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Research Article

ESRP: Energy Sensitive Routing Protocol for Wireless Sensor Networks

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Abstract

In Wireless Sensor Networks sensor nodes are used to sense the environment to collect important information. These tiny sensor nodes are generally battery operated and deployed randomly out of human reach. Thus efficient utilization of battery power is an important issue. In this paper, we proposed a new protocol: Energy Sensitive Routing Protocol (ESRP) for Wireless Sensor Networks, which introduces a new clustering technique in order to select cluster heads. In ESRP, we grouped the sensor nodes of a network into four classes based on their initial and residual energy. Node belongs to higher level energy class having greater probability to become a cluster head. This technique introduces a balanced and dynamic method where the cluster head election probability is more efficient. Simulation results prove that ESRP successfully achieves a long stability period, network lifetime and better average throughput than existing protocols like LEACH and SEP.

Keywords: *Clustering, Networks Lifetime, Networks Stability, Throughput, Wireless Sensor Networks.*

1. Introduction

Now a days the effectiveness of WSNs cannot be ignored. The vast diversity of sensor nodes provides WSNs with a wide range of applications in military, industry, security and environmental research. Among the various scopes one of the major applications of sensor network is to collect information periodically from a remote area where each node continually senses the environment and sends back this information to the base station (BS). However sensor networks are limited by the lifetime of the node's battery. Once they are deployed, the network can keep operating only until the battery power is sufficient. But it is almost impossible to replace the battery once deployed over an inaccessible area. Therefore, it is desirable that the network protocol should take care of issues like energy-efficiency, network-stability, network-lifetime, self-configuration etc. Clustering is a key approach to achieve an enhanced lifetime of wireless sensor networks. So far, many clustering technique have been introduced. In clustering the nodes are grouped into small cluster regions. The leader node of a cluster region is referred to as cluster head (CH). All nodes in cluster transmit their sensed information to corresponding CH. CH manages the group communication with the BS; see Figure 1.

Apart from these a sensor network can also be homogeneous or heterogeneous, based on nodes initial energy (V. Mhatre *et al*, 2004; V. Katiyar *et al*, 2011). In homogeneous networks, all nodes equipped with same amount of initial energy and in heterogeneous networks,

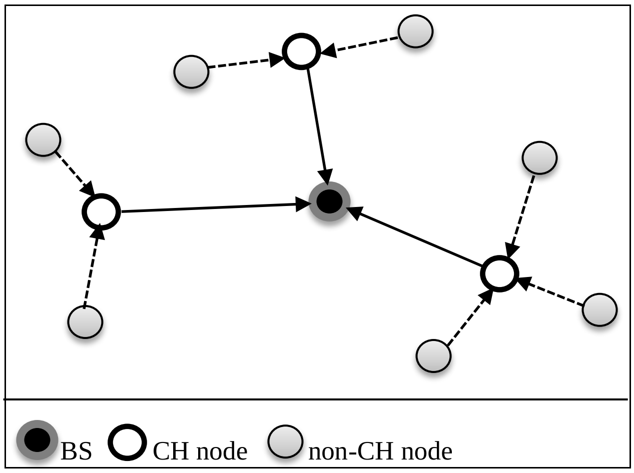

Figure 1: Cluster Formation in WSN.

few nodes, which are known as advance nodes have more initial energy than the other normal nodes. In our proposed protocol, we have used heterogeneous network environment. To achieve the energy consumption in a distributed manner, we grouped all sensor nodes into classes based on their initial and available residual energy. The probability of becoming cluster head will be increased among the nodes in the order of lower energy classes to higher energy classes. This technique significantly increases lifetime of every single nodes of WSNs as well as throughput of sensor networks.

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In the following sections we organized our paper as follows: Section 2 reviewed the related work in this field. In section 3, we briefly discussed our proposed clustering technique and algorithm. Simulation result is presented in section 4. And finally draws the conclusion and discusses the scopes of future work in section 5.

