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EETSR: Energy Efficient Threshold Sensitive Hierarchical Routing Protocol for Wireless Sensor Network

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Abstract: ***Wireless sensor Networks (WSNs) has enabled the designers to create autonomous sensors, which can be deployed randomly, without human supervision, for the purpose of sensing and communicating valuable data due to increased use of Wireless sensor Networks (WSNs) in variety of applications. In Wireless Sensor Networks, efficient energy management has a great importance. In this paper, we propose a novel hierarchical routing protocol; Energy Efficient Threshold Sensitive Routing Protocol (EETSR) to prolong network lifetime and stability period. We utilize static clustering with threshold aware transmissions to achieve these targets. Our hybrid protocol is suitable for both proactive and reactive networks. Simulations are done in MATLAB and the results show that our protocol has improved stability period than LEACH, SEP, TEEN. We also implemented the Uniform Random Model (URM) to find Packet Drop to make our scheme more practical.***

Keywords: Wireless sensor Networks, LEACH, SEP, TEEN.

1. Introduction

Wireless Sensor Networks (WSNs) consist thousands of nodes that are capable of sensing different physical and environmental attributes in real time, such as, temperature, humidity, light, pressure and have the ability to provide efficient and reliable communication using a microwave link. Nodes in WSNs are usually battery operated sensing devices with limited energy resources. Thus energy efficiency is one of the most important issues and designing power-efficient protocols is critical for prolonging the lifetime of network. Sensor nodes sense the data and forward it to the Base Station (BS) through direct or multi-hop communication. The first phase in developing a wireless sensor network is initialization and distribution of sensor nodes . Usually, the deployed sensor nodes are portably battery powered and has a limited power supply. These sensor nodes are normally deployed in potential working environments, such as, observing precarious applications over battlefield in military or in any remote or hostile environments. They are left unattended after dispersing in the network field. Consequently, to recharge or renew their batteries becomes impossible. However, the data collected by these nodes may be of scientific and strategic importance and is highly critical. Hence, efficient energy consumption in the wireless sensor networks has become a critical measure to form a vigorousness network.

WSN may be either reactive or proactive. The nodes react immediately to sudden or drastic changes in a specific attribute and keep their transmitters off otherwise in reactive protocol that's why these are well suited for time critical applications. The nodes periodically switch on their sensors and transmitters, sense the environment and transmit the data of interest in proactive protocols. Thus, these are well suited for periodic data monitoring applications.

WSNs may be categorized into homogenous and heterogeneous networks in terms of initial energy levels of nodes. In homogenous network all nodes are initially equipped with same energy level, while in heterogenous network all nodes are equipped with different energy levels. In heterogeneous routing protocols, nodes are organized into clusters. One node having maximum energy in each cluster acts as CH, while others send sensed data to their respective CHs which forward the data to BS. In hierarchical routing protocols clustering of nodes has great importance. Clustering is the partition of network area into logical regions that are known as clusters and is used to avoid inefficient use of energy. Clustering may be dynamic or static. In dynamic clustering, cluster and number of nodes associated with cluster change after every round while in static clustering, cluster and number of nodes associated with cluster remain fixed throughout the network lifespan.

Rest of the paper is organized as follows: section 2 presents the background study, while Section 3 presents the motivation. Proposed protocol design is described in section 4. Section 5 presents the simulations and results, and finally, section 6 concludes the paper.

2. Background study

The very first cluster based routing protocol, LEACH [1], is proposed by W. Heinzelman. It is a hierarchical routing protocol [7]. The communication scheme in this protocol is multi-hop. Selection of CHs is probabilistic, therefore, distribution of CHs is not uniform [3]. This may result in unbalanced distribution of CHs in the network. Since LEACH uses dynamic clustering so it consumes more energy in cluster formation after every round. The reactive protocols, TEEN [2] and APTEEN [4] have been implemented which are proposed for temperature specific applications. The protocols outperform LEACH [1] in terms of lifetime. However, these protocols are limited for temperature specific applications. LEACH uses randomized rotation of cluster-head for balancing energy load among all sensors. This approach is generally applied to homogenous environment. But in real life, sensor node is not able to keep energy uniformity. Therefore the concept of heterogeneity is introduced. Stable Election Protocol, SEP [6] heterogeneous aware routing protocol which is used to extend the time period before the first node in the network dies. In SEP [6], each node has weighted probability to become cluster head which depends upon the remaining energy in each node relative to average energy of the network. In REECH-ME [12] and DREEM-ME [13], static clustering technique is implemented. Authors in [12] proposed a Regional Energy Efficient Cluster Heads based on Maximum Energy (REECH-ME) by using static clustering technique. Selection of CHs is on the basis of residual energy of nodes. The protocol achieves longer network lifetime than LEACH. However, energy holes may be created due to unequal areas of static clusters. Static clustering [13] is proposed to prolong network lifespan by dividing the circular network into different regions. However, both REECH-ME and DREEM-ME fail to uniformly distribute the nodes in divided regions. A. Ahmad, *et al.*, [11] introduced a new routing technique; Density Controlled Divide-and-Rule (DDR) for WSNs. The protocol solves the problem of unbalanced energy utilization that causes energy and coverage holes in WSNs. A hybrid approach of uniform-random deployment of nodes is used in this work. The protocol beats LEACH [1] and REECH-ME [12] in terms of energy consumption, lifetime and stability period of the network.

