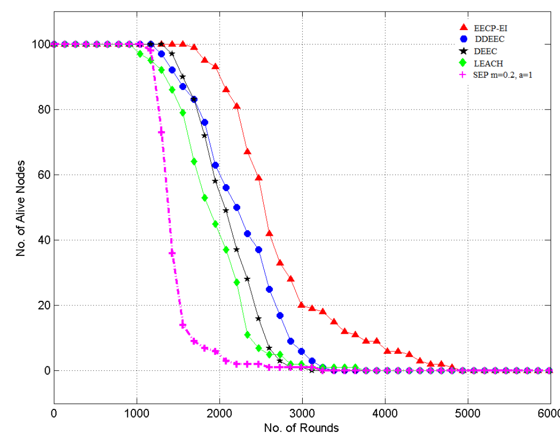


**Figure 3: No. of Alive Nodes per Round**

## 4.2 Energy Consumed per Round

The simulation results of energy consumed per round in Fig. 4 demonstrate the balance of energy dissipated in each round. It is clear from the results that EECP-EI is consuming less energy in the beginning, leading to the higher stability period. However, this higher stability doesn?t lead to poor network lifetime as is the case in LEACH [12], DEEC [14], and DDEEC [15]. The SEP protocol [13] consumes high energy in the beginning, but it exhausts energy in no time.

## 4.3 The Number of Packets Sent to BS

The number of packets sent to BS demonstrate the reliability of the protocol, if a protocol is sending a greater number of packets then obviously, it has greater life-time. Moreover, a protocol with greater lifetime can remain in touch with BS for greater extent. The EECP-EI protocol has the maximum number of packets to the BS than any other protocol. EECP-EI protocol shows 66.67% improvement in packets sending to BS as compared to DDEEC [15]. Moreover, 75.93%, 92.60% and 93.33% improvement are measured while simulating in comparison to DEEC [14], LEACH [12] and SEP [13] respectively as shown in Fig. 5.

The number of packets sent to BS is always less than the number of packets received at BS (throughput) as shown in Fig. 6 due to

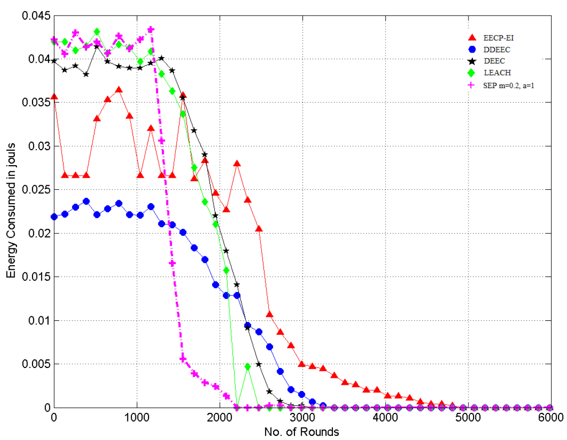


**Figure 4: Energy Consumed per Round**

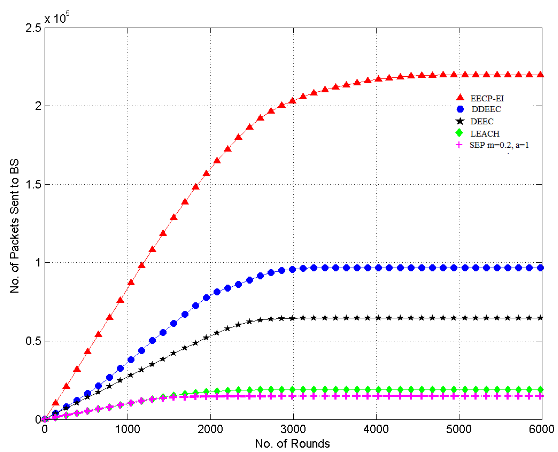


**Figure 5: No. of Packets Sent to BS**

Signal to Noise Ratio (SNR). To avoid signal interference and to achieve an acceptable level of SNR, the time scheduling algorithm is used in our EECP-EI protocol.

## 4.4 The Number of CHs per Round

The excessive use of CHs results in smaller life-time of the network. The simulation results in the Fig. 7 show that DDEEC protocol [15] achieves the highest number of CHs per round. More CHs implies that more network energy will be consumed because of CHs extra responsibilities of data fusion within the cluster and transmitting aggregated data to the base station. In EECP-EI, although the number of CHs sometimes are below one, the use of hybrid technique in our EECP-EI makes it possible to communicate the required data to the base station.

