ESRA: Enhanced Stable Routing Algorithm for Heterogeneous Wireless Sensor Networks

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Abstract: **The sensor technology is getting advanced day by day in terms of facilitating human in different aspects of human life. The one of the major constraints on the wireless sensor nodes is the battery embedded on them. As these batteries are irreplaceable, the routing to preserve the energy of the sensor nodes becomes prominent. The cluster-based routing has not only acquired network longevity but also has helped in the energy balancing in the network. But, Cluster Head (CH) selection is NP (Non-Polynomial)-hard problem therefore, in this paper, we have proposed Enhanced Stable Routing Algorithm (ESRA) for Heterogeneous Wireless Sensor Network (HWSN). The CH selection is enhanced by involving the distance factor in the threshold formula. While doing so, the energy consumption is reduced, and stability period is enhanced significantly. It is observed that through the simulation in MATLAB, the stability period by ESRA is enhanced by 15.43%, 64.39% and network lifetime by 30.95%, 73.16% as compared to P-SEP and DSEP protocols, respectively.**

Keywords*: *Wireless Sensor Network (WSN); ESRA; DSEP; CH selection; stability period

I. Introduction

Wireless sensor network (WSN) has made it possible to access the remote areas wherever the human reach was not possible. It is to be noted that the WSN is entirely application specific and it is the application that decides whether the sink or the node should be static or mobile.

The architecture of WSN shows (fig. 1) how the nodes communicate with each other and the way they send data to the sink. Finally, the collected data is forwarded to the user via internet [1].

There are four main components that a node is integrated with battery, power unit, sensing unit, and microcontroller.

Sometimes the application dependent devices are also connected to these sensor nodes to make them worthy for such applications. The one of the most prominent factors is the limited battery resources that are very difficult to be replaced. It is due to the reason that these nodes are deployed in the remote areas where the human intervention is not possible. Therefore, the primary concern is to preserve the battery of sensor nodes so that they can be made to operate for longer period.

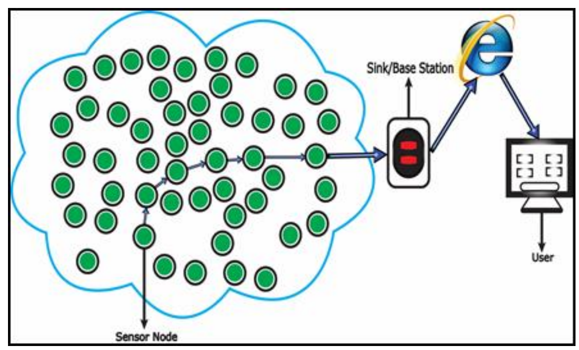

Fig. 1. WSN architecture [1]

Since the development of WSN, various routing protocols came into existence that not only helped in the energy preservation but also enhanced network lifetime. The clustering of nodes is one of the important solutions that not balances the energy of the nodes but also helps in reducing the number of data transmissions to the network. The clustering provides scalability to the network. As every cluster has one cluster head (CH), its selection becomes one of the crucial aspects. The CH plays two important roles, first is the collection of data packets and second is the forwarding the data to the sink[2]. The CH selection is one of the highlighting areas of research that helps in acquiring enhanced network lifetime.

Generally, the network in which WSN is made to operate in two types; homogeneous and heterogeneous [3]. Where the former deals with the same configuration nodes that are operated in the given simulation environment, and the latter deals with the nodes with different configuration. These configuration can be referred to the energy, computation capability, sensing range and etc. [4] [5].

The significant contributions by this work is stated as follow.

a) The selection of CH is done in P-SEP [6] protocol is improved by incorporating distance factor in the probability formula meant for CH selection.

b) The performance of proposed protocol Enhanced Stable Routing Algorithm (ESRA) for Heterogeneous Wireless Sensor Network (HWSN) is evaluated by validating its performance with SEP [7], DSEP[8] and P-SEP protocols.

The remaining of the manuscript is organized as follows. The related work is discussed in Section 2. Section 3 demonstrates the proposed protocol. The simulation analysis and results are discussed in Section 4. The conclusion is given in Section 5. Thereafter, the references are given.