3. Motivation

Energy is a very scarce resource and must be used very efficiently, especially when it is the case of portable and non chargeable power supply. LEACH [1] uses dynamic clustering that results in a variable number of clusters. Also, the selection of CHs is probabilistic. These factors lead to quick death of the nodes in LEACH. In DDR [11], the nodes uses static clustering but the use of periodic transmissions make the nodes die quickly. As a result, the network in DDR has a smaller lifetime. From TEEN [2] we got motivation that reactive protocol increases network life time and stability region. So for time critical applications, reactive protocol is a preferred option. From SEP [6] and TSEP [10], we got motivation that for stable CH election we must bring heterogeneity and CH election should be heterogeneity aware. DREEM-ME [13] motivated us to use static clusters and CH election should be based on maximum energy. So we realize that there exists a need for the sensor networks to be reactive and heterogenous with static clusters. So, in our research, we have focused to develop a protocol which can fulfill these requirements and can prolong the network lifespan.

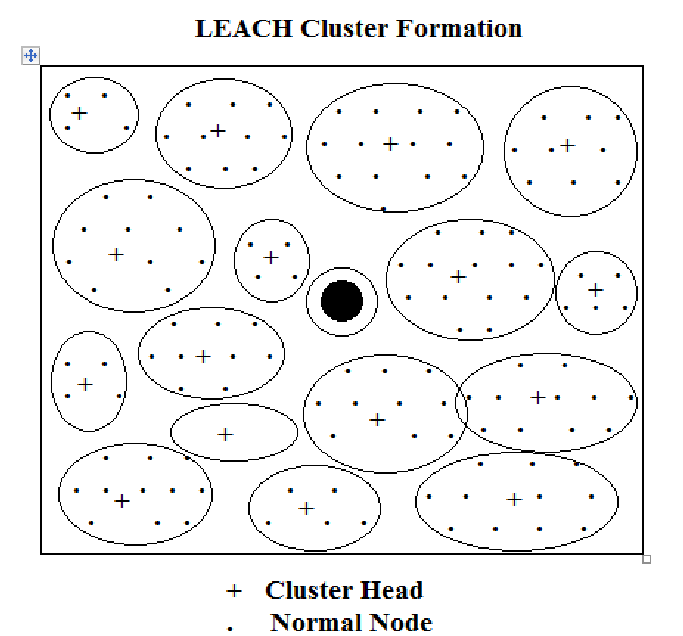


Fig. 1.Cluster formation in LEACH

4. Proposed protocol design

In this section, we firstly describe the radio model and network field division into clusters. Then we present the communication architecture and cluster head selection. Energy consumption in clusters and protocol operation is then explained in the end of this section. Mean features of our protocol are listed below:

- It is a reactive protocol with two levels of thresholds i.e. hard threshold and soft threshold.
- Static clustering with CH election based on maximum energy.
- Multi hop communication is applied.

4.1 Radio model

We assume a simple first order radio model [1]. The radio parameters for our model are shown in table 1. We also take into account d^2 energy losses due to channel transmission. Thus to transmit a k-bit message at distance d, the mathematical expressions are:

$$E_{Tx}(k,d) = E_{elec} * k + E_{fs} * k * d^2 \quad , \text{if } d < d_0$$
$$E_{Tx}(k,d) = E_{elec} * k + E_{mp} * k * d^4 \quad , \text{if } d >= d_0 \qquad (1)$$

Energy consumed in receiving data:

$$E_{Rx}(k) = E_{elec} * k$$

Where, $$d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}} \qquad (2)$$

E_{elec} is the energy dissipated per bit to run the transmitter or receiver circuit, E_{fs} and E_{mp} depend on the transmitter amplifier. A basic radio model is shown in Fig. 2.

