SEP-E (RCH): Enhanced Stable Election Protocol Based on Redundant Cluster Head Selection for HWSNs

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Abstract. In this paper, an improved redundant cluster head selection mechanism for SEP-E has been proposed to balance the network load and to extend the network life time. In order to select reasonable cluster heads, our scheme first select an initial cluster head and a tentative or redundant cluster head in every cluster at each round. The node which has higher remaining energy and minimum mean distance is elected as cluster head of current round. Simulation results illustrate that SEP-E (RCH) prolongs the network life effectively, the time which first node dies, half of the node dies and last node dies is longer than SEP-E.

Keywords: Wireless sensor network, clustering, heterogeneity, Energy Efficient.

1 Introduction

With the advances in the technology of micro-electromechanical system (MEMS), developments in wireless communications and wireless sensor networks have also emerged [1]. The last few years have seen an increased interest in the potential use of wireless sensor networks (WSNs) in various fields like disaster management, battle field surveillance, and border security surveillance [2,3,4]. In such applications, a large number of sensor nodes are deployed, which are often unattended and work autonomously. Sensor nodes are typically powered by batteries with a limited lifetime, and in most cases, the batteries cannot be recharged. The energy problem in WSNs remains as one of the major barriers that prevent the complete exploitation of this technology. Clustering is a key technique used to extend the lifetime of a sensor network by reducing energy consumption [5]. It can also increase network scalability.

In recent years, Most studies of Clustered topology [6] schedule in Wireless Sensor networks (WSNs) such as LEACH[7], MPTC[8], AToM[9], GENSEN[10] aimed at the homogeneous sensor networks (the nodes of the sensor network equipped with the same amount of energy). Even for the wireless sensor networks composed of same type of nodes, the new nodes are arranged on the basis of the old ones, in order to

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prolong the networks life. The nodes newly added have more energy than the old ones. On the other hand, it is impossible for every node to use its own energy uniformly, because of the failure of wireless link or other accidents. It is necessary to design clustered topology suited to heterogeneous sensor networks. In this paper, we propose a redundant and energy efficient cluster head selection protocol that significantly increases the lifetime and reliability of the network. The selection criteria for cluster heads are weighted by remaining energy of a node and the minimum mean distance from all the ordinary nodes to the cluster heads in the network. Our simulation results justified that our algorithm provides longer stability period than SEP-E.

The rest of the paper is organized as follows. We briefly review related work in section 2. We then describe the radio model and network model used by our protocol in section 3. In section 4, we present our SEP-E (RCH) protocol. Section 5 describe the performance matrices over with network is analyzed. Section 6 provides simulation results and analysis. We conclude the paper in section 7.

2 Related Work

Clustering techniques have been employed to deal with energy management in WSNs. In [7], Low Energy Adaptive Clustering Hierarchy (LEACH), a clustering based protocol that utilizes randomized rotation of local cluster base station (cluster-heads) to evenly distribute the energy load among the sensors in the network was proposed. These sensors organize themselves into clusters using a probabilistic approach to randomly elect themselves as heads in an epoch. However, LEACH protocol is not heterogeneity-aware, in the sense that when there is an energy imbalance between these nodes in the network, the sensors die out faster than they normally should have if they were to maintain their energy uniformly. In real life situation it is difficult for the sensors to maintain their energy uniformly, thus, introducing energy imbalances. LEACH assumes that the energy usage of each node with respect to the overall energy of the system or network is homogeneous. Conventional protocols such as Minimum Transmission Energy (MTE) and Direct Transmission (DT) [13] do not also assure a balanced and uniformly use of the sensor’s respective energies as the network evolves.

Stable Election Protocol (SEP) [11] was proposed for the two-level heterogeneous wireless sensor networks, which is composed of two types of nodes according to the initial energy. The advance nodes are equipped with more energy than the normal nodes at the beginning. SEP prolongs the stability period, which is defined as the time interval before the death of the first node. In [14], an extension of SEP i.e. Enhanced Stable Election Protocol (SEP-E) is presented to properly distribute energy and ensure maximum network life time. It operates in a WSN under three-level heterogeneity.

