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An Advance Node Pairing Protocol for Wireless Sensor Networks

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Abstract: In the recent developments in the communication system, the role of Wireless sensor network (WSN) is remarkable. In WSN information is collected using sensors and then it is transmitted to sink node. For this collection and transmission, the nodes need power back up and hence the power back up of nodes is one of the most crucial factor which will influence the proper functioning of WSN. This is the reason behind why we focus on the less consumption of the power by the nodes while making any WSN algorithm. This paper presents a node pairing protocol along with clustering of nodes. Overall, field in which sensor node are deployed is divided into zones and in zone 1 simple clustering based mechanism is used for data transfer to BS, while in zone 2, node pairing concept is used, and in a round only one node remain active while other remains in sleep mode thus energy saving is ensured. Simulations results show that the proposed protocol improve stability period 142%, 85.37%, 100.4%, 69.8% 35.5% and 72.43% the improved network lifetime of 55%, 128.9%, and 113.2% , 96.42% 27.38% and 40.93% as compared to LEACH, DEEC, DDEEC, MAHEE, S-SEP and EECP-EI respectively.

Keywords: WSN, LEACH, DEEC, MAHEE, S-SEP, Lifetime, Stability period, throughput

1. Introduction

In the case of WSNs, (Homogenous, Heterogeneous) to conserve battery power is a challenging job, and to do so various class of protocols have emerged over the period of time [1]. As sensor nodes are deployed in the fields therefore their position i.e., their distance from the sink node and residual battery power is important design criterion. In sensor nodes energy depletes with each subsequent transmission, and depletion in energy is more as nodes distance increases from the sink [2]. Therefore to deal with fast depletion of energy of the distant nodes idea of clustering of nodes was proposed [3]. This is the reason behind why we focus on the less consumption of the power by the nodes while making any WSN algorithm. Following the same rule, a progressive clustering algorithm, LEACH protocol was introduced. LEACH gives very good results in homogeneous conditions as the selection of local cluster head in this protocol is random and each node has same probability of being chosen as a cluster head. But, this is applicable for only homogeneous conditions. We have another protocol for heterogeneous environment, i.e. SEP [5]. This protocol is different from LEACH in the manner that it possesses both normal and advance nodes. The difference between the two (normal and advanced nodes) is of the energy they have. Advance nodes have more energy in comparison to normal nodes. Unlike LEACH, the probability of a node to be selected as a cluster head is not even in SEP. In other words, the possibility of the advanced nodes to be a cluster head is more than that of the normal nodes.

We have a protocol dedicated specially to the multi-level heterogeneous network named as the Distributed Energy-Efficient Clustering (DEEC) [6] protocol. The selection of the cluster heads in this protocol is made on the basis of the residual energy that the sensor nodes posses and the network's average energy. CH is selected with the help of a

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number of epochs and in this selection process, the energy of sensor nodes (initial and residual) plays a vital role. In the advanced version of DEEC [7], the dynamic probability selection process is used for selecting CH which in turn makes a remarkable reduction in the consumption of energy present in the sensor nodes. Another algorithm for heterogeneous network is MAHEE [8]. We have two kinds of nodes in this algorithm i.e. normal and advance nodes. The difference between these two kinds of nodes is the initial energy they posses. On the basis of the residual energy and the distance at which a node is located from BS, this algorithm selects a node as CH. Here we discuss about another multi-level WSN protocol that works on the basis of Energy Intervals (EECP-EI) [9]. In this protocol, there are two factors responsible for selecting a cluster head for a specific round. These two factors are: (a) in certain interval average energy of the nodes (b) and at the same time total energy of the network. The cluster head makes sure that the residual energy of sensor nodes remains the same. It also collects the data to be communicated and transmit it to the base station with the help of hierarchy of cluster heads that are positioned at the interval of ten-meter. As we have no optimal formation of cluster, therefore it is possible that some of the sensor node may directly transmit data to the base station.

2. Related Works

Recently, two protocols Z-SEP and S-SEP are proposed. In Zonal SEP (Z-SEP) protocol field of size (2X+Y) × (2X+Y) is divided into three zones. In two zones i.e., zone 1 and zone 2 advanced nodes whose energy is greater than normal nodes are placed. The size of each zone is (2X+Y) × X. In zone 0 whose area is (2X+Y) × Y normal nodes are placed. The position of base station is (X+Y/2) × (X+Y/2). The advanced nodes transfer information to BS via clustering mechanism, while normal nodes directly send information to BS. The basic idea behind Z-SEP is that the nodes which are at corner of the field are from far distance as compared to other nodes, and due to more energy consumption they will die out soon leads to the network instability.

Advance nodes forms dis-joint clusters. Each cluster formed contains some number of sensor nodes with one node acting as cluster head (CH). The CH collects data from its member nodes and after aggregation of data relay to base station (BS). The optimal numbers of clusters are selected on the basis energy efficiency [10].

Z-SEP Operation

The nodes transmit the data directly to BS in the Zone 0 while we need clustering head in the Head zone 1 and Head zone 2 for the data transmission. As we know, it is not possible to transmit data from Head zone 1 and Head zone 2 without CH, so there must be a proper selection process for CH and it is done with the help of probability. The proper way of selecting a cluster head is quite important as it will be responsible for collecting and transmitting data to the base station. We can have an idea about the random deployment of advanced nodes in Head zone 1 and Head zone 2 with the help of Fig.1. The cluster head is selected only from advance nodes. The optimal probability of cluster head could be defined as [10]

$$\beta_{opt} = \frac{K_{opt}}{n_A} \tag{1}$$

where K_{opt} represent an optimal number of clusters and the variable n_A is used to define the number of advanced nodes.