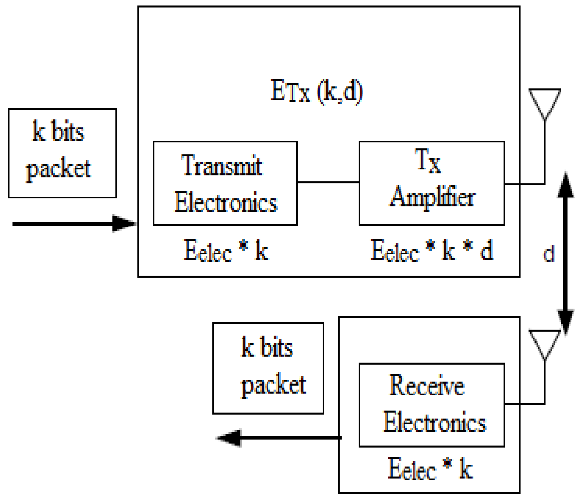


Fig. 2.First order Radio model

4.2 Network model

There are three types of sensor nodes [5, 6].They are normal nodes, advanced nodes and super nodes. Let m be the fraction of the total number of nodes N, and m_o is the percentage of the total number of nodes which are equipped with b times more energy than the normal nodes, called as super nodes, the number of these nodes is N.m.mo [8, 9]. The rest N.m.(1-m_o) nodes are equipped with a times more energy than the normal nodes; called as advanced nodes and remaining N.(1-m) are known as normal nodes. The total initial energy of the three-level heterogeneous networks is given by:

$$E_{total} = N.(1-m).E_0 + N.m.(1-mo).(1+a).Eo + N.m.mo.Eo.(1+b) \quad (3)$$

Thus we can say that the total energy of the system is increased by a factor of (1+ m.(a + m_o.b)) than SEP[6].

In our protocol, we divide the network area in different sub regions as shown in Fig. 3. First of all, the whole network area is divided into three concentric squares and the BS is situated at centre of network field. The total number of nodes is 100 out of which 20 nodes are normal, 40 are advanced and 40 are super.

4.2.1 Cluster Formation

The entire network field is divided into nine regions. Nodes are deployed randomly and distributed heterogeneously in each region. Firstly, network has been divided into 3 equidistant concentric squares. These concentric squares are named as: Internal Square (Is), Middle Square (Ms) and Outer square (Os). The inner square is named as Region 1 or R1 and deployed with normal nodes. The middle square is divided into 4 rectangular regions and are named as R2, R3, R4 and R5. The outer square is divided into 4 rectangular regions and are named as R6, R7, R8 and R9 as shown in Fig. 3. The boundaries of all regions are taken as:

- R1 - (30 - 70, 30 - 70)
- R2 - (70 - 85, 30 - 85)
- R3 - (15 - 70, 70 - 85)
- R4 - (15 - 30, 15 - 70)
- R5 - (30 - 85, 15 - 30)
- R6 - (85 - 100, 15 - 100)
- R7 - (0 - 85, 85 - 100)
- R8 - (0 - 15, 0 - 85)
- R9 - (15 - 100, 0 - 15)

Each region contains fixed number of nodes. R1 contains 20 nodes which are normal, whereas regions R2, R3, R4 and R5 contain 10 nodes per region and are advanced type. Regions R6, R7, R8 and R9 contain 10 nodes per region and are super type. The BS is located at the center of the field.

