

SECTORIAL STABLE ELECTION PROTOCOL FOR WIRELESS SENSOR NETWORK

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Abstract

Wireless sensor networks (WSNs) are gaining popularity in applications like, defence, health monitoring and in agriculture etc. An efficiently design protocol can provide higher throughput, better stability period and longer network lifetime. In the similar context various protocols are proposed where much emphasis is given on minimization of energy used for per transmitted bit. Most of the designed protocols are based on two stages heterogeneous network consisting of two kinds of nodes; normal and advanced. The initial energy of the advanced nodes is higher in comparison to normal nodes. Generally, nodes form clusters and cluster head is utilized for the purpose of transferring packets to base station. Recently, stable election protocol (SEP) was proposed. In the case of SEP, both normal as well as advance nodes contain weighted probability to transform into cluster head. Advance nodes have more chances to be turned out as cluster head in comparison to normal nodes. To further enhance the performance of the protocol, Zonal-SEP is proposed, where field is divided into zones. In this paper, it is shown that, the concept of zones can be further extended into sectors and careful selection of sectors can further improves the performance with same number of advance nodes.

Keywords: Normal nodes advanced nodes, WSN, Dead nodes.

1. Introduction

Wireless sensor network (WSN) has gained popularity in past few years. The main idea in WSN is to collect information from various sensors and deliver them to sink node. In successful operation of WSN battery power of the motes plays an important role. Therefore, in WSN algorithms are designed in such a way that minimizes the energy consumption [1-3]. In the similar context LEACH protocol

Nomenclatures

α	Time more energy in comparison to normal nodes
E_{amp}	Amplifier energy, pJ/bit/m ⁴
E_0	Initial energy, J
E_{RX}	Energy consumed during reception, nJ/bit
$E_{RX-elec}$	Energy consumed at the time of reception, nJ/bit
E_{TX}	Transmission Energy, nJ/bit
$E_{TX-elec}$	Energy consumed at the time of transmission, nJ/bit
G	Set of nodes which have not been cluster heads
G'	Set of advance nodes that have not been cluster head
K_{opt}	Optimal number of clusters
m	Fraction of advanced nodes
n	Total number of nodes
r	Round
P_{opt}	Optimal probability of cluster head
x	Distance
X	Coordinate
Y	Ordinate

Abbreviations

BS	Base Station
DEEC	Distributed Energy-Efficient Clustering
E-SEP	Enhanced Stable Election Protocol
LEACH	Low-energy adaptive clustering hierarchy
SEP	Stable Election Protocol
TDMA	Time Division Multiple Access
TEEN	Threshold sensitive Energy Efficient sensor Network
WSN	Wireless Sensor Networks

was developed [4]. LEACH is a progressive clustering algorithm which sensibly utilizes the energy in the network. In this protocol, local cluster head is randomly chosen, thus it works quite effectively in homogeneous conditions. In LEACH each node has same likelihood to turn out a cluster head. Though, it is not effective for heterogeneous conditions.

For heterogeneous environment, SEP was proposed [5]. As far as SEP is concerned, it is a two stages heterogeneous protocol presenting two kinds of nodes (normal and advance). The energy of advance nodes exceeds as compared to normal nodes. In SEP, normal nodes along with advance nodes contain weighted probability to turns into cluster head. Advance nodes have greater chances to be turned out as cluster head in comparison to normal nodes. SEP doesn't ensure proficient deployment of nodes. Later on E-SEP Protocol was proposed which is based on three level hierarchies [6]. Here, intermediate nodes whose energy lies between advance node and normal node is placed. Further, DEEC was proposed [7]. In this, protocol cluster head is selected on the basis of the node's residual energy and average energy of the network. Moreover, in DEEC, it is nodes with high energy have greater chances to become cluster head as compared to lower energy nodes. TEEN could be defined as a reactive protocol for the applications that are time critical [8]. It was introduced for homogeneous network. In TEEN the

selection criteria for cluster head is similar to that of LEACH, though TEEN acquaints soft and hard threshold to decrease the transmissions number and hence the energy of nodes is saved. This in turn increases the life span and stability period of the network.

In the above discussed protocols very simple and straight extensions are detailed, where advance nodes have more energy than normal nodes are deployed, which increase throughput. In this work, we have made an attempt regarding the distribution of the nodes in the field such that throughput can be increased without increasing the energy of advance nodes.