2. Related Work

The most challenging issue in sensor networks is limited and un-rechargeable energy source as nodes are deployed in areas where it is not feasible to replace the battery. Hence they are prone to failure, and therefore the network topology changes frequently. So, many efficient power saving schemes have been introduced to provide reasonable energy consumption and to improve the overall networks lifetime. But approaches like Direct Communication and Minimum Transmission Energy (T. J. Shepard *et al*, 1996) do not guarantee balanced energy distribution among the sensor nodes. In Direct Communication Protocol each sensor node transmits information directly to the base station, regardless of distance. As a result, the nodes furthest from the BS are the ones to die out first (W. B. Heinzelman *et al*, 2002). On the other hand, in case of Minimum Transmission Energy routing protocol data is transmitted through intermediate nodes. Thus each node acts as a router for other nodes' data in addition to sensing the environment. Nodes closest to the BS are the first to die out in MTE routing. So far cluster-based technique is one of the approaches which successfully increases the lifetime and stability of whole sensor networks. To support data aggregation through efficient network organization, nodes can be partitioned into a number of small groups called clusters. Cluster heads change as nodes move, in order to keep the network fully connected. Clustering makes the network scalable and thus reduces energy consumption of the nodes. Here some existing widely used clustering technique are discussed briefly.

2.1. Low Energy Adaptive Clustering Hierarchy (LEACH)

W. R. Heinzelman, A. P. Chandrakasan and H. Balakrishnan proposed Low Energy Adaptive Clustering Hierarchy (W.R. Heinzelman *et al*, 2000) in the year of 2000. It is one of the most popular hierarchical routing algorithm for homogeneous sensor networks. In LEACH, cluster heads are selected in a random fashion. The non-cluster head nodes sense the informations and send it to the associated cluster heads that further forward the aggregate information to the base station. This technique saves energy since the transmissions is only be done through cluster heads rather than all sensor nodes. Generally in LEACH the optimal number of cluster heads are estimated to be 10 percent of the total number of alive nodes in a network. Cluster heads change randomly over time in order to balance the energy dissipation of nodes. This decision is made by the node choosing a random number between 0 and 1. The node becomes a cluster head for the current round if the number is less than the threshold value generated by the systems. However, LEACH is only effective for homogeneous network as it sets same probability of becoming cluster head to all sensor nodes.

2.2. Stable Election Protocol (SEP)

In 2004, G. Smaragdakis, I. Matta and A. Bestavros proposed a heterogeneous aware protocol known as Stable Election Protocol (G. Smaragdakis *et al*, 2004). SEP, an extension of LEACH, introduced heterogeneous network where few nodes known as advanced nodes have more initial energy than other normal nodes. SEP maintains the constraint of well-balanced energy consumption. In SEP, initially, advanced nodes have to become the CHs more often than normal nodes. Thus, SEP yields longer stability region by utilizing the extra energy of powerful nodes. But the main drawback of SEP method is that the election of the cluster heads among the two type of nodes is not dynamic, which results that the nodes that are far away from the powerful nodes will die first.

2.3. Enhanced Stable Election Protocol (ESEP)

An extension of SEP, Femi A. Aderohunmu and Jeremiah D. Deng proposed E-SEP (F.A. Aderohunmu *et al*, 2009). E-SEP considers three types of nodes- normal nodes, intermediate nodes and advance nodes. Where, advance nodes are in a fraction of total nodes with an additional energy as in SEP and a fraction of nodes with some extra energy greater than normal nodes and less than advance nodes, called intermediate nodes, while rest of the nodes are normal nodes. Like SEP, in ESEP CHs are selected depending on probability of each type of node. In ESEP energy dissipation is controlled to some extent due to three levels of heterogeneity. But also, ESEP has same drawbacks as of SEP.

2.4. Distributed Energy Efficient Clustering Protocol (DEEC)

In 2006, Q. Li, Z. Qingxin and W. Mingwen proposed Distributed Energy Efficient Clustering Protocol (L. Qing *et al*, 2006). In this protocol, the cluster heads are selected using the probability based on the ratio between residual energy of each node and the average energy of the network. The nodes with high residual energy have more chances to become the cluster heads as compared to nodes having low residual energy. The main disadvantage of DEEC is advanced nodes are always penalized, particularly when their residual energy reduced and become in the range of the normal nodes. In this position, the advanced nodes die rapidly than the others.