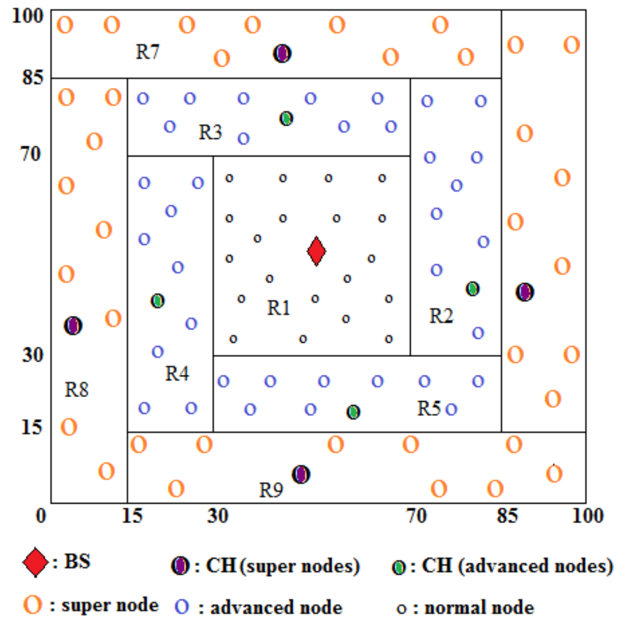


Fig. 3.Nodes distribution in network area

4.2.2 Communication Architecture

In our proposed model, data from the sensors reach BS by using multi-hop scheme. It consists of 3-Tier communication architecture. In Tier-1, all the non-CH nodes forward their sensed data to their respective CHs. In Tier-2, CHs of the outer regions Os send their data to the nearest CHs of the middle region Ms. To achieve energy efficiency, CHs of Os find their distance to the next level CHs and send the data to the nearest CHs. For instance, CH of region M6 finds its distance with the CHs of region M2, M5 and M7, and forwards its data to the minimum distant CH. In Tier-3, nodes of inner region Is and CHs of middle region Ms communicate with BS. Fig. 4 depicts this 3-Tier architecture of our implemented work.

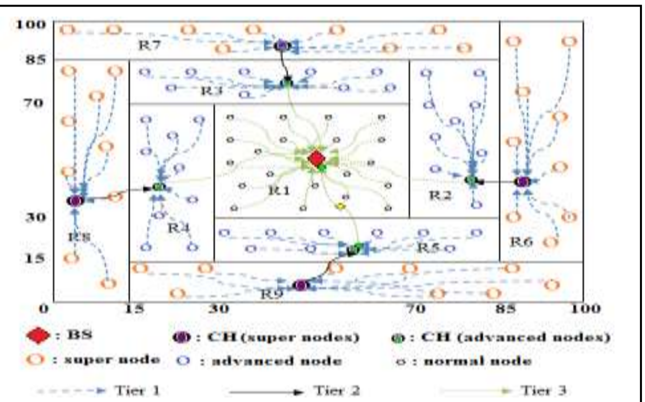


Fig. 4. Communication Architecture

value of p is different for these types of nodes. The probabilities of normal, advanced and super nodes are:

$$P_i = \begin{cases} \dfrac{\text{Popt} \times \text{Ei(r)}}{(1 + m(a + mo \times b))E'(r)} & \text{if } s_i \text{ is the normal node} \\ \dfrac{\text{Popt} \times (1+\text{a}) \times \text{Ei(r)}}{(1 + m(a + mo \times b))E'(r)} & \text{if } s_i \text{ is the advanced node} \\ \dfrac{\text{Popt} \times (1+\text{b}) \times \text{Ei(r)}}{(1 + m(a + mo \times b))E'(r)} & \text{if } s_i \text{ is the super node} \end{cases} \quad (5$$

4.2.3 Cluster Head Selection

In any clustering protocol, selection of CHs is a very important step. As already stated, our protocol uses static clustering, number of clusters and CHs remain fixed throughout the network operation. One CH is selected in each region except region 1. Hence, total of 8 CHs are selected in every round. As our protocol uses a multi-hop scheme, this significantly brings robustness in the network, and energy consumption is controlled to a greater extent. CH is selected on the basis of maximum energy. Any node can become the CH for first round for that particular region because initial energy of all nodes of every region is same. For every next round, the CH is selected on the basis of their remaining energies and this process continues during the network lifespan. Traditionally as per LEACH, Cluster head algorithm is broken into rounds. At each round node decides whether to become a cluster head based on threshold calculated by the suggested percentage of cluster heads for the network (determined a priori) and the number of times the node has been a cluster-head so far. This decision is made by the nodes by choosing the random number between 0 and 1. If the number is less than a threshold T(s) the node becomes a cluster head for the current round. The threshold is set as:

$$T(n) = \begin{cases} \dfrac{p}{1 - p\left(r \times mod \frac{1}{p}\right)} & , \ if \ n \in G \\ 0 & , \ otherwise \end{cases} \qquad (4)$$

where p, r, and G represent, respectively, the desired percentage of cluster-heads, the current round number, and the set of nodes that have not been cluster-heads in the last 1/p rounds. Using this threshold, each node will be a cluster head, just once at some point within 1/p rounds. In the three level heterogeneous networks there are three types of nodes normal nodes, advanced nodes and super nodes, as discussed in section 4, based on their initial energy. Hence the reference