Normal nodes and advance nodes in SEP are deployed in a random way. In the event a major number of normal nodes are deployed at a great distance from base station, more energy will be consumed during the transmission of data which consequently shorten the stability period and diminishing throughput. Therefore, efficiency of SEP decreases. In order to overcome these defects, network field is divided into zones and resulted protocol is known as Z-SEP [9, 10]. Due to the fact that corners in the field are highest inaccessible areas where more energy is required by nodes for the transmission of data to base station, normal nodes are put closer to the base station and in this way they can make the transmission of their data to base station directly. Still, advance nodes are deployed at far distances from base station because they have more energy. In the case data is transmitted directly by the advance nodes to base station more energy is consumed. Therefore in order to save energy of advance nodes, clustering process is used just for advance nodes. Still in zonal SEP, the selection of zones is critical, and how zones will be obtained from rectangular field is important. Let considering a field of dimension $X \times Y$. In Z-SEP zones are chosen by considering entire length in X direction and dividing Y direction into three segments Y_1 , Y_2 and Y_3 such that $Y = Y_1 + Y_2 + Y_3$. Therefore, the areas of three zones are $X Y_1$, $X Y_2$ and $X Y_3$ respectively. In this paper zone word is used when entire X direction and segment in Y direction is considered.

In S-SEP, sectors are created by dividing both X and Y directions into segments as detailed in section 3 of the paper. In this paper sector word is used when segments in both X and Y direction is considered.

In this paper, it is shown that by carefully selecting sectors with same number of advanced nodes better throughput can be obtained. The sectors sizes are varied for various values of X_1 , X_2 and X_3 and Y_1 , Y_2 and Y_3 and optimal values are selected where maximum throughput is obtained.

In WSN three main areas of research are routing, information exchange and energy hole problem. In WSN energy hole problem is feel by the nodes which are closer to the sink because these nodes not only send their own data but also the data of far nodes. To deal this problem solution such as multi-hop approach [11], two nodes with extra energy [12] and non-uniform distribution of nodes [13], etc. are proposed. In previous works LEACH, SEP, Z-SEP, CN-LEACH protocol etc. are developed which do not consider energy hole problem, and to make a fairer comparison we have not considered energy hole problem in this work.

2. Zonal-Stable Election Protocol

In a great number of routing protocols, nodes are being set up in an unorganized manner in network field. Also, in network the energy of nodes is not being used in

an efficient manner. Theme is modified in zonal stable protocol: network field is classified in three zones. These three zones are named as zone 0, zone 1 and zone 2. The classification of these zones is done on the grounds of energy level and using X and Y co-ordinate of network field. Considering, total nodes which are distributed over entire field as 'n'. We take the assumption that a small number of nodes is equipped with greater energy and defined as advance nodes. Suppose m is the fraction of the total nodes which consist of ' α ' time more energy in comparison to normal nodes. We allude these nodes as advance nodes, and total advance nodes are nm and normal nodes are $(1-m)\times n$. The energy of normal nodes is $(1-m)\times nE_0$ while the energy of advance node is $mnE_0(1+\alpha)$. Therefore total energy of all nodes is $(1+am)nE_0$.

For example, considering a field of dimension $100\times 100\text{ m}^2$, where normal and advanced nodes are distributed randomly in different zones. In Z-SEP tree zones are defined as:

Zone 0: In Zone 0, normal nodes are deployed in a random way, staying between $20 < Y \leq 80$.

Head zone 1: This zone is defined in $0 < Y \leq 20$, half of the advanced nodes are deployed at random in this zone.

Head zone 2: The other half of advance nodes are deployed in a random manner in Zone 2, staying in $80 < Y \leq 100$.

Z-SEP operation

In Zone 0, data is directly transmitted to base station by nodes. Normal nodes sense conditions, collects data of interest and make its transmission to base station directly.

Nodes that lie in Head zone 1 and Head zone 2 transmit information to base station with the help of clusters head. In the Head zone 1 and Head zone 2, Clusters head is elected among the nodes using probability. Each cluster head collects data from member nodes and transmits it to base station. The selection of Cluster head is quite vital. Figure 1 shows the deployment of advance nodes in random way in Head zone 1 and Head zone 2. The formation of Cluster is possible only in advance nodes.