3. ESRP: Proposed Protocol

Cluster head selection plays significant role for energy efficiency of clustering algorithms. The algorithm that we have presented in this paper introduces a new technique of cluster heads selection. ESRP is an Energy Sensitive Routing Protocol for Wireless Sensor Networks. The main idea of ESRP is to minimize energy consumption and thus enhance networks stability and lifetime of each sensor nodes. ESRP maximizes the selection of cluster heads from the nodes which are grouped in to the highest energy level class. The model is described as follows**.**

3.1. Cluster Formation

In ESRP the network is grouped in to four classes: classA, classB, classC and classD. All advance nodes belong to classA. ClassB consists normal nodes whose individuals remaining energy is more than the half of its initial energy. ClassC consists normal nodes, which do not belong to classB and whose individuals remaining energy is more than one fourth of its initial energy. ClassD consists rest normal nodes, which do not belong to classB and classC and whose individual remaining energy is more than zero. The probability of becoming cluster head of classA nodes is maximum. Then it decreases in order of classB, classC and classD. If the total number of cluster heads are ten, then four cluster heads (40% of total number of cluster heads) will be selected from classA, three cluster heads (30% of total number of cluster heads) will be selected from classB, two cluster heads (20% of total number of cluster heads) will be selected from classC and one (10% of total number of cluster heads) from classD. Traditionally, as per LEACH , 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 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 $T(n)$ the node becomes a cluster head for the current round. The threshold is set as:

$$T(n)=\begin{cases} \frac{P}{1-P[r \bmod (\frac{1}{P})]} & ; if\ Nnrm \in G' \\ 0 & ; otherwise \end{cases} \quad (1)$$

where P is the desired percentage of cluster heads (e.g. 0.1), r is the current round and G' is the set of nodes that have not been cluster heads in the last $1/P$ rounds. After electing CHs in each region, CHs inform their role to neighbor nodes by broadcasting a control packet. Upon received the packet from CH, each node transmits acknowledge packet. Node who find nearest CH, becomes member of that CH.

3.2. Algorithm

The operational algorithm of our proposed cluster based Energy Sensitive Routing Protocol can be divided by three phases: Node class setup phase, Cluster head selection setup phase and Data transmission in steady state phase.

***Algorithm 3.2.1: Node Class Setup Algorithm*:**
Input: No. of Sensor nodes, Node initial energy, Node residual energy.
Output: Sensor nodes are grouped in to four classes based on their energy level.

Algorithm 3.2.1: *Node Class Setup Phase*

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1. **START**
2. **if** (node_energy > 0.5) **then**
3. node.class=A
4. **else if** (node_energy> node_initial_energy/2 && node.class ~=A) **then**
5. node.class=B
6. **else if** (node_energy> node_initial_energy/4 && node.class ~=A && node.class ~=B) **then**
7. node.class=C
8. **else if** (node_energy> 0 && node.class ~=A && node.class ~=B && node.class ~=C) **then**
9. node.class=D
10. **end if**
11. **END**

Algorithm 3.2.2: *Cluster head Selection Algorithm*

Input: No. of Sensor nodes, Probability (P), Node initial energy, Node residual energy.
Output: Cluster heads, Clusters.

Algorithm 3.2.2*: Cluster head Selection Algorithm*

1. **START**
2. Base station broadcasts *HELLO* packets.
3. **if** a node receives *HELLO* packet **then**
   3.1. Reply with residual energy and location to BS.
4. **end i**f
5. **if** network life time is not over **then**
   5.1. Call: Node Class Setup Phase Algorithm.
   5.2. Base Station chooses p1%, p2%, p3% and p4% of (*P · total number of alive nodes)* as Cluster heads from Class A, B, C and D respectively, where p1>p2>p3>p4.
6. **end if**
7. **if** a node is Cluster head **then**
   7.1. It broadcasts its Cluster head advertisement packet.
   7.2. All non-Cluster head nodes, sends *Join_Cluster* request packet to those cluster head, who's received signal strength is more.
8. **end if**
9. Cluster head accepts the *Join_Cluster* request and forms respective clusters.
10. **END**

Algorithm 3.2.3**:** *Data Transmission Algorithm*
Input: Cluster heads, Clusters.
Output: Actual data transmission, Residual energy of network, No. of dead nodes.