The proposed algorithm uses conditional probability and minimum mean distance to choose cluster head and redundant cluster head. On one hand cluster heads are distributed in a more reasonable manner, the energy consumption is decreased and the network life time is extended. On other hand, this protocol solves the problem of cluster head failure and damage by attackers. The reliability and security has thus been improved.

3 Radio Energy and WSN Model

We have used the energy model as in [7, 14]. In this energy model, E_{elec}^{Tx} and E_{elec}^{Rx} are defined as the energy being dissipated to run the transmitter's or receiver's circuitry, respectively, to send or receive one bit of the data packet. ε_{amp} represents the energy dissipation of the transmission amplifier to convey one bit of the data packet to the receiver node with a distance of d. As such, transmit (E_{Tx}) and receive (E_{Rx}) energies are calculated as follows [7]:

$$E_{Tx}(l,d) = \begin{Bmatrix} l.E_{elec}^{Tx} + l.\varepsilon_{amp}.d^2 & if\ d < do \\ l.E_{elec}^{Tx} + l.\varepsilon_{amp}.d^4 & if\ d \geq do \end{Bmatrix} \quad (1)$$

$$E_{Rx}(l,d) = l.E_{elec}^{Rx} \quad (2)$$

Where l is the length of the transmitted/received message in bits, d represents the distance over which the data is communicated and d_o is the distance threshold for swapping amplification models, which can be calculated as $d_o = \sqrt{\varepsilon_{fs}/\varepsilon_{mp}}$. As it can be seen, the transmitter expends energy to run the radio electronics and power amplifier, while the receiver only expends energy to run the radio electronics.

In this paper, we consider both free space ($\varepsilon_{amp} = \varepsilon_{fs}$) and two-ray multipath ($\varepsilon_{amp} = \varepsilon_{mp}$) models to approximate signal attenuation as a function of the distance between transmitters and receivers.

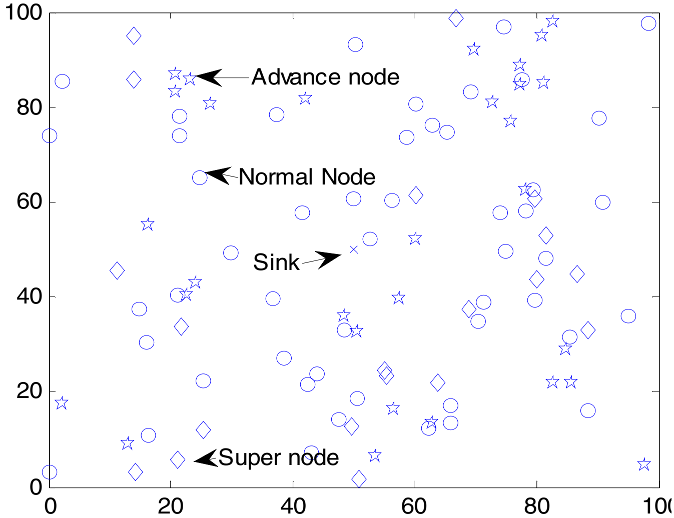

Fig. 1. Random Wireless Sensor Network

We describe our model of a wireless sensor network with heterogeneous nodes. Assume that there are n sensor nodes, which are uniformly dispersed within an M x M m^2square region (Figure. 1). The nodes always have the data to transmit to base station (sink). The heterogeneous settings and network model we have used is same as in [15]. Suppose E_o is the initial energy of each normal node. The energy of each super node is then $E_o(1+\beta)$ and each advanced node is then $E_o(1+\alpha)$.

4 SEP-E (RCH)

SEP-E (RCH) is a redundant and energy efficient cluster head selection method for enhanced stable election protocol. In this we first select initial cluster heads and initial redundant cluster head, and then compare the two nodes. The node which has better performance will be elected as cluster head, and other node will be as redundant cluster head in current round.