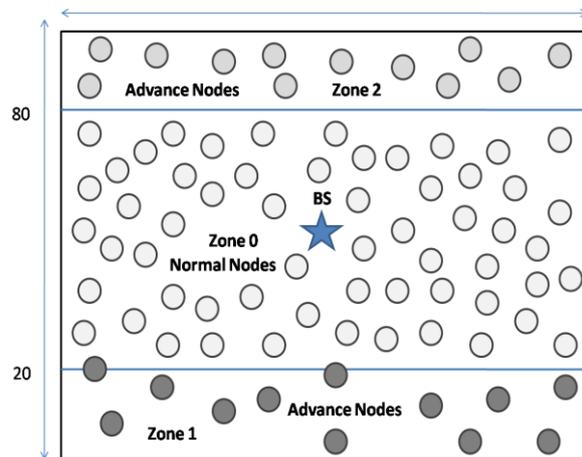


Fig. 1. Node deployment in $100\times 100\text{ m}^2$ rectangular field.

Let us take an optimal number of clusters C_{opt} and n as the quantity of advance nodes. In accordance to the SEP, we can define optimal probability of cluster head as [10]

$$P_{opt} = \frac{C_{opt}}{n} \quad (1)$$

Each node makes the decision whether to turn out as a cluster head or not in present round. For this a random number between 0 and 1 we call it rand (1) is generated. If $\text{rand}(1) \leq \text{threshold } T_H(n)$ for a node at that point we elect it as cluster head. Threshold $T_H(n)$ is defined as

$$T_H(n) = \begin{cases} \frac{P_{opt}}{1 - P_{opt} \left(r \times \left\lfloor \frac{1}{P_{opt}} \right\rfloor \right)} & \text{if } n \in C_H \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

In the above equation, the variable C_H represents the set of nodes which was not elected as cluster heads in the past $1/P_{opt}$ rounds. The possibility for advance nodes to turn out to be cluster head is defined in [9, 10] which is given below

$$P_A = \frac{P_{opt}}{1 + \alpha \cdot m} (1 + \alpha) \quad (3)$$

As per the threshold for advance nodes is

$$T_H(A) = \begin{cases} \frac{P_A}{1 - P_A \left(r \times \left\lfloor \frac{1}{P_A} \right\rfloor \right)} & \text{if } A \in C'_H \\ 0 & \text{elsewhere} \end{cases} \quad (4)$$

C'_H is defined as the set of advance nodes that have not been elected as cluster head in the recent $1/P_{adv}$ rounds.

Now, after the cluster head selection, the cluster head shoots a message to the nodes. The message is received by the nodes and they makes the decision to which cluster head it will go for the present round.

According to the strength of received signal, nodes give response to cluster head and join cluster head as a member. Cluster head at this moment assign a TDMA format for the nodes at the time in which nodes can transfer data to cluster head. After the completion of the development of clusters of data of each node, transmission of the data to the cluster head inside the slot of time made definite to the node by the cluster head. Figure 2 illustrates this phase.

At the moment, data reached from nodes, cluster head collects this data and transmit it to the base station (Fig. 3). This mechanism reduces the energy dissipation of advanced nodes. As in each round new cluster head is elected therefore residual energy of cluster head does not fall sharply.

In Z-SEP, zones are created by diving only Y axis (refer Fig. 4). This kind of deployment of nodes is not very efficient, because the in the zone-0, the distance of

the normal nodes is un-equal assuming BS is at (50, 50), then minimum distance is 30 m and maximum distance is 58.30 meter. Thus in the distance huge difference is seen. This problem can be suppressed using S-SEP as described in next section.

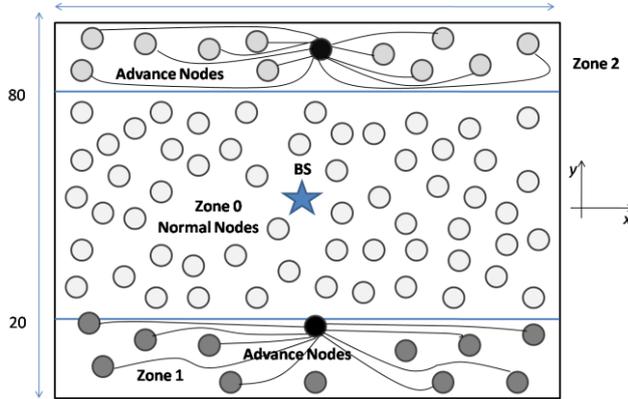


Fig. 2. Data transmission to cluster head by various nodes.