II. Related Work

The WSN has been the result of sensing technology that has brought revolution in the modern technological world. The energy conservation is one of the essential concerns that is looked after by the researchers working on WSN. It is noteworthy that the homogeneity does not prevails in reality. Therefore, the heterogeneity is introduced to enhance stability period of the network. SEP (Stable Election Protocol) was the first protocol that proposed two level of energy heterogeneity in the network. However, it did not perform adequately when it was made to perform for more than two levels.

DEEC (Distributed Energy-Efficient Clustering) [9] incorporated the energy ratio factor i.e., ratio of residual energy to the average energy of the nodes. However, due to it, the advanced nodes suffered from the frequent rotation of CHs. This situation is termed as penalization effect. As a result, the CH consumed their energy at a much faster rate.

DDEEC (Developed DEEC) presented the threshold value that removed the penalization effect by making the nodes following the threshold value [10]. This algorithm worked only for two level due to which there was requirement for doing the same for three level heterogeneity. The energy heterogeneity was extended to the three levels in EEHC (Energy Efficient Hierarchical Clustering) [11] which was the first protocol that worked for three level heterogeneity. The nodes used were, normal, advanced and super nodes. The protocol EEHC improved LEACH protocol by 10% in terms of network lifetime [12][16]. However, as it had happened with DEEC, EEHC suffered from the pitfall that it could not cope up with the penalizing effect. EDDEEC (Enhanced DDEEC) [13] worked similar to the DDEEC, however it worked for three levels nodes. BEENISH (Balanced Energy Efficient Network Integrated Super Heterogeneous Protocol) [14][15] incorporated the four levels of heterogeneity as ultra-nodes are used along with normal, advanced and super nodes. P-SEP is the advanced version of SEP protocol which changed the threshold formula for CH selection. The simulation results of P-SEP protocol provide 55% and 40% improvement that LEACH and SEP protocol respectively. The following section covers the main research issue which has been targeted in heterogeneous routing protocols.

III. Enhanced Stable Routing Algorithm (ESRA)

In this work, two levels of energy heterogeneity is considered; normal nodes and advanced nodes. The proposed formula of probability for normal nodes for becoming CH is given by equation (1). The proposed work introduced the distance factor in the threshold-based equation with the predefined condition if the nodes are located within the average distance of all the nodes to the sink given by D_{avg} as shown in equation (2).

However, if the distance of a node from the sink is more than D_{avg} the threshold equations remain same as that of P-SEP. This helps in the avoiding the selection of CH at larger distance from the sink. Consequently, leading to the reduction in the energy consumption in the network. The formulae for the CH selection among the normal and advanced nodes are given in following sections A and B respectively.

A. CH selection among normal nodes

Among normal nodes the cluster head is selected by using equations (1), (2) and (3). $D_{(i)}$ is the distance of i^{th} node (where *i* ranges from 1 to 100) from the sink.

$$P_{nrm} = \frac{p_{opt}}{(1+am)*E_i(n)} \quad (1)$$

If $D_{(i)} > D_{avg}$

$$T(S_{nrm}) = \begin{cases} \dfrac{3*P_{nrm}(i)*E_{avg}(r)}{\left(1-P_{nrm}\left(r \bmod\left(\frac{1}{3*P_{nrm}(i)}\right)\right)*E_i(n)\right.} & \text{if } S(i) \in G' \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

If $D_{(i)} <= D_{avg}$

$$T(S_{nrm}) = \begin{cases} \dfrac{3*P_{nrm}(i)*E_{avg}(r)*D_{(i)}}{\left(1-P_{nrm}\left(r \bmod\left(\frac{1}{3*P_{nrm}(i)}\right)\right)*E_i(n)*D_{avg}\right.} & \text{if } S(i) \in G' \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

In equations (2) and (3) $T(S_{nrm})$is the threshold value for the normal nodes, which is compared with the random number generated by that node. If the generated random number is less than the $T(S_{nrm})$ it will be selected as CH else it will be treated as normal cluster member node.

B. CH selection among advanced nodes

The advanced nodes have higher probability of becoming the CH as compared to the normal nodes.