Where $E'(r)$= remaining energy
N = total nodes
E_{total} = total energy of network
r = current round
R= total rounds

Threshold for cluster head selection is calculated for normal, advanced, super nodes by putting above values in Eq. (4).

$$T(s_i) = \begin{cases} \dfrac{Pi}{1 - Pi\left(r \times mod \frac{1}{Pi}\right)} & if \ Pi \in G' \\ \dfrac{Pi}{1 - Pi\left(r \times mod \frac{1}{Pi}\right)} & if \ Pi \in G'' \\ \dfrac{Pi}{1 - Pi\left(r \times mod \frac{1}{Pi}\right)} & if \ Pi \in G''' \end{cases} \qquad (7)$$

$$E'(r) = \frac{1}{N} \times E_{total} \times \left(1 - \frac{r}{R}\right) \qquad (6)$$

Where G' is the set of normal nodes that have not become cluster heads within the last 1/Pi rounds of the epoch where s_i is normal node, G'' is the set of advanced nodes that have not become cluster heads within the last 1/Pi rounds of the epoch where s_i is advanced node, G''' is the set of super nodes that have not become cluster heads within the last 1/Pi rounds of the epoch where s_i is super node.

4.2.4 Protocol Operation

In our proposed protocol, a reactive WSN is being implemented. The nodes send their data to BS and CHs only when the sensed attribute crosses a pre-defined threshold, and keep their transmitters off otherwise. We use the static clustering technique in which the network area is divided into 9 regions. The number of deployed nodes and clusters in these regions remain static throughout the network lifetime. Once the network is deployed, the sensors start sensing. The sensors transmit only if the threshold value is crossed. Algorithm 1 describes the stepwise operation of our proposed protocol. Following are the two types of threshold values:

1) Hard Threshold (HT): This is the first threshold value with which each normal sensor compares its sensed attribute. It is an absolute value of the attribute beyond which, the node crossing this value, turns transmitter on and reports to its CH.

2) Soft Threshold (ST): This is the second value of the threshold with which the sensor compares its value, only when the sensor has crossed hard threshold. It's a very small change in the value of the sensed attribute which triggers the node to turn its transmitter on and report to its CH. A higher value of ST may lead to lower power consumption and higher network lifetime but at the cost of lesser transmissions (which may involve critical data), and vice versa.

Algorithm 1 Protocol Operation

Step 1⟶ Deploy Nodes and Initialize Network
Step 2⟶ Check type of nodes
Step 3⟶ **if** nodes belong to I_s **then**
nodes send data to BS
else nodes belong to M_s
CHs send data to BS
else nodes belong to O_s
CHs send data to CHs of M_s
end if
Step 4⟶ Initialize N_i with nodes of each region M_i
Step 5⟶ **if** CH.N_i belongs to Os **then**
if CH.N_i belongs to M6 **then**

This enhancement is achieved because the threshold sensitive nature of our protocol.