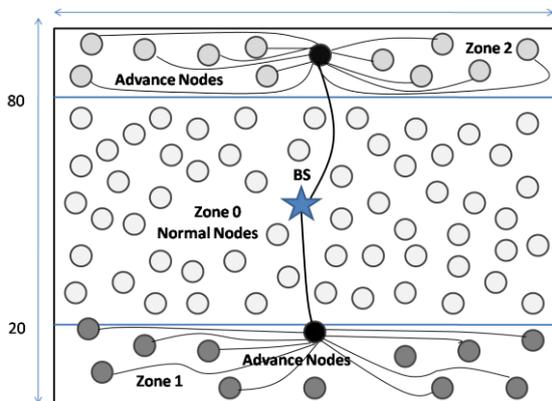


Fig. 3. Data transmission for cluster head to base station.

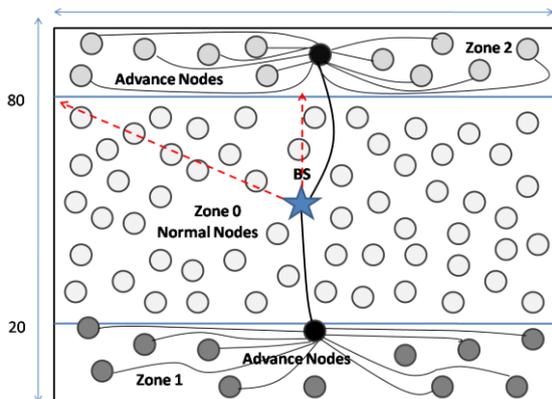


Fig. 4. Network architecture with node distances.

3. Proposed Protocol S-SEP

The S-SEP protocol is similar to Z-SEP except zones are divided into sectors. The cluster head selection process for normal and advance nodes is same in Z-SEP. The main aim of S-SEP is to distribute advance nodes more uniformly throughout the field and they are kept in vicinity of boundary of the field. Therefore, normal nodes which are close to the boundary may use advance nodes as cluster heads for data transfer to BS. In S-SEP total area is divided into four sectors as shown in Fig. 5. Each sector range is defined as

Sector 1: $0 < x < X$ and $0 < y < y_1$

Sector 2: $0 < x < X$ and $y_2 < y < Y$

Sector 3: $0 < x < x_1$ and $0 < y < Y$

Sector 4: $x_2 < x < X$ and $0 < y < Y$

It is important to note that the normal nodes should be kept close to BS while advance nodes can be kept closer to the boundaries of the field. The sectors size can be varied and number of normal and advance nodes can also be varied to get desired results.

In modified distribution of nodes, normal nodes are placed in the region $x_1 < x < x_2$ and $y_1 < y < y_2$, while the advanced nodes are placed in left over part of the field, in four sectors described above and as in Fig. 5.

Again considering $100 \times 100 \text{ m}^2$, in the proposed sectorial division, the shortest distance is 30 m while the longest distance is 50 m. Thus, in S-SEP farthest distance is reduced.

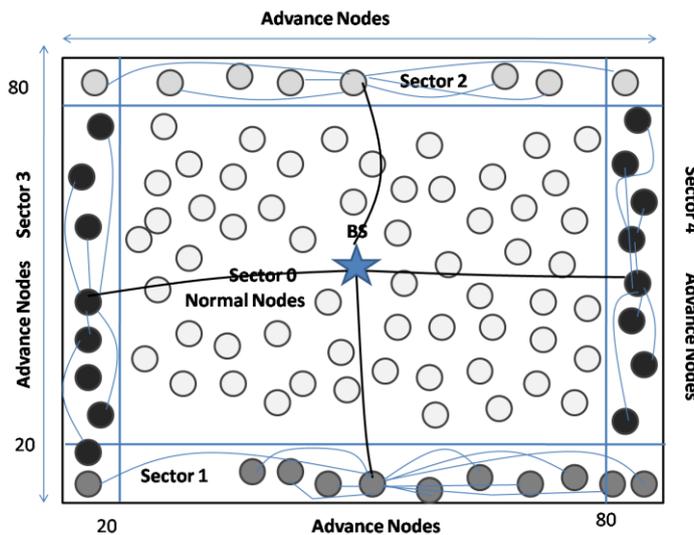


Fig. 5. Network architecture with four sectors.

The total numbers of nodes in the field are n out of which mn ($m < 1$) are the advanced nodes. These mn nodes are equally divided into four sectors having $mn/4$ number of nodes in each sector. The operation of S-SEP is similar to Z-SEP. However, the operation of S-SEP is more stable, as it is divided into four sectors and these sectors contain advanced nodes, and in case of failure of few nodes, the

left over nodes can become cluster head. Thus network is less susceptible to failure of nodes.

The main advantages of S-SEP are:

1. More uniform distribution of advance nodes.
2. Far distances from BS are covered with a few advance nodes.
3. The farthest distance between BS and nodes has decreased.
4. With lesser initial energy comparatively higher throughput and better stability period is obtained.