4.1 Selection of Initial Cluster Head

SEP-E (RCH) assigns a weight to the optimal probability p_{opt}.This weight must be equal to the initial energy of each node divided by the initial energy of the normal node. Let us define p_{nrm} the weighted election probability for normal nodes, p_{adv} the weighted election probability for advanced nodes, and p_{sup} the weighted election probability for super nodes [15].

$$p_{nrm} = \frac{p_{opt}}{1+m*(\alpha+m_o*\beta)} \tag{3}$$

$$p_{adv} = \frac{p_{opt}}{1+m*(\alpha+m_o*\beta)} * (1+\alpha) \tag{4}$$

$$p_{sup} = \frac{p_{opt}}{1+m*(\alpha+m_o*\beta)} * (1+\beta) \tag{5}$$

Where m is the proportion of advanced nodes to the total number of nodes n with energy more than the rest of the nodes and m_o is the proportion of super nodes. The threshold $T(nrm)$, $T(\text{sup})$, $T(adv)$ for normal, advanced and super nodes respectively remains the same as in [14].

For a node s , s generates a random number $rand(s)$ from 0-1, $rand(s)$ multiply a factor representing the remaining energy level of a node be as the new random number $rand'(s)$:

$$rand'(s) = rand(s) * \left(E_{max} - \frac{E_{current}}{E_{max}}\right) \tag{6}$$

More remaining energy of a node, smaller the new random number produced, the probability is greater if $rand'(s)$ is less than the threshold $T(s)$, the node is more likely to become a cluster head. So if the cluster node in the cluster which generates random number $rand'(s)$ less than threshold $T(s)$, it will be selected as initial cluster head, and then broadcasts a message to the base station and other nodes that it was elected as initial cluster head. If $rand'(s)$ is bigger than threshold $T(s)$, node s will be the ordinary node. The ordinary nodes send join-request to the nearest cluster head.

4.2 Selection of Redundant Cluster Head

In section-V, part A, the improved cluster head selection algorithm only considered its remaining energy of cluster head, but not considered the location of cluster head and energy consumption in data transmission from other nodes to cluster head. As an example, some cluster head may be located at the edge of the cluster. The other nodes require lots of energy in sending data to them compared to the cluster heads which are located at the center of the cluster.

We select a node in the cluster that has more energy than other nodes except the initial cluster head in the cluster as the initial redundant cluster head. Initial cluster head and initial redundant cluster head both have chance to be cluster head. We can choose one which has optimal performance as the cluster head at this round, and the rest node will become the redundant cluster head. In the next section, we will describe the detail process of cluster head determination.

4.3 Determination of Cluster Head

After selecting initial cluster head (ICH) and redundant cluster head (RCH), we should determine which node is elected as cluster head. The specific steps are as follows:

- ICH and RCH both use flooding way to broadcast status information.
- When ordinary nodes receive the status information they broadcast their own status information and forward the other nodes status information which they received.
- ICH and RCH calculates mean distance to all other nodes in the cluster. Both of the nodes send their minimum mean distance K_{ICH} and K_{RCH} respectively, and residual energy to the base station.
- Base station receive the information and calculate the weight as follows:

$$C_{K_{ICH}} = \frac{K_{ICH}}{K_{ICH}+K_{RCH}}$$

$$C_{K_{RCH}} = \frac{K_{RCH}}{K_{ICH}+K_{RCH}}$$

$$C_{e_{ICH}} = \frac{E_{Curr-ICH}}{E_{Curr-ICH} + E_{Curr-RCH}}$$

$$C_{e_{RCH}} = \frac{E_{Curr-RCH}}{E_{Curr-ICH}+E_{Curr-RCH}}$$

- Compute C_I and C_R:

$$C_I = C_{K_{ICH}} \times C_{e_{ICH}}$$

$$C_R = C_{K_{RCH}} \times C_{e_{RCH}}$$

- Compare C_I with C_R,

  If $C_I >= C_R$

  Node ICH is the cluster head in this round

  Else

  Node IRCH is the cluster head.

  End if.

This cluster head selection will be more reasonable and the energy consumption of the entire network will be less than enhanced stable election protocol.