Algorithm 3.2.3: Data Transmission Algorithm

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1. **START**
2. Cluster head creates TDMA schedule for all sensor nodes in their cluster.

3. All non-cluster head nodes send their sensed data to associated Cluster head as per the assigned TDMA schedule.
4. All Cluster heads aggregate their cluster's data to reduce packet size.
5. Then cluster heads send their own data with aggregates data to the base station.
6. **END**

3.3. Radio Model

In our work first order radio model (IF. Akyildiz *et al*, 2002; J. N. Alkaraki *et al*, 2004) is adopted for measuring energy consumption by sensor nodes while communicating. Radio Energy Dissipation Model shown in Fig. 2. Equation 2 represents the amount of energy consumed for transmitting *l* bits of data to distance *d*. Equation 3 represents the amount of energy consumed for receiving *l* bits of data which is caused only by circuit loss.

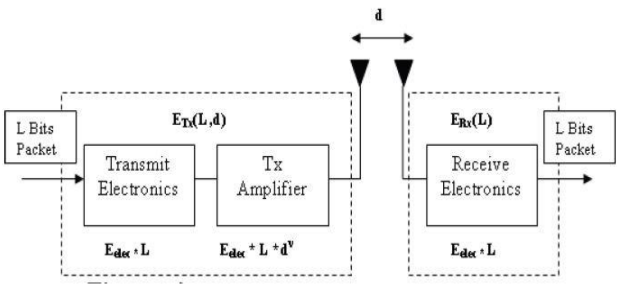

Figure 2: Radio Energy Dissipation Model.

$$E_{TX}(l,d)=\begin{cases} l \cdot E_{elec} + l \cdot \varepsilon fs \cdot d^2, & d < d_0 \\ l \cdot E_{elec} + l \cdot \varepsilon mp \cdot d^4, & d \geq d_0 \end{cases} \quad (2)$$

$$E_{RX}(l,d)=l \cdot E_{elec} \quad (3)$$

where d refers the transmission distance i.e. distance between a member-node and its cluster-head or between cluster-head and base station (BS). d_0 is threshold distance.

E_{elec} *is* the energy consumption per bit in the transmitter and receiver circuitry by a node when $d < d_0$ and $d \geq d_0$ respectively, where $d_0 = \frac{\sqrt{\varepsilon fs}}{\sqrt{\varepsilon mp}}$. ε_{fs} and ε_{mp} are the energy consumption coefficient of the amplifier, when the transmission distance is less than the threshold distance, free space channel model is used. On the contrary, Multi-path fading channel model is used.

In addition to transmission and reception of data, data aggregation performed at CHs needs a significant amount of energy (EDA).

4. Results

In the following section we have described Simulation settings, Performance metrics and Results.

4.1. Simulation Settings

Simulation experiments are conducted in MATLAB R2007b environment. We have used a 100m × 100m region of total 100 nodes deployed randomly shown in Fig. 3. Base station is in the center position and so, the maximum distance of any node from the base station is approximately 70m. To have a fair comparison with SEP and LEACH we introduced same number of advance nodes and normal nodes with different energy levels as in our proposed ESRP protocol. The simulation results of ESRP is shown in Fig. 4, Fig. 5 and Fig. 6, which clearly depicts that our proposed protocol outperforms LEACH and SEP in terms of energy consumption per round. We prove that ESRP is providing a better stability period, throughput and network lifetime. For simulations of Fig. 4, Fig. 5 and Fig. 6, we have considered 10% of nodes to be advance nodes with additional energy of factor: α= 2. Rest 90 % of nodes are normal nodes having 0.5J initial energy. So advance nodes are initially equipped with 1J (0.5×2) of energy.