4. Network Model

In the network model, a few reasonable assumptions are made which are as follows:

1. In total n sensor nodes are distributed uniformly in a square field of dimension $X \times Y$.
2. The network is static in nature; therefore all the nodes and the BS are stationary after deployment.
3. There are two types of nodes, thus network is heterogeneous.
4. All the sensors nodes are deployed randomly are they are location-unaware.
5. The BS is in the centre of the sensor field.
6. Each node has a distinct identity (id).

As WSN nodes are uniformly distributed where $X \in [0, L]$ and $Y \in [0, L]$. Therefore, pdfs are given as

$$f_x(x) = \frac{1}{L} \quad \text{where } 0 \leq x \leq L \quad \text{and} \quad f_y(y) = \frac{1}{L} \quad \text{where } 0 \leq y \leq L$$

Thus, the mean values in X and Y directions are $\frac{L}{2}, \frac{L}{2}$ respectively. The variance is $\frac{L^2}{48}$ in both the directions.

It is also notable that BS receives data from various nodes thus load on the BS will be higher, therefore parallel processing of data is necessary which can be done using software define networking.

Radio model

As per the radio energy dissipation model which is shown in the above Fig. 6, with the end purpose to acquire a feasible Signal-to-Noise Ratio (SNR) in the process of transmission of an L_p -bit message over a distance x , we can represent the energy expended by the radio as:

$$E_{TX}(L_p, x) = \begin{cases} L_p \cdot E_{elec} + L_p \cdot \epsilon_{fs} \cdot x^2 & \text{if } x < x_0 \\ L_p \cdot E_{elec} + L_p \cdot \epsilon_{mp} \cdot x^4 & \text{if } x \geq x_0 \end{cases} \quad (5)$$

where, $x_0 = \sqrt{\frac{\mathcal{E}_{fs}}{\mathcal{E}_{mp}}}$.

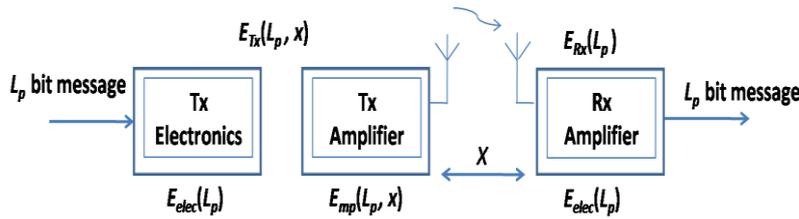


Fig. 6. Radio model representation.

Now, here the variable E_{elec} represents the energy dissipated per bit for successful operation of the transmitter or at the receiver circuit. The parameters \mathcal{E}_{fs} and \mathcal{E}_{mp} is dependent on the used transmitter amplifier model, and the parameter x represents the distance between the sender and the receiver [7]. To receive an L_p -bit message the radio expends $E_{RX}(L_p) = L_p E_{elec}$. The base station is situated at the centre of field; therefore distance of any node from BS is less than x_0 . The list of parameters used in calculation and simulation are shown in Table 1.

Table 1. List of parameters and their values.

Parameters	Value
Initial Energy E_0	0.25, 0.50 J
Energy for data aggregation E_{DA}	5 nJ/bit/signal
Transmission and Receiving energy	5 nJ/bit
Amplification energy for short distance \mathcal{E}_{fs}	10 pJ/bit/m ²
Amplification energy for long distance \mathcal{E}_{mp}	0.013 pJ/bit/m ⁴
Packet size	4000 bits
Total nodes	100
Fraction of advance nodes	0.2
Probability P_{opt}	0.2
Dimension (X,Y)	100 m
Dimension (x ₁ , y ₁)	20 m
Dimension (x ₂ , y ₂)	80 m
Distance (L)	100 m

In Fig. 7, simulation snapshot of 100×100 m² field is shown for Z-SEP. Advanced nodes are shown with green ‘o’ and are deployed in 0<Y<20 and 80<Y<100. While the normal nodes are deployed in region 20<Y<80 and mark with blue ‘o’. Finally, BS is shown with ‘x’. The BS is positioned at mean value (50, 50) as discussed above. The energy of the normal nodes is E_0 while for advanced nodes energy is $E_0(1+\alpha)$. The simulation is performed in MATLAB, and simulation is run for 5000 rounds.