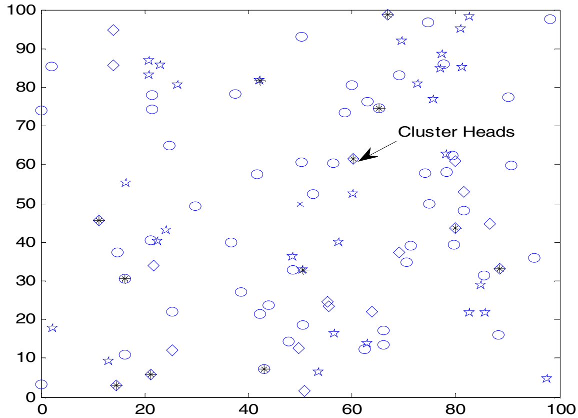

Fig. 2. Cluster head nodes in one round

4.4 Data Transmission Phase

In this phase, cluster members will transmit *l* bits to CH with probability *p* ($0< p <1$) by multiple frames. In each frame, each cluster member will transmit its data during its allocated transmission slot specified by the TDMA schedule in Cluster formation phase, and then sleep in other slots to save energy. After a CH receives data frames from its cluster members, it will perform data aggregation to remove the redundancy in the data. Then CH will transmit the aggregated data bits to the base station.

5 Performance Matrices

In this section the measures used to evaluate the performance of clustering protocols have been defined.

- *Stability Period:* is the time interval from the start of network operation until the death of the first sensor node. We also refer to this period as "stable region."
- *Instability Period:* is the time interval from the death of the first node until the death of the last sensor node. We also refer to this period as "unstable region."

- *Network Residual Energy:* It measures the instantaneous amount of energy being consumed in the network per round. This is simply the energy difference from the beginning till the end of the round
- *Number of alive per round:* This instantaneous measure reflects the total number of nodes and that of each type that has not yet expended all of their energy.
- *Data Packets received at base station:* It is total number of data packets or messages that are received by the base station. This measure varies linearly for all protocols.

Clearly, the larger the stable region and unstable region, the better the reliability of clustering process of sensor network is.

6 Simulation Results and Discussions

In order to validate the performance of the SEP-E (RCH) scheme, we compare it with SEP-E in the same heterogeneous setting, where the extra initial energy of advanced nodes and super nodes is uniformly distributed over the sensor field. We use $100m \times 100m$ region of 100 sensor nodes. MATLAB is used to implement the simulation. The key parameters [7, 13, 11] have been listed in Table 1. The simulation is performed to evaluate the performance of SEP-E (RCH).

Table 1. System parameters value

Parameters	**Value**
Network Size	100×100 meter^2
Sink	(50,50)
Number of Nodes	100
Initial Energy of Nodes	0.3 J
M	0.2
m_0	0.3
A	2
B	1
E_{elec}	50 nJ/bit
E_{fs}	10 pJ/bit/m^2
E_{mp}	0.0013 pJ/bit/m^4
E_{DA}	5 nJ/bit/message
Data Packet	4000 bits

Figure 3 indicate that the total number of alive nodes per round in SEP-E (RCH) is greater than SEP-E. This is due to fact that cluster heads moves to the center of the cluster at each round because we choose minimum mean distance as one of the cluster head selection criteria.

This leads to less consumption of energy for sending data to cluster head by the cluster members, hence increases the life time of the network. The stability period and instability period of SEP-E (RCH) was prolonged than SEP-E as demonstrated by Figure 3.