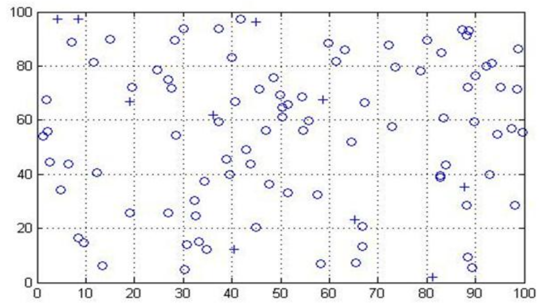

Figure 3: Random deployment of sensor nodes.

The other parameters used in simulation are shown in Table 1. Any change in these values is explicitly mentioned.

Table 1: Parameter settings

Parameter	Value	Comments
N	100	Number of nodes.
P	0.1	Probability to become a cluster head.
E_0	0.5 J	Nodes initial energy.
E_{TX}	50*0.000000001	Transmitter energy per node.
E_{RX}	50*0.000000001	Receiver energy per mode.
E_{fs}	10*0.000000000001	Amplification energy when d < d_0
E_{mp}	0.0013*0.000000000001	Amplification energy when d >= d_0
EDA	5*0.000000001	Data Aggregation Energy.
R_{max}	7000	Rounds of simulation.
d_0	sqrt(E_{fs} / E_{mp})	Distance between CH and BS.

4.2. Performance Metrics

The terminologies which we used in our paper are:

- **Network Lifetime:** It is the time interval from which the network starts operating and until the time when the last alive node runs out of battery charge.
- **Stability Period**: It is the time interval between the start of networks operation and the death of the first sensor node.

- **Instability Period:** It is the time interval from the death of the first node to the death of the last sensor node.
- **Throughput:** The rate of data sent to the base stations from cluster head as well as the nodes from direct zone.
- **Epoch:** Number of rounds after which a CH can become eligible for being CH again.
- **Data Aggregation:** Deployed nodes in an area prone to collect similar information. Data aggregation is to minimize the redundant information.
- **Number of cluster heads per round:** This measurement reflects the number of nodes which would send aggregated information directly to the base station.
- **Number of alive nodes per round:** This instantaneous measure reflects the total number operation of sensor nodes.

4.3. Simulation Results

In this section, we compare the performance of LEACH, SEP and ESRP under heterogeneous network system. The result shows that ESRP prolonged the stable region compared to LEACH and SEP. Normal nodes are considered dead after consuming 0.5 joule energy and advance nodes are considered dead after consuming 1 joule energy. ESRP protocol obtains the longer stability period and network lifetime because the energy consumption is well distributed among nodes. Network is divided into logical regions based on the nodes residual energy and in order to ensure minimum energy consumption in each round per epoch, the high residual energy nodes are elected as cluster heads with higher probability over the less powerful ones. Thus ESRP balances energy consumption among sensor nodes. On the other hand, in heterogeneous network, nodes of LEACH protocol die quickly. SEP performs better than LEACH in heterogeneous network. But ESRP performs better than LEACH and SEP and successfully increases the stability period of network, lifetime of each sensor nodes, and throughput of the whole network.

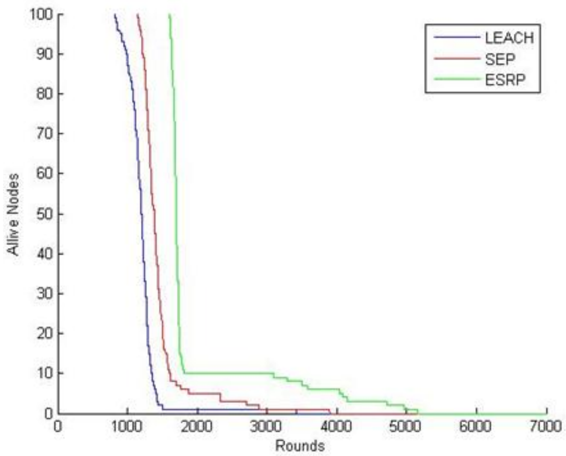

Figure 4: Shows number of alive nodes per round of LEACH, SEP, ESRP under heterogeneous networks when m=0.1 and a=2.

No. of rounds is varied with corresponding no. of operational nodes and is plotted in Fig. 4 and Fig. 5. As time passes on with more rounds, nodes gradually die out. From Fig. 4 & Fig. 5 we can see that first node dies in LEACH after 804 rounds and in SEP after 1145 rounds. But in ESRP first node dies at 1603 round. So ESRP performs approximately 2 times better than LEACH and 1.4 times better than SEP.