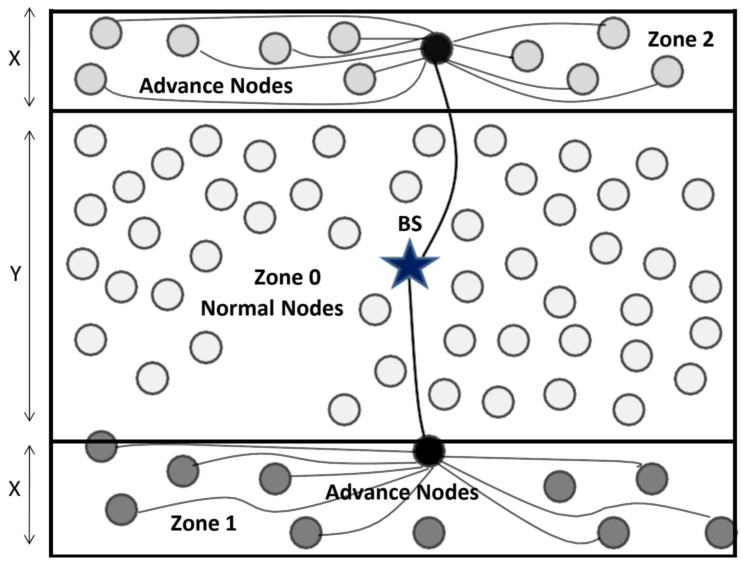

Fig. 1 - Node deployment in (2X+Y) × (2X+Y) m^2 rectangular field (Z-SEP)

No other factor than the node itself is responsible for a node to be a CH in a particular round. A random number between 0 and 1 is generated for the node which decides whether the node will turn into a CH or not. If generated number is ≤ the threshold $Th(n)$ for node, then it is elected as a cluster head. We can define Threshold $Th(n)$ as

$$Th(n) = \begin{cases} \dfrac{\beta_{opt}}{1-\beta_{opt}\left(r \times \bmod \dfrac{1}{\beta_{opt}}\right)} & \text{if } n \in H \\ 0 & \text{elsewhere} \end{cases} \tag{2}$$

H is defined as the set of advance nodes that are eligible for CH selection or in other words, nodes which are not being chosen as cluster head in the recent past $1/\beta_{opt}$ rounds.

The following given equation defines the probability of an advanced node to be selected as a cluster head [9]:

$$\beta_{adv} = \frac{\beta_{opt}}{1+\alpha.m}(1+\alpha) \tag{3}$$

where, $(1+\alpha)$ is the ratio of the energy of advance to normal nodes, ('m'<1) is the ratio of advance to normal nodes.

As per the above discussion, threshold value for advance nodes is evaluated as

$$T(adv) = \begin{cases} \dfrac{\beta_{adv}}{1-\beta_{adv}\left(r \times \bmod \dfrac{1}{\beta_{adv}}\right)} & \text{if } adv \in H' \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

H' is defined as the set of advance nodes that are eligible for CH selection or in other words, nodes which are not being chosen as cluster head in the recent $1/\beta_{adv}$ rounds.

S-SEP Protocol

We have a number of similarities between the Sectorial SEP [11] protocol and Zonal SEP [10]. The difference between these two protocols is the separation of zones into sectors in the S-SEP [11] protocol.

We have the same process of selecting the cluster head for normal and advance nodes in both protocols. The working of S-SEP protocol is different from Z-SEP in the way that it deploys the advance nodes in a more uniform manner throughout the field and nearer to the boundary. Due to this deployment, it is possible for the normal nodes positioned near the boundary will be able to transmit the data to the base station with the help of the advanced nodes.

The variable n is use to show the total numbers of nodes in the field. We have mn (m < 1) number of advanced nodes. Each sector has equal number of mn nodes, i.e. $mn/4$ nodes. We have a more stable operation of S-SEP than Z-SEP due to the division of the sectors. This division makes it possible to overcome the situation of failure of nodes. Suppose, we have a situation of failure of nodes in a particular sector, then the remaining nodes will become cluster head and this will continue the transmission of the data to the base station.

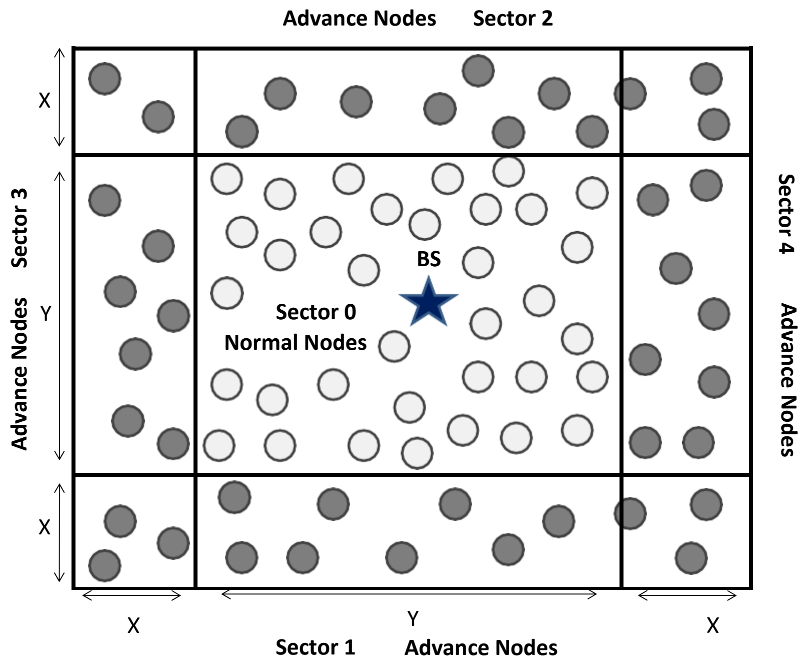

Fig. 2 - Node deployment in (2X+Y)×(2X+Y) m^2 rectangular field (S-SEP)