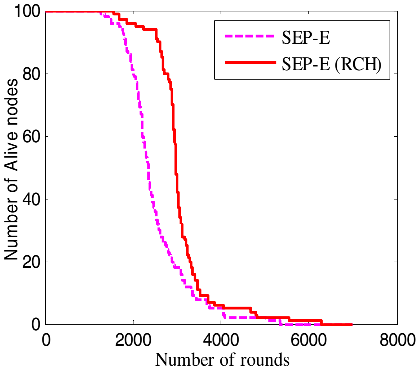

Fig. 3. Numbers of Nodes Alive

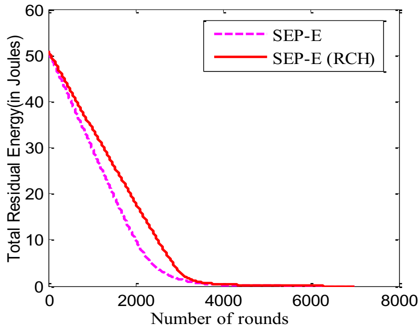

Fig. 4. Total residual energy of the per round

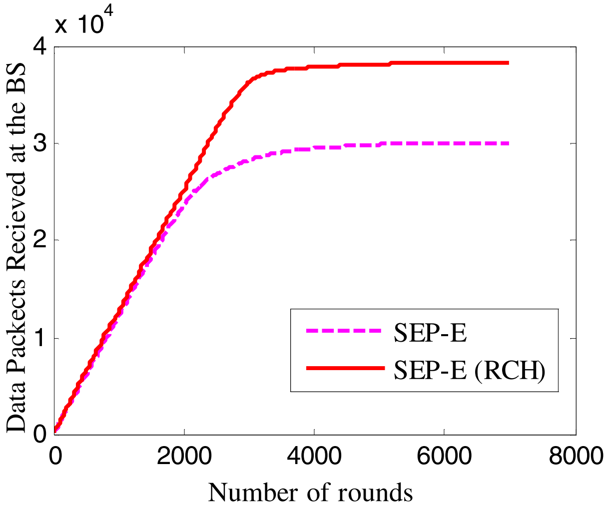

Fig. 5. Data packets received at the base station

Figure 4 depicts that the total residual energy of the network in SPE-E (RCH) at each round is greater than SEP-E because there are more number of alive nodes per round in SEP-E (RCH). The energy consumption per round is very less in SPE-E (RCH) as compared to SEP-E.

The initial energy of each node is 0.3 J.The energy consumption of SEP-E (RCH) is reduced by 14.5% as compared to SEP-E within 1000 rounds. Table 2 depicts the total residual energy of the network at different rounds as 1st, 1000th, 2000th and 4000th for both of the protocol. SEP-E (RCH) always has higher residual energy as compared to SEP-E.

Table 2. Comparison of total residual energy (in Joules)

Number of rounds	Total Residual Energy (in Joules)	
	SEP-E (RCH)	**SEP-E**
1	50.9820	50.9820
1000	34.3299	29.9742
2000	17.9360	9.9038
4000	0.2716	0.0610

Figure 5 demonstrate the number of data packets received at the base station. The results show that for both the protocols it goes linearly for around 200 rounds and after that the difference can be seen. It is clear SPE-E (RCH) has more numbers of data packets received at base station in comparison to SEP-E. Then we compare the both of the protocols based on the death of the nodes i.e. the time when first node dies (Stability Region), 25% nodes dies, 50% node dies and all node dies. Figure 6 shows the comparison using bar chart.

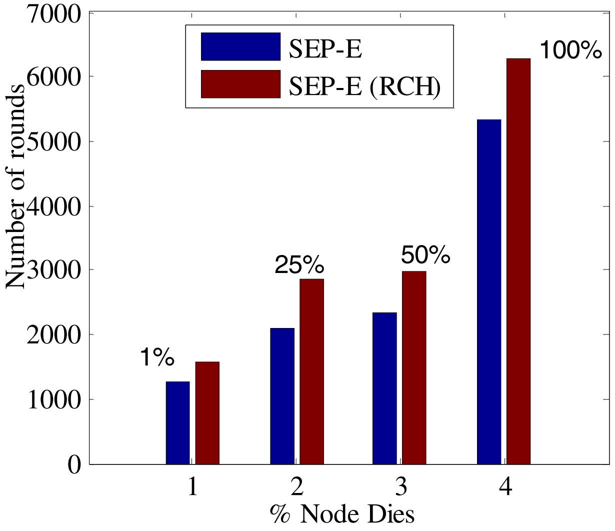

Fig. 6. Comparison between % node die

In SEP-E, the death of first node is encountered at 1273th round while in SPE-E (RCH) it is happened at 1571th round. Hence the stability region is significantly increased by 23.4%. Similarly, 25% of the node died at 2092th round and 2872th round and 50% of the node died at 2349th round and 2988th round in SEP-E and SPE-E (RCH) respectively (Table 3.2). At 5335th round and 6289th round the all of the nodes are goes down for SEP-E and SEP-E (RCH) respectively. Hence the instability period is also increased by 17.8%.

7 Conclusion

This paper designs a SEP-E (RCH) scheme for the redundant and energy efficient cluster head selection to balance the network load and to extend the network life time. In order to select reasonable cluster heads, our scheme first select an initial cluster head and a tentative or redundant cluster head in every cluster at each round. The node which has higher remaining energy and minimum mean distance is elected as cluster head of current round.

Simulation results shows that this method of electing cluster heads is more robust, energy efficient and increases the life time of the network than SEP-E protocol.

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