In Fig. 8, simulation snapshot of 100×100 m² field is shown for S-SEP. Normal nodes are shown with blue ‘o’ and are deployed in square 20<X<80 and 20<Y<80.

While the advance nodes are deployed in the left over region Again, BS is shown with 'x'.

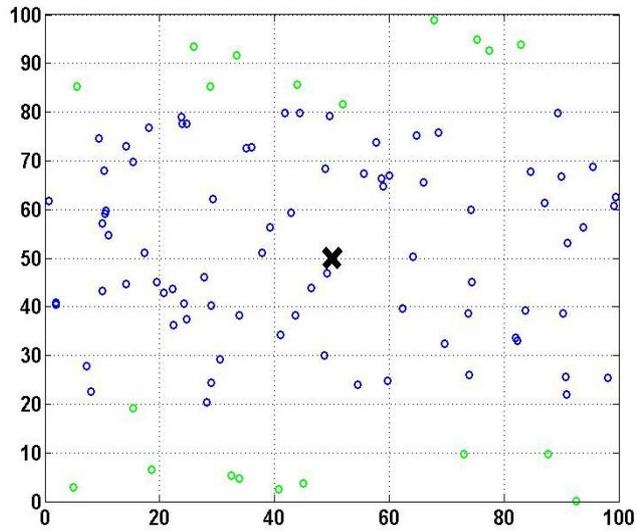


Fig. 7. Sensor deployment in Z-ZEP (simulation).

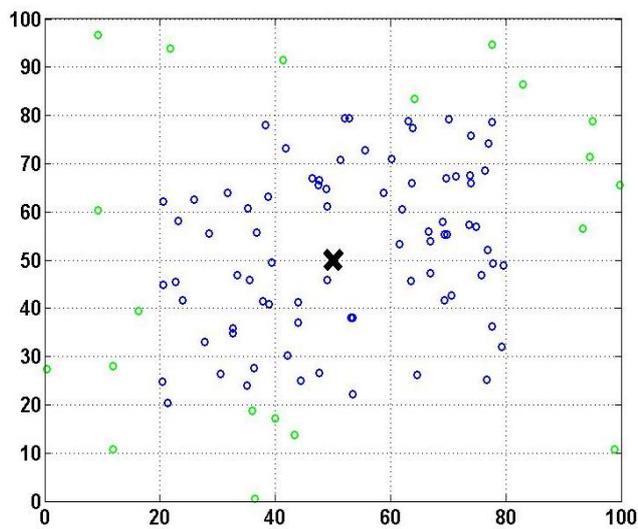


Fig. 8. Sensor deployment in S-ZEP (simulation).

The performance evaluation of the S-SEP is performed in terms of stability period, network lifetime and throughput and defined as under:

Stability period: The stability period could be defined as the time interval from the start of network to the death of the very first sensor node. It is desirable that the stability period should be as high as possible.

Network lifetime: This is the time interval lapsed from the beginning of the network to the death of the last alive node. Network lifetime should also be as high as possible.

Throughput: Defines the data sent from the nodes to base station in terms of number of packets. High throughput is also a desirable feature of WSN.

Various protocols proposed in the past aim to maximize stability period, network lifetime and throughput. However, most of the times it is not possible to maximize all the three parameters therefore as per the network requirements desired parameter/parameters is/are maximized.

In Fig. 9, alive nodes vs. rounds for Z-SEP and S-SEP protocol, with normal node energy as $0.25J$ and advanced node energy as $0.50 J$ is plotted. In Z-SEP protocol first node dies after 751 rounds while last node dies after 1866 rounds. However in S-SEP protocol first node dies after 1739 rounds and last node after 3731 rounds. Thus, stability period for S-SEP is much higher than Z-SEP. Therefore, S-SEP protocol is much better in comparison to Z-SEP. This advantage is gained as in Z-SEP the distance of nodes from BS is unequal while in S-SEP protocol the distance of nodes is equal in all directions. Moreover, in S-SEP the distance of normal nodes is lesser in comparison to Z-SEP.