Some of the important upsides of S-SEP are as follows:
1. We have a proper and uniform deployment of advance nodes.
2. We can transmit the data from far located nodes with the help of a few advance nodes.
3. It will reduce the maximum distance between BS and nodes.
4. This protocol provides higher throughput with improved stability period in spite of having less initial energy.

3. Proposed Protocol

The node deployment in proposed protocol is same as in S-SEP as shown in figure. The transmission mechanism for advance nodes is exactly same as in Zonal-SEP and Sectorial-SEP protocols, while in case of normal nodes coupling among the nodes is done and sleep and awake mechanism is used for conservation of battery power. In case of normal nodes we also assume clustering among the nodes. The detailed functionality of normal nodes is as follows

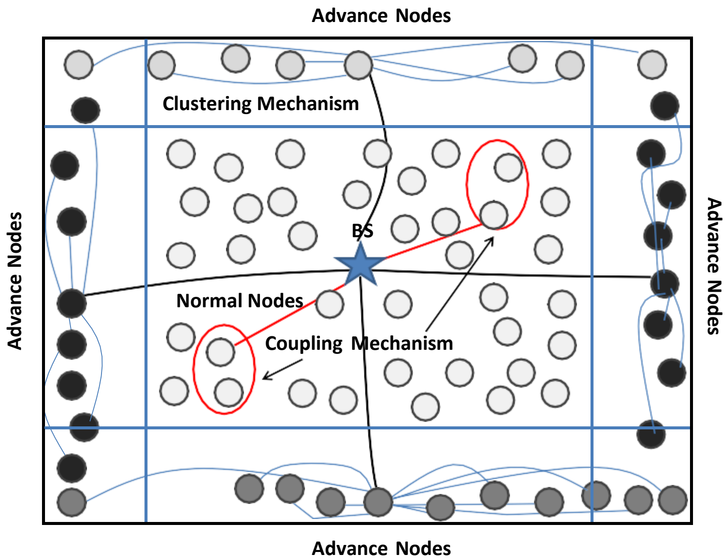

Fig. 3 - Node deployment in (2X+Y)×(2X+Y) m^2 rectangular field (Proposed)

Node Coupling Mechanism

GPS (Global Positioning System) technique is used in the beginning stage for estimating the distance of the senor nodes from BS. The nodes make transmission of their position information, type of application supported by node and its ID to the Base Station (BS). Next BS computes mutual distance between various nodes. The pseudo code for the node coupling mechanism is shown below

Node Coupling

ID=0;
for i=1:1:n
for
i=1:1:n
$d_{i,j} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$ (distance between the
if($d_{i,j} <= d_o$ (coupling distance))
if($d_{i,j} < d_{i,j}(n)$ (neighbour distance
))
$d_{i,j}(n) = d_{i,}$
$_j$;ID=j;
end
e
nd
end
e
nd
end
if (ID>0)
pair nodes
x=*x*+

Nodes located within the cluster range or nodes which run the similar application are coupled by BS. At that point BS broadcast neighbouring information to every one of the nodes in network. Thus nodes come to know about its neighbour and pair with them, however some of the nodes initially in each coupled nodes nodes which has lesser distance to BS remain active and it gathers information and transmit to BS, during this phase other coupled node remain in sleep mode, and in the next transmission phase sleep mode awake and other coupled mode goes to sleep, thus both coupled nodes sleep and awake alternatively, and thus save energy.

Clustering Mechanism

In the proposed protocol election of cluster head is made after first round. Thus, in the proposed protocol only awake nodes (*A*) will only participate in clustering mechanism. Let γ is the probability that a node will be elected as cluster head, and then the total number of cluster would be γ*N*, where *N* denotes the total number of normal nodes. Therefore, on average every node will become cluster head after 1/γ rounds. The parent cluster head (PCH) selection process is similar to SEP, protocol where *Th*(*n*) is given by

$$Th(n) = \begin{cases} \dfrac{\gamma}{1-\gamma\left(R \times \bmod \dfrac{1}{\gamma}\right)} & if \;\; n \in (A) \\ 0 & otherwise \end{cases} \tag{5}$$

In equation 5, R denote first round. In case of more than one awake node satisfies threshold criterion, than node with more residual energy will be chosen as PCH. In each round awake and sleeping node will change its state therefore all awake node send its information to PCH and depending on its residual energy and its distance from each node elect a node as child cluster head CCH. The sleep and awake algorithm as follows:

Algorithm : Node State set up
END OF ROUNDS ONE
If (node ==coupled)
if (node $_{mode}$==awake && CCH$_{FLG}$==1) (FLG represents FLAG)
node$_{mode}$=awake
else if (node $_{mode}$==awake && CCH$_{FLG}$==0)
node $_{mode}$=sleep
else if (node $_{mode}$==sleep && neighbor CCH$_{FLG}$==1)

node $_{mode}$=sleep
else if ($node_{mode}$==sleep && $neighborCCH_{FLG}$==0)
node $_{mode}$=awake
end if
else if ($node_{coupled}$ && node $_{neighbor}$==dead)
$node_{mode}$=awake
else
$node_{mode}$=awake
end if

Nodes which are not coupled with other nodes are known as isolated nodes. and they remain active till they are alive. In the proposed protocol, the energy of advance nodes is $E_0(1+\mu)$ while the energy of the coupling nodes varies between E_0 to $E_0(1+\mu)$ or $E_0(1+U\mu)$ where U is uniform random number between 0 and 1. Let 'n' denotes the total number of nodes and out of which '*mn*' are advance nodes therefore the left over nodes are $n(1-m)$where '*m*' is a fraction. Therefore total energy is

$$E_T = E_0 n(1-m)(1+U\mu) + E_0(1+\mu)mn = E_0 n[1+U\mu+m\mu(1-U)] \quad (6)$$

It is also noticeable that in *mn* number of nodes forms clusters, without node pairing because node pairing will not be beneficial as distance between the nodes is larger. We define this region as 1. Let 'p_1' is the probability of a node to become cluster head, then the average number of clusters would be mnp_1. Similarly, $n(1-m)$ nodes forms paring of nodes, and further let that isolated nodes are denoted by *I*, therefore number of active nodes in a particular round would be $A = [n(1-m) - I]/2$, and we define this area as region 2. Let 'p_2' is the probability of a node to become cluster head, then the average number of clusters would be Ap_2. In region 1 and region 2, the number of nodes in each cluster except cluster head are $(1/p_1-1)$ and $(1/p_2-1)$ respectively.

4. Energy Calculations

For the description and simulation of proposed protocol first order radio model is used and list of symbols used and their descriptions are detailed in Table 1. For the packet size of '*S*' bits and distance between transmitter and receiver as'*d*' the transmission energy will be given by

$$E_{TX} = \begin{cases} SE_{el} + SE_{fs}d^2 & d \le d_0 \\ SE_{el} + SE_{mp}d^4 & d > d_0 \end{cases} \quad (7)$$

where, $d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}}$.

And the receiver energy is

$$E_{RX} = SE_{el} \quad (8)$$

Region 1:

In a single round, energy dissipated at node cluster head (CH) is

$$E_{CH} = SE_{el}\left(\frac{1}{p_1}-1\right) + SE_{DA}\frac{1}{p_1} + SE_{el} + SE_{fs}d^2_{CH-BS} \quad (9)$$

where, d^2_{CH-BS} is the distance of cluster head to base station.

Energy dissipation in non-cluster head (N-CH) is

$$E_{N-CH} = SE_{el} + SE_{fs}d^2_{CN-CH} \quad (10)$$

where, d^2_{CN-CH} is the distance of cluster nodes to cluster heads.

Total energy dissipated in a cluster in a round is

$$E^T_{CH} = E_{CH} + \frac{1}{p_1}E_{N-CH} \quad (11)$$

Region 2:

In a single round, energy dissipated at non- cluster head node is

$$E_{CH} = \left(\frac{1}{p_2}-1\right)(E_{ei} \times S \times E_{mp} \times S \times d^2_{CN-CH}) \quad (12)$$

Energy dissipation in data receiving is

$$E_{Rc} = SE_{Rx}\left(\frac{1}{p_2}-1\right) \tag{13}$$

Data aggregation energy is

$$E_{AG} = SE_{AD}\frac{1}{p_2} \tag{14}$$

Energy dissipated by cluster to transmit aggregated data to BS is

$$E_T = S\times E_{el}E_{mp}\times S\times d^2_{CH-BS} \tag{15}$$

Total energy dissipated in a cluster in a round is

$$E^T_{CH} = E_{Rc}+E_{AG}+E_T \tag{16}$$

Therefore, in both the regions dissipated energy is different; distance among the nodes is more in region 1 as compared to region 2. Therefore different packet transfer schemes are adopted.

5. Results

In figure 4, node deployment in 100×100 m^2 is shown; in the region 20≤ x ≤80 and 20≤ y ≤80 normal node aredeployed, while on the left over place advance nodes are deployed, the energy of advance is higher than normal nodes.

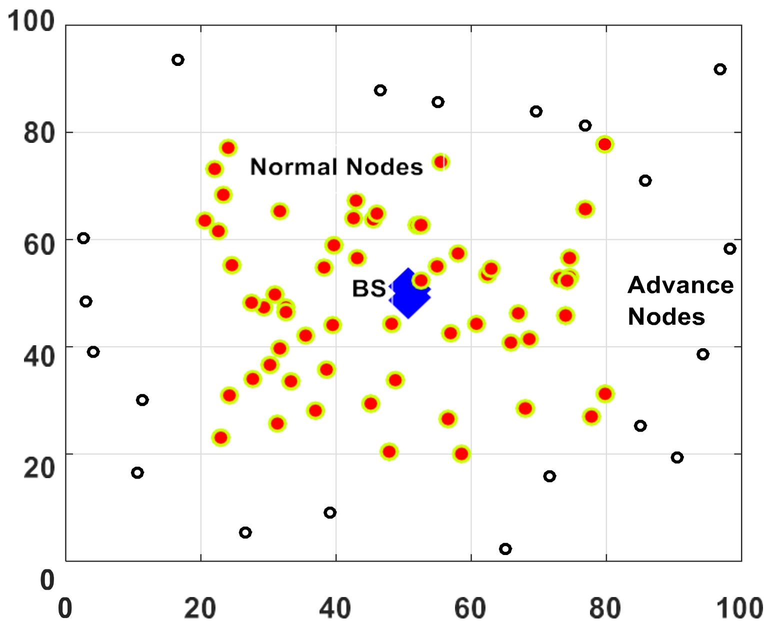

Fig. 4 - Node deployment in 100×100 m^2 rectangular field (Proposed)