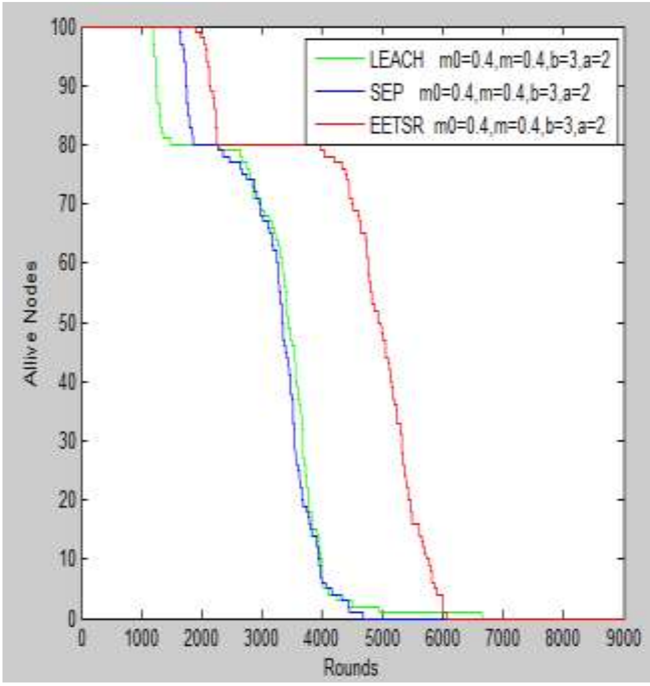


Fig . 5. Alive nodes (stability period) of LEACH, SEP and EETSR

5. Simulations, results and Discussions

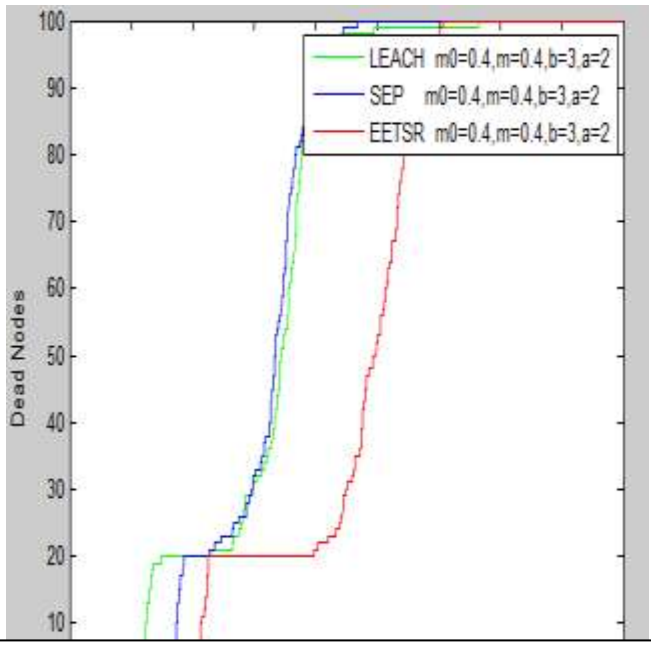
In this section, we present and discuss the simulation results of our proposed protocol. The results are compared with the existing traditional protocols by considering following metrics: number of alive nodes, stability period, network lifetime, number of packets sent, number of packets dropped and energy consumption. Simulation configuration for our protocol is shown in Table 1.

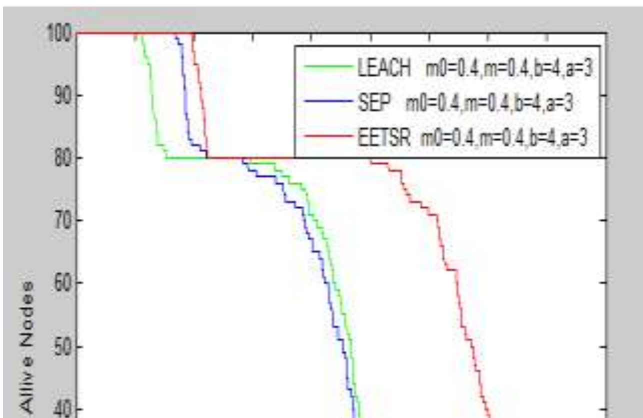
The results shown in Fig. 5, Fig. 6 and Fig.7 are the MATLAB simulation outcomes when super nodes contain 3 times more energy than normal nodes and advanced nodes contain 2 times more energy than normal nodes i.e. b=3, a=2.The fraction of super nodes is 0.4 and of advanced nodes is also 0.4 that means normal nodes are 20%, advanced nodes are 40% and super nodes are also 40%. As shown in Fig. 5 the first node of our protocol, EETSR dies later than LEACH and SEP, thus improves the stability period of network. The reason of this later dying of node is the static clustering concept, heterogenous nodes distribution and the threshold sensitive nature of our proposed protocol.

energy of super nodes and advanced nodes, stability period and throughput of network is increased and packet drop rate (instability period) is also decreased in comparison of previous case when b=3 and a=2.