Among advanced nodes the cluster head is selected by using equations (10), (11) and (12).

$$P_{adv} = \frac{p_{opt}}{(1+am)*E_i(n)}(1+a) \quad (4)$$

If $D_{(i)} <= D_{avg}$

$$T(S_{adv}) = \begin{cases} \frac{3*P_{adv}(i)*E_{avg}(r)*D_{(i)}}{\left(1-P_{adv}\left(r \bmod\left(\frac{1}{3*P_{adv}(i)}\right)\right)\right)*E_i(n)*D_{avg}} & \text{if } S(i) \in G' \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

Else if $D_{(i)} > D_{avg}$

$$T(S_{adv}) = \begin{cases} \frac{3*P_{adv}(i)*E_{avg}(r)}{\left(1-P_{adv}\left(r \bmod\left(\frac{1}{3*P_{adv}(i)}\right)\right)\right)*E_i(n)} & \text{if } S(i) \in G' \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

In equations (5) and (6) $T(S_{adv})$ is the threshold value for the advanced nodes, hence comparison is made with the random number generated by that node. If the generated random number is less than the $T(S_{adv})$ it will be selected as CH else it will be treated as normal cluster member node.

TABLE I. SYMBOLS REPRESENTATIONS

Symbols	*Expansions*
P_{nrm}	Probability of normal nodes to be selected as CH
p_{opt}	Optimum probability
A	Advanced fractions
M	Number of advanced fractions
r	Round
E_i	Energy of ith node
n	Total number of nodes
$D_{(i)}$	Distance of ith node
D_{avg}	Average distance of a node
$T(S_{nrm})$	Threshold for normal nodes
G'	Set of nodes that have not become CH yet
$T(S_{adv})$	Threshold for advanced nodes
$P_{adv}(i)$	Probability of advanced nodes to be selected as CH
E_{avg}	Average energy of the nodes

When the CH selection is done, the nodes will consume their energies according to the equations specified by radio energy consumption model.

C. Radio Energy Consumption Model

The same energy model as that of used by P-SEP, DSEP and SEP protocols. It is used to compute the energy consumption of the nodes in the network.

D. Network Area and simulation parameters

The simulation network area is (100meter X 100meter) with 100 nodes randomly deployed in the network. The placement of sink is done inside the network at (50, 50) meter (m).

TABLE II. SIMULATION PARAMETERS

Parameter	*Value*
Network coverage	(100, 100) m
Eelec	50nJ/bit
Efs	$10pJ/bit/m^2$
Emp	$0.0013pJ/bit/m^4$
d_0	87m
Eda	5nJ/bit/signal
Data packet size	2000bits
Initial energy (Quantity)	In Joules
Node Number	100

The energy of the normal nodes is kept at 0.1 J and advance fractions are a=1 and m=0.1. The simulation parameters are given in the Table 1.

IV. SIMULATION AND DISCUSSIONS

ESRA protocol is simulated in MATLAB software version 2013a. The number of advanced nodes is 10 and 90 nodes out of 100 total nodes are normal nodes. Energy of advanced nodes are 0.2 Joules and 0.1 Joules of energy is rendered to normal nodes.

1. Stability Period:

The number of rounds covered when first node is dead is termed as stability period.

As the simulation are performed in MATLAB the stability period in ESRA is improved by 15.43% as compared to P-SEP and 64.39% as compared to D-SEP protocol. Such enhanced stability period is achieved due to the CH selection in the proposed approach. It is because the CH consumes less energy as their selection is done near to the sink. SEP has 229 rounds, DSEP and P-SEP covers 264 and 376 rounds whereas ESRA covers 434 rounds until the first node is dead as shown in Figure 2.

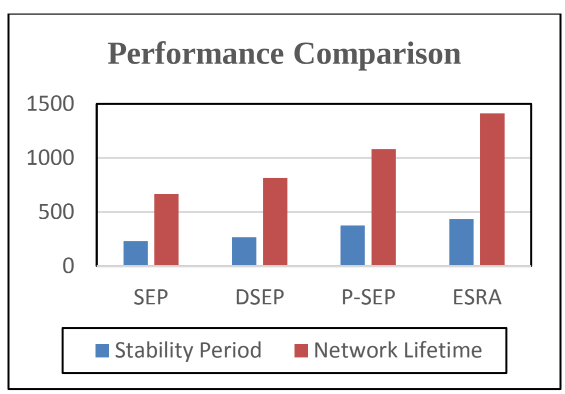

Fig. 2. Performance Comparison of protocols

2. Network Lifetime:

When the data transmission is in progress, the sensor nodes send data to the sink and their energy is consumed. In the process, sensor nodes die as they get exhausted of their energies. The moment when all nodes are dead it is termed as Network Lifetime or Last Node Dead (LND). The LND is acquired at 1413 rounds in ESRA as compared to 1079 rounds and 816 in P-SEP and DSEP, respectively making it to 30.95 % and 73.16% improvement as compared to P-SEP and DSEP protocols, respectively.