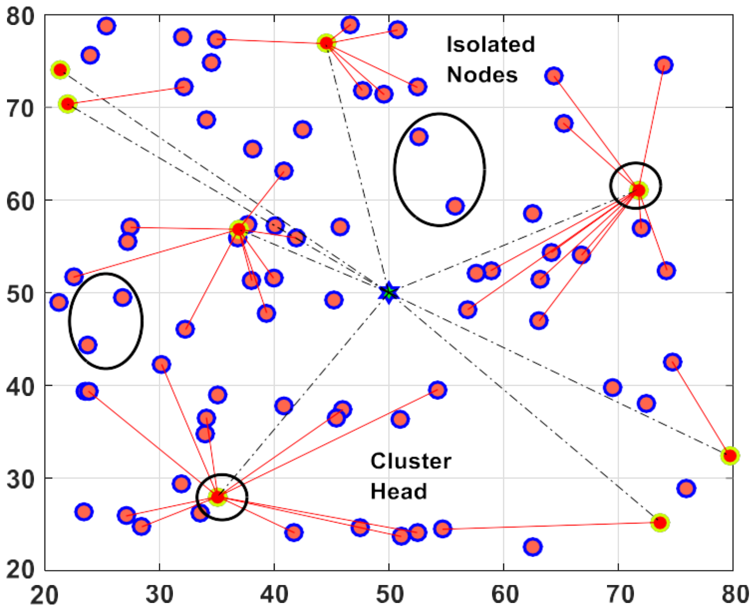

Fig. 5 - Schematic representation of various mechanisms

In figure 5 snapshot of the various mechanisms is sown, the concept of isolated nodes, pairing and clustering mechanism.

Table 1 - Simulation Parameters

Parameters	Value
Initial Each node Energy (E_0)	0.5 J
Energy lost during data aggregation (E_{AD})	5 nJ/bit/signal
Energy lost during Transmission/Receiving(E_{ei})	5 nJ/bit
Amplification energy for Free space (E_{fs})	10 pJ/bit/m^2
Amplification energy for multi path propagation (E_{mp})	0.013 pJ/bit/m^4
Packet size (S)	4000 bits
Total nodes (n)	100
Fraction of advance nodes (m)	0.2
Probability β_{opt}	0.2
Coupling Distance	8 m
Cluster Range	16 m

Considering the values as in table 1, the total energy of the proposed protocol along with other values are shown in figure 6. Here energy of the advance nodes is fixed while energy of the pairing nodes varies. Form figure it is clear that after the first round the energy of the pairing node varies significantly. If in an epoch more than one node qualifies for cluster head selection, than node with higher energy will be elected as cluster head. However, in previous protocols like LEACH, SEP etc. node which qualifies for cluster head selection will become cluster heads. Therefore, in these protocols number of cluster heads are more and their energy deplete to a faster rate.