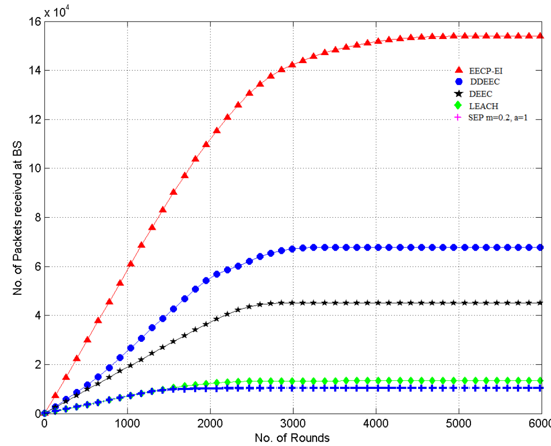


**Figure 6: Packets Received at BS**

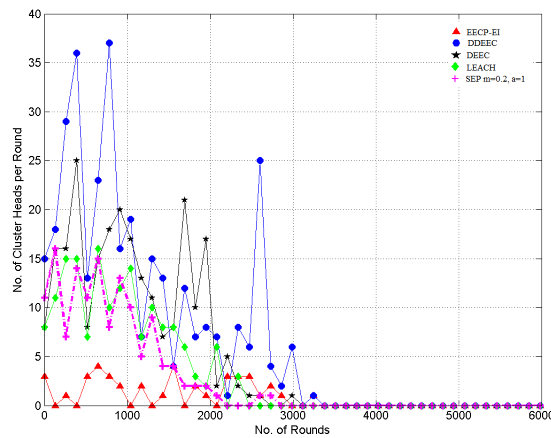


**Figure 7: No. of CHs per Round**

## 4.5 Packets Dropped

The possibility of packet loss is always present due to various factors such as noise, sudden link drop and the overloaded link to name a few. The average number of packets dropped (per fifty rounds) is shown in Fig. 8. Simulation results show the higher packet drop for EECP-EI as compared to LEACH [12], SEP [13], DEEC [14], and DDEEC [15]. This is because of the enhanced network lifetime of EECP-EI that makes it possible for EECP-EI to deliver more messages, and hence the higher packet drops. We considered 0.3 as the packet drop probability and calculated it by applying uniform random distribution.

Table 2 presents the comparison of the proposed scheme with existing schemes for stability, network life time and throughput.

# 5 CONCLUSION

In this paper, an energy efficient clustering protocol based on energy intervals (EECP-EI) is proposed and evaluated for wireless

**Table 2: Radio Parameters**

| Scheme | Stability (No. Of Rounds) | Network Lifetime (No. Of Rounds) | Throughput (No. Of Packets) |
|---|---|---|---|
| EECP-EI | 1433 | 51433 | 14.7 x $10^4$ |
| DDEEC | 1233 | 3399 | 6.9x $10^4$ |
| DEEC | 1333 | 3166 | 4.6 x $10^4$ |
| LEACH | 866 | 3733 | 1.2 x$10^4$ |
| SEP | 1099 | 3204 | 0.9 x $10^4$ |

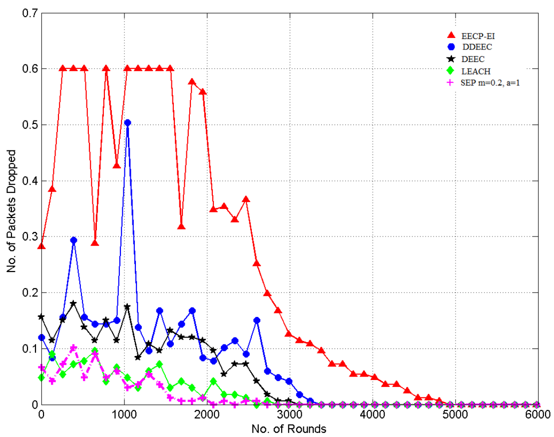


**Figure 8: No. of Packets Dropped per Round**

sensor networks. In EECP-EI, the sensor nodes are associated to clusters based on energy intervals. The residual energy of sensor nodes inside the cluster of certain energy interval is considered for the selection of cluster head in the cluster. The role of cluster head is rotated among the sensor nodes inside the cluster to evenly distribute the load among all the sensor nodes in a cluster. The estimated average energy of the network is considered as a reference energy and the data is aggregated at the cluster head to reduce the amount of information that needs to be communicated to the base station. EECP-EI uses hybrid technique for sending the data from the cluster head to the base station. When the cluster formation and cluster head selection is optimal, our protocol sends the data to the cluster head that is not more than 10 meters far from the cluster head. However, when the cluster head selection no longer remains optimal, every sensor node in the network transmit sensed data to the base station directly. Simulation results show that EECP-EI significantly improves the stability and network lifetime over its comparatives.

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