Also ESRP increases the network lifetime and lifetime of each sensor nodes than LEACH and SEP. As last node dies in LEACH, SEP and ESRP after 3419, 3906 and 5150 rounds respectively, that implies ESRP provides better network lifetime also. The result is shown in Fig. 5.

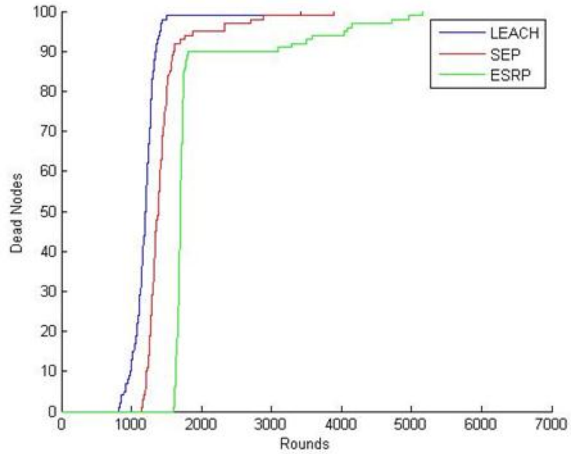

Figure 5: Shows number of dead nodes per round of LEACH, SEP, ESRP under heterogeneous networks when m=0.1 and a=2.

From the above scenario we observe that ESRP performs well than LEACH and SEP. LEACH does not use the advantage of extra energy provided by heterogeneous nodes. LEACH sets same probability for all nodes to be cluster head. As a result the stability period of LEACH becomes short. SEP has a longer stability period than LEACH because of nodes discriminations. SEP sets two probabilities for selecting CHs based on nodes initial energy. But the possibility in SEP is that after certain rounds an advance node might become normal node due to more energy consumption. In such conditions, SEP selects low energy node as a maximum probability of being cluster head as it is only aware of nodes initial energy. But ESRP selects cluster heads based on its initial as well as remaining energy. In ESRP, system sets maximum probability of selecting a cluster head from high energy nodes at each round. Hence stability period and network lifetime of ESRP increases.

In the above figure (Fig. 6) the throughput of ESRP is observed. Throughput is defined as the maximum number of packets that can be sent to the destination (Base station). We can see that throughput of ESRP is better than LEACH and SEP because of the proper selections of cluster heads. As stability period is longer, thus ESRP delivers more messages to base station. Which again proves that ESRP is more efficient than existing protocol like LEACH and SEP.

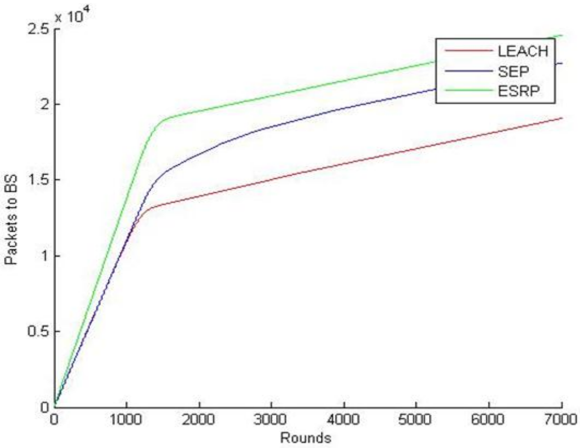

Figure 6. Shows number of packet sends to base station per round of SEP, LEACH, and ESRP under heterogeneous networks when m=0.1 and a=2.

Conclusions

In this paper we proposed ESRP, an Energy Sensitive Routing Protocol which used four level hierarchy based on their initial and residual energy. As ESRP sets the probability of becoming cluster head based on nodes residual energy thus energy consumption is done in an equitable manner. Simulation result also shows this heterogeneous model effectively utilize the extra energy to increase the networks lifetime. Though the technique can be extended further to employ protocol switching between homogeneous and heterogeneous settings. Also we can incorporate sleep and awake strategy for nodes far from base station to increase stable region**.**

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