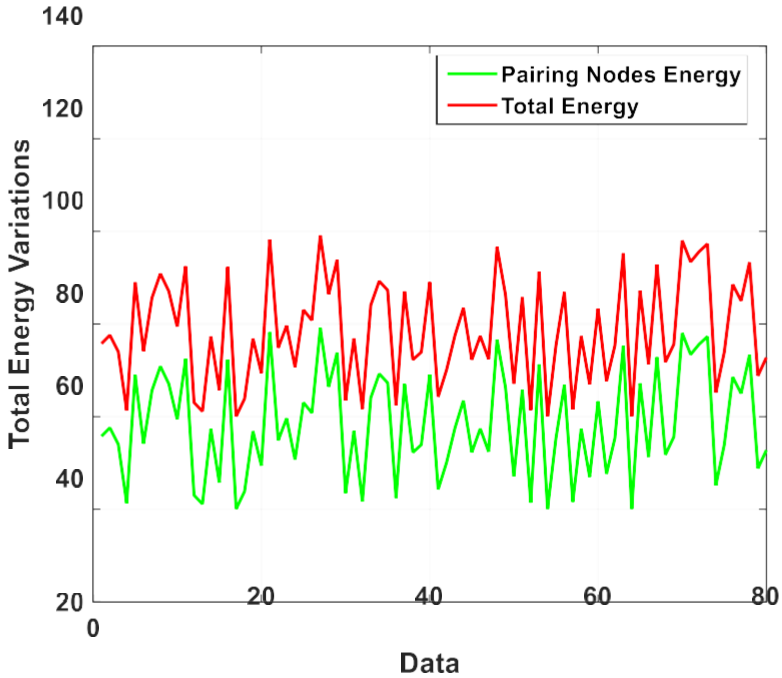

Figure 6: Total energy variation in proposed protocol

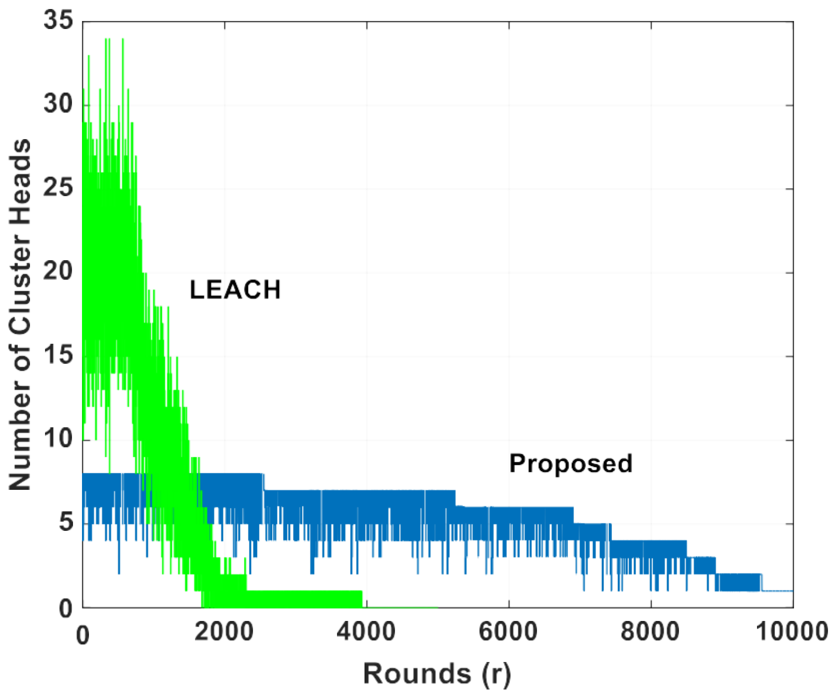

Fig. 7 - Number of cluster head vs. rounds

In figure 7, number of cluster heads vs. rounds is shown for LEACH and proposed protocols. In LEACH protocol a large number of nodes are elected as cluster head, therefore their energy also deplete to a brisk rate, and node die after a few rounds of transmissions. However, in the proposed protocol number of cluster heads are not vary randomly, here a fixed number of nodes are selected as cluster heads and it continues till any one of the cluster head node dies, and for a period constant number of cluster heads are chosen. Thus, data transfer rate is maintained and better throughput is possible.

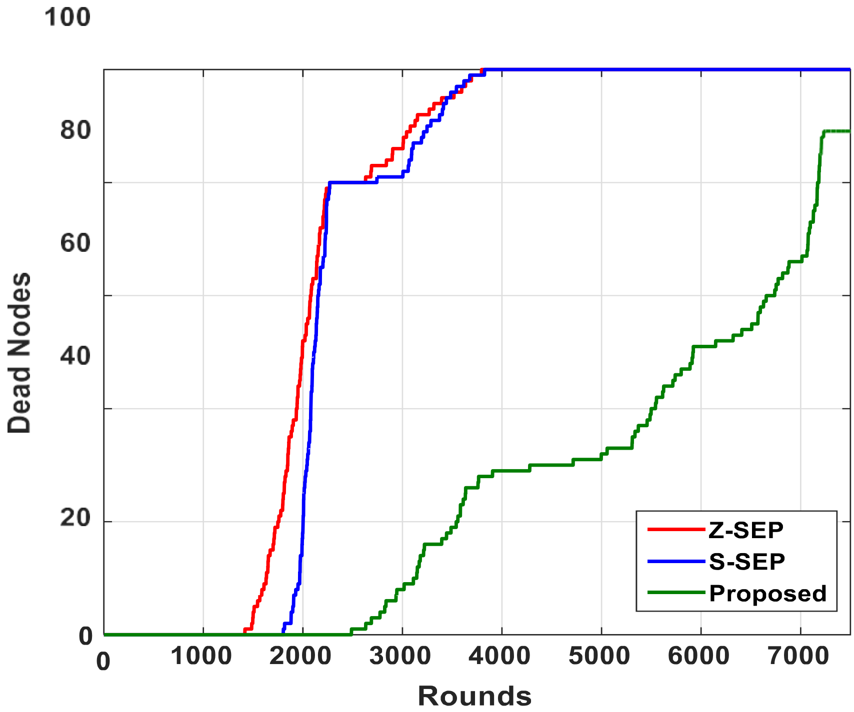

Fig. 8 - Number of dead nodes vs. rounds (E_0 = 0.5, *a*=1)

In figure 8, number of dead nodes vs. round is plotted for Zonal SEP, Sectorial SEP and proposed protocols. The pattern of dead nodes is similar in both Zonal SEP and Sectorial SEP. In Zonal SEP protocol all the nodes are alive 1422 rounds or in other words stability period I case of Zonal SEP is 1422 rounds. In case of SEP protocol the stability period is 1763 rounds. However, in case of proposed protocol the stability period is 2471. The network life which is a measure of the number of rounds till last node dies, for Zonal SEP and Sectorial SEP it is very similar and equals to nearly 3800 rounds, while with proposed protocol network lifetime is 7248 rounds. Thus, with the proposed protocol both stability period and network lifetime improves significantly. In comparison of Zonal SEP and Sectorial SEP stability period is improved by 74% and 40% respectively.