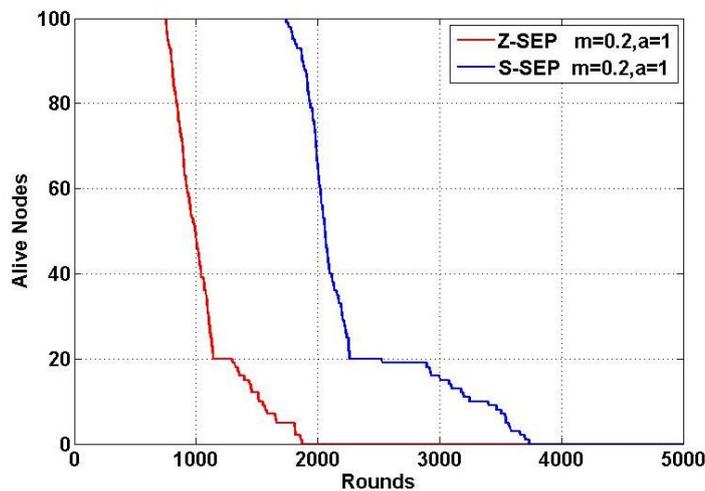


Fig. 9. Alive nodes vs. rounds for Z-SEP and S-SEP protocol with normal node energy as 0.25.

In Fig. 10, packets to BS vs. rounds, for Z-SEP and S-SEP protocol with normal node energy as 0.25 is plotted. In this figure the value of 'a' is considered to be 1. Thus, the energy of the advanced nodes is twice of that of normal nodes. For Z-SEP protocol number of packets transmitted to BS is 1.064×10^5 and for S-SEP the number of packets to BS is 2.276×10^5 . Therefore, rise in packets to BS is 114%. In summary, comparative results for S-SEP and Z-SEP are detailed in Table 2. It can be observed that the S-SEP protocol maximize all the three desired parameters. Both stability period and network lifetime both improves by more than 100 percent.

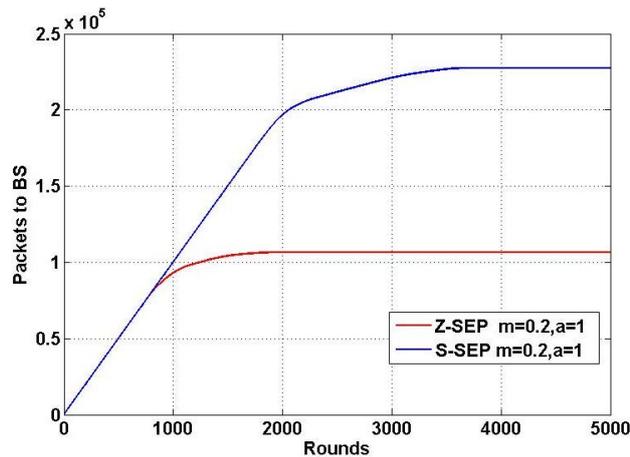


Fig. 10. Packet to base station vs. rounds for Z-SEP and S-SEP protocol with normal node energy as 0.25.

The above results can be explained as; in Z-SEP protocol advance nodes are distributed in three zones, while in S-SEP nodes are distributed in four sectors. Therefore, nodes are more uniformly distributed in the field and they are relatively close to the BS. Thus, numbers of dead nodes reduces and throughput increases, even at low energy of nodes. However, as the energy increases both the protocols have nearly same performance as extra energy leads to the longer alive periods and with higher throughput.

In Fig.11, alive nodes vs. rounds for Z-SEP and S-SEP protocol, with normal node energy is now increased to 0.50 is plotted. Now, in Z-SEP protocol first node dies after 1478 rounds while last node dies after 3740 rounds. However, in S-SEP protocol first node dies after 1767 rounds and last node after 3851 rounds. Thus, as energy increases the performance of Z-SEP improves; still the performance is inferior to S-SEP.

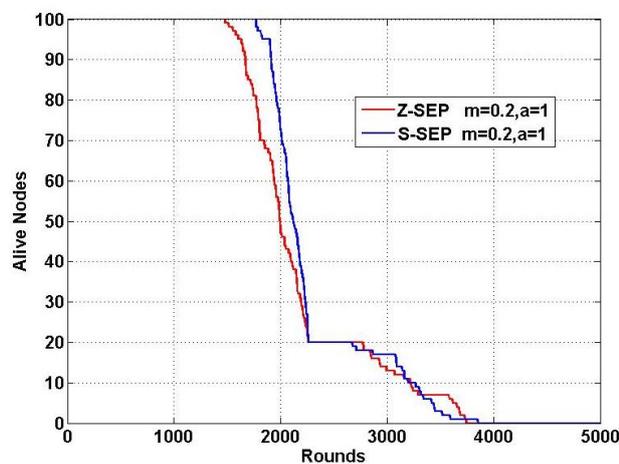


Fig. 11. Alive nodes vs. rounds for Z-SEP and S-SEP protocol with normal node energy as 0.50.