3. Number of dead nodes vs rounds:

It is interesting to analyze the number of dead nodes as the number of rounds are enhanced. From the Figure 3, it shows that graph of number of dead nodes vs rounds of ESRA has outperformed as compared to P-SEP and SEP. This graph is the analysis in the context of dead nodes while the data transmission is in the progress.

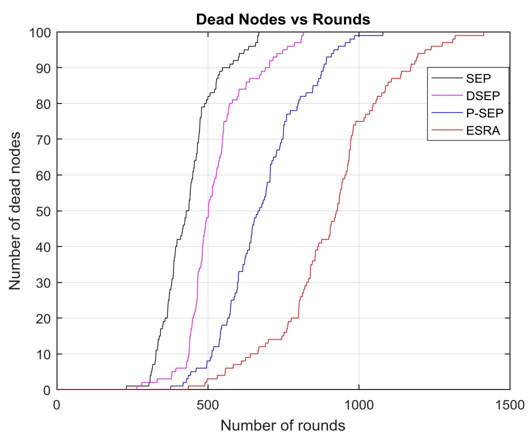

Fig. 3. Dead Nodes Comparison

4. Remaining Energy of Network:

In order to have analysis of the remaining energy of the nodes, this metric is taken into consideration. The remaining energy of the ESRA outperforms other rounds as compared to the P-SEP and SEP protocols as given in the Figure 4.

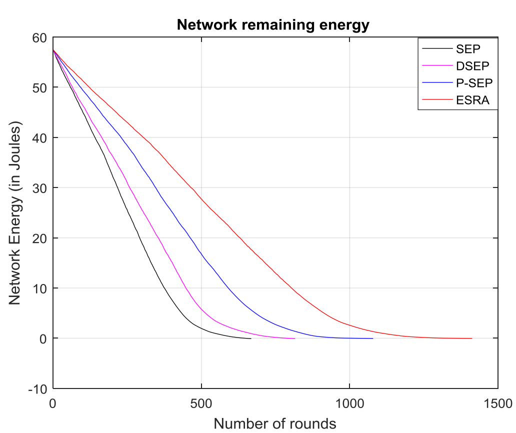

Fig. 4. Remaining energy of network

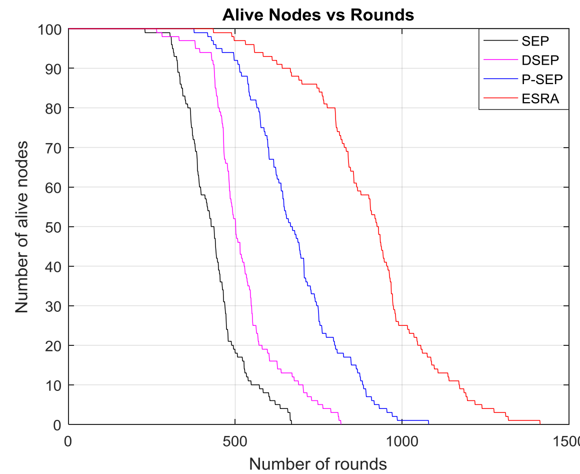

Fig. 5. Number of alive nodes vs rounds

5. Number of alive nodes vs rounds:

As far as the load balancing of the network is concerned, this metric plays a crucial role. It can be seen in Fig. 5, as the protocol ESRA covers more rounds as compared other protocols so it is due to the load balancing prevailing in the network.

V. CONCLUSION AND FUTURE WORK

WSN has proved to be promising in dealing with attended and unattended applications. However, the limited battery constraints have greatly influenced its performance. In this paper, Enhanced Stable Routing Algorithm (ESRA) is proposed that improved stability period and network lifetime significantly as compared to the PSEP, DSEP and SEP protocols. It is found that ESRA algorithm improved stability period by 15.43% and 64.39% and network lifetime by 30.95% and 73.16% as compared to PSEP and DSEP protocols, respectively. Such improvement is observed due to the distance factor that is introduced in CH selection formula to reduce the energy consumption in the network. Involving distance factor along with the energy not only increases the chances of the CH selection nearby to the sink but also prolongs the node operation. In future work, the sink mobility can be introduced to increase the Quality of Service (QoS) of the network.

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