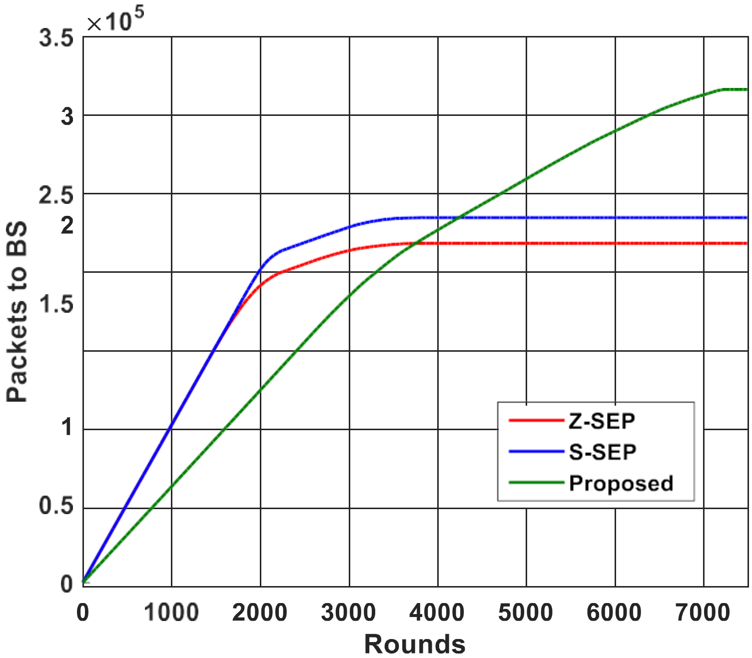

Fig. 9 - Packets transmitted to BS vs. rounds (E_0 = 0.5, *a*=1)

In figure 9, Packets to BS vs. Rounds for Zonal SEP, Sectorial SEP and for proposed protocols is plotted. Here the performance of the Zonal SEP protocol is poorest. The performance of the Sectorial SEP is very close to Zonal SEP, but it is slightly better. Thus the performance of the protocol is dependent on how long all the nodes remain alive. We have improved results with the proposed protocol is far much more superior to the other two protocols. In case of Zonal

SEP the numbers of packets received at the sink are 2.16×10^5, while in case of Sectorial SEP and proposed protocols the received packets are 2.32×10^5 and 3.14×10^5 respectively. Thus, the improvement with proposed protocol over Zonal SEP and Sectorial SEP is 45% and 35% respectively.

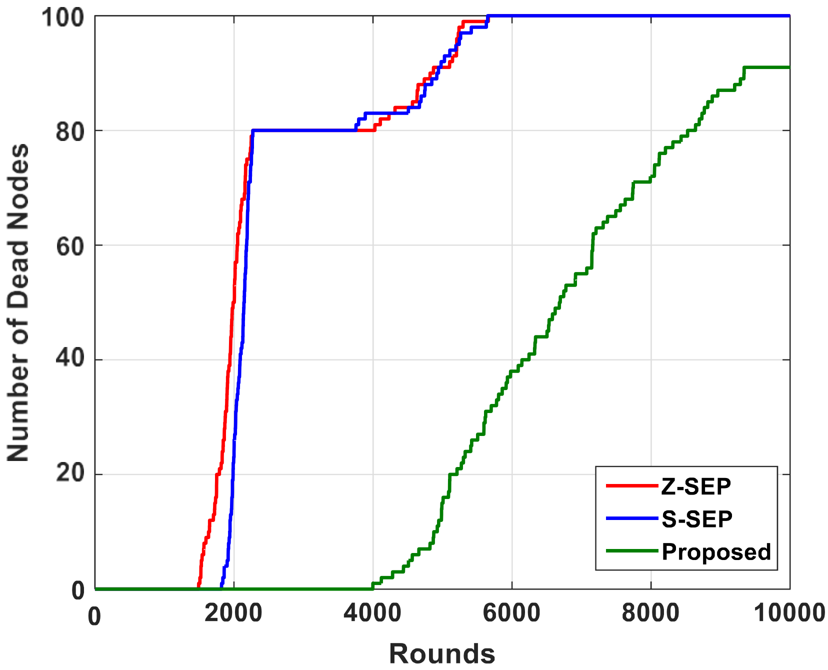

Fig. 10 - Number of dead nodes vs. rounds (E_0 = 0.5, a=2)

In figure 10 dead Nodes vs. Rounds for Zonal SEP, Sectorial SEP and proposed protocol is plotted. As 80% nodes are normal nodes, and rest 20% are advanced nodes. Thus for nearly 2000 rounds 80% are dies out. Thereafter, advanced nodes survive. In Zonal SEP, Sectorial SEP protocol, normal nodes loses its energy first; thereafter advance nodes lost their energy. However, in Zonal SEP and Sectorial SEP protocol loss in energy is faster in comparison to proposed protocol; therefore network life time is least in Zonal SEP. The depletion of energy is fast due to the large number of cluster heads selections in Zonal SEP in Sectorial SEP as in LEACH protocol (Figure 7).

In figure 11, Packets to BS vs. Rounds for Zonal SEP, Sectorial SEP and for proposed protocols is plotted while considering a=2. Here, again the performance of the Zonal SEP protocol is poorest. In case of Zonal SEP the numbers of packets received at the sink are 2.50×10^5, while in case of S-SEP and proposed protocols the received packets are 2.64×10^5 and 3.96×10^5 respectively. Thus, the improvement with proposed protocol over Zonal SEP and Sectorial SEP is 58% and 50% respectively.