In Fig. 12, packet to BS vs. rounds for Z-SEP and S-SEP protocol with normal node energy as 0.50 is plotted. Again the value of 'a' is considered to be 1. Thus, the energy of the advanced nodes is twice of that of normal nodes. For Z-SEP protocol number of packets transmitted to BS is 2.188×10^5 and for S-SEP the number of packets to BS is 2.299×10^5 . Therefore, rise in packet to BS is nearly 5%. In summary, comparative results for S-SEP and Z-SEP are detailed in Table 3. The improvement in stability period is 19.55%, while improvement in network lifetime is only 3%. Thus as the energy of the normal and advanced nodes increases, the performance of both the protocol starts to converse. This is obvious that in case of more energy both normal and advance nodes have greater capacity to transmit information to BS, thus the effect of zones/ sectors diminishes.

It is customary to note that the S-SEP protocol perform better at lower energy levels, this makes it very efficient protocol.

Table 2. Comparison of protocols for $m=0.2$, $a=1$ and $E_0=0.25$.

Parameters	Z-SEP	S-SEP
Stability Period (Rounds)	751	1739
Network Lifetime (Rounds)	1866	3731
Throughput (Packets)	1.064×10^5	2.276×10^5

Table 3. Comparison of protocols for $m=0.2$, $a=1$ and $E_0=0.50$.

Parameters	Z-SEP	S-SEP
Stability Period (Rounds)	1478	1767
Network Lifetime (Rounds)	3740	3851
Throughput (Packets)	2.188×10^5	2.299×10^5

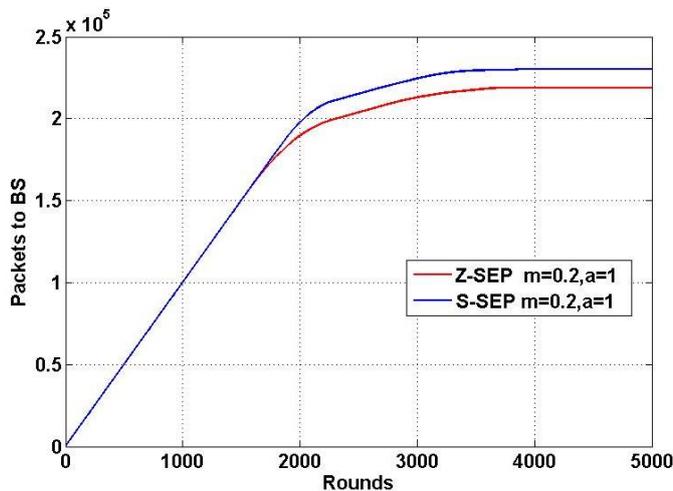


Fig. 12. Packet to base station vs. rounds for Z-SEP and S-SEP protocol with normal node energy as 0.50.

5. Comparison with Recent Protocols

In recent notable work, Double Cluster Based Energy Efficient Routing Protocol (DL-LEACH) is proposed [14, 15], in this protocol cluster head selection is made

on the basis of residual energy of nodes, nodes distances from base station and also on its distance from neighbouring nodes. In this protocol two levels of hierarchy, in the first level some chosen head nodes collect data from member nodes and do the fusion, and from the non-head nodes again heads are chosen to send data to base station.

From Table 4, it is clear that both the protocols are comparable to each other, the S-SEP protocol works on distribution of nodes in the field while CN-LEACH works on efficient packets transfer to BS, using two levels of clusters for aggregation and packets transfer. Here, it can be concluded that, if both the protocols (CN-LEACH and S-SEP) can be combined together a significant improvement can be observed in stability period, network lifetime and throughput.

Table 4. Comparison of protocols for $m=0.1$, $a=1$ and $E_0=0.1$.

Parameters	CN-LEACH	S-SEP
Stability Period (Rounds)	269	283
Network Lifetime (Rounds)	940	951
Throughput (Packets)	5.5×10^4	5.6×10^4

6. Conclusions

This paper, discusses the performance evaluation Z-SEP and S-SEP. This work aims for the designing and performance evaluation of wireless sensor network protocol. On the basis of the obtained results following conclusions can be made:

- The numbers of alive nodes have an impact on the packet transferred to BS.
- The energy of advance nodes has an impact on the packet transferred to BS.
- Careful selection of geometry is very important for the placement of the advance nodes.
- The performance of S-SEP is better in comparison to Z-SEP protocols.
- The stability period and lifetime for S-SEP is also much better in comparison to Z-SEP protocols.
- Simulation results clearly reveal that careful distribution of nodes in the network can lead to betterment of results.

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