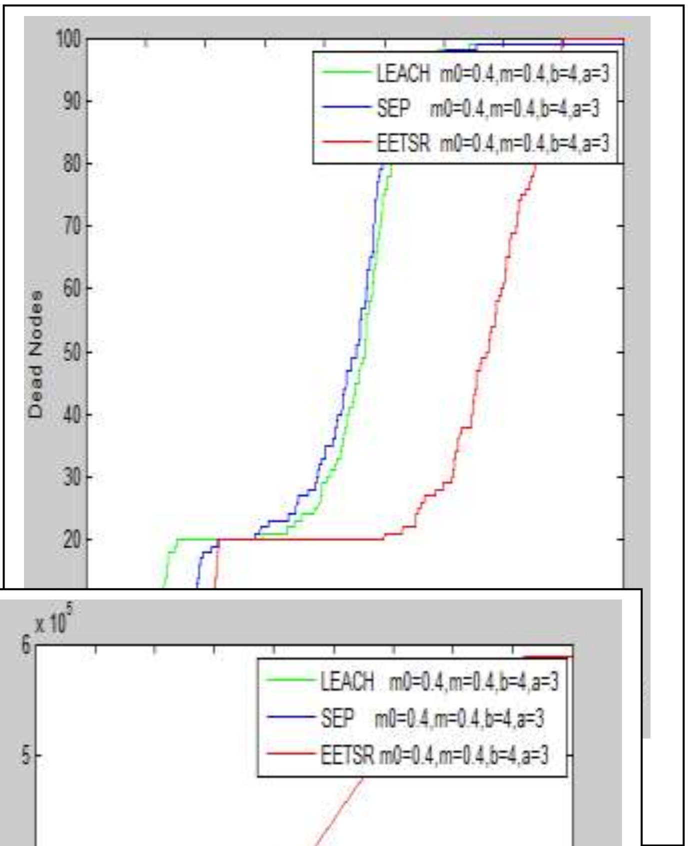
Table 1. Radio Parameters

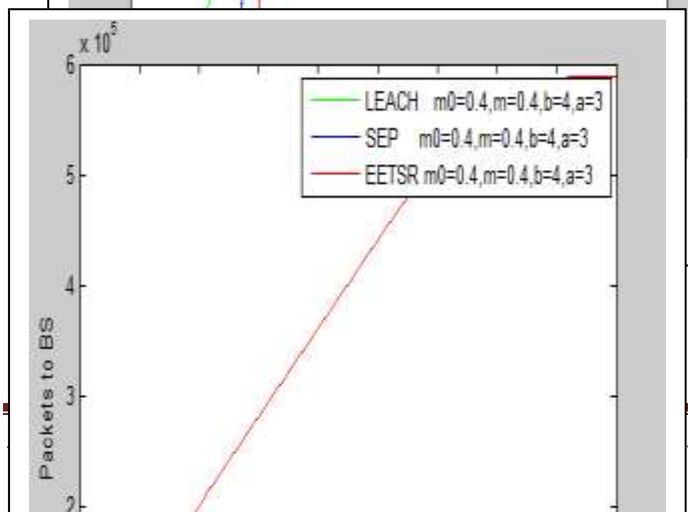
Parameters	Value
Initial energy E_0	0.5 J
Initial energy of advance nodes	$E_0(1+\alpha)$
Energy for data aggregation E_{DA}	5 nJ/bit/signal
Transmitting and receiving energy E_{elec}	5 nJ/bit
Amplification energy for short distance E_{fs}	10 Pj/bit/m^2
Amplification energy for long distance E_{amp}	0.013 pJ/bit/m^4
Probability P_{opt}	0.1





In Fig. 6, we can see that all the nodes of EETSR died after 6000th round while in case of LEACH and SEP all nodes died before 6000th round. It shows that instability period of LEACH and SEP is more than our proposed protocol, EETSR. The reason behind this is the heterogenous concept and threshold attributes which avoids unnecessary transmissions and hence, lesser energy consumption, so the nodes of EETSR live more time than LEACH and SEP and increases network lifetime. Fig. 7 demonstrates the throughput of our protocol outperforms than LEACH and SEP. The packets sent to BS reaches at 4.5×10^5 which is much more than that of LEACH (0.4) and SEP (0.7).





6. Conclusion and Future work

In this paper, we focus on efficient utilization of energy to overcome the problem of energy and coverage holes in WSNs. A novel approach is proposed to avoid frequent communication by using reactive and threshold dependent transmission scheme. Static clustering technique along with heterogenous distribution of nodes has been used to prolong the stability period and network lifetime. CHs are selected on the basis of maximum energy by using concepts of LEACH. To minimize energy consumption, 3- Tier communication architecture is introduced. The performance outcomes of our proposed protocol is compared with LEACH and SEP. Results validate that EETSR outperform the existing routing protocols in terms of stability period, network lifetime and throughput.
In future, we are also interested to scale it up for user defined number of sensor nodes and for larger areas as well.

Acknowledgements

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