The summary of the results are also detailed in Table 2 and 3 for a=1 and a=2 respectively. Here, comparison is also made with notable protocols LEACH and SEP. The stability period of the proposed protocol is improved by 142% as compared to LEACH protocol, while the network lifetime is improved by 55% (Table 2). The throughput has improved 15.8 times as compared to LEACH protocol.

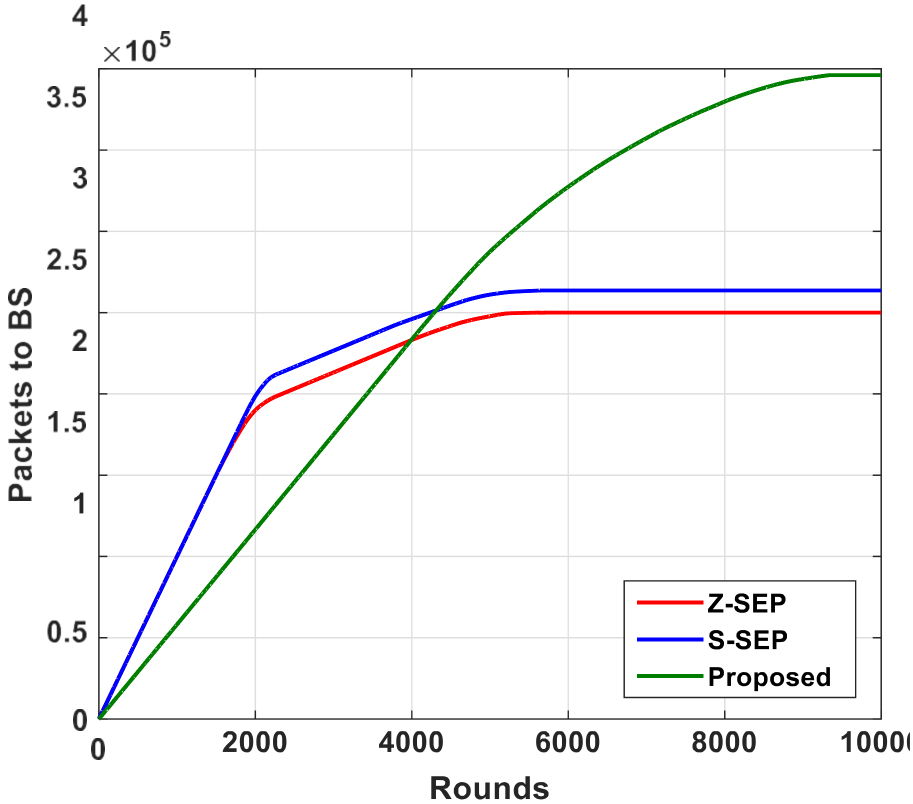

Fig. 11 - Packets transmitted to BS vs. rounds (E_0 = 0.5, a=2)

In table 3, energy of the nodes in increased thus further improvement is expected in the results. Here, the stability period is improved by 344% over LEACH protocol while the network lifetime is improved by 68%. The improvement in throughput is 16.22 times. Therefore the proposed protocol outperforms the other considered protocols.

Table 2 - Comparison of notable protocols for *p*=0.2 and *a*=1

Protocol	Stability Period (Rounds)	Network Lifetime (Rounds)	Throughput (Packets)
LEACH	1018	4685	1.99×10^4
SEP	1089	3005	3.43×10^4
Z- SEP	1422	3791	2.16×10^5
S-SEP	1763	3824	2.32×10^5
Proposed	2471	7248	3.14×10^5

Table 3 - Comparison of notable protocols for *p*=0.2 and *a*=2

Protocol	Stability Period (Rounds)	Network Lifetime (Rounds)	Throughput (Packets)
LEACH	899	5583	2.44×10^4
SEP	1150	5078	4.02×10^4
Z-SEP	1490	5678	2.50×10^5
S-SEP	1824	5690	2.64×10^5
Proposed	3996	9374	3.96×10^5

Table 4 - Comparison of recent protocols for *p*=0.2 and *a*=1

Protocol	Stability Period (Rounds)	Network Lifetime (Rounds)	Throughput (Packets)
EECP-EI	1433	5143	1.51×10^5
DDEEC	1233	3399	6.89×10^4
DEEC	1333	3166	4.61×10^4
MAHEE	1455	3690	1.84×10^5
Proposed	2471	7248	3.14×10^5

In table 4, comparison of proposed protocol with recently proposed protocols is done. These protocols are designed to increase stability period, network lifetime and throughput. The proposed protocol improved stability period of 142%, 85.37%, 100.4%, 69.8% 35.5% and 72.43% the improved network lifetime of 55%, 128.9%, and 113.2% , 96.42% 27.38% and 40.93% as compared to LEACH, DEEC, DDEEC, MAHEE, S-SEP and EECP-EI respectively. The throughput of the proposed protocol is much superior to other compared protocols.

6. Conclusions

This paper discusses the performance evaluation of node-pairing protocol. It has been found that, the coupling of nodes reduces energy consumption. The nodes which are not coupled follow normal LEACH protocol. The simulation results are presented and results are obtained in terms of packet transferred to sink, and number of dead nodes vs. round. The number of clusters in each round is also plotted. Here, the stability period is improved by 344% over LEACH protocol while the network lifetime is improved by 68%. The improvement in throughput is 16.22 times. Therefore the proposedprotocol outperforms the other considered protocols.

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