AN ENERGY-AWARE AND COVERAGE-PRESERVING HIERARCHICAL ROUTING PROTOCOL FOR WIRELESS SENSOR NETWORKS

Tzu-Shiang Lin[1], Cheng-Long Chuang[1], Chia-Pang Chen[1], Chwan-Lu Tseng[2]
En-Cheng Yang[3,] Chi-Shan Yu[2] and Joe-Air Jiang[1]
[1]*Department of Bio-Industrial Mechatronics Engineering, National Taiwan University, Taipei 106, Taiwan*
[2]*Department of Electrical Engineering, National Taipei University of Technology, Taipei 106, Taiwan*
[3]*Department of Entomology, National Taiwan University, Taipei 106, Taiwan*

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Abstract: Coverage-preserving and lifetime-prolonging are essential issues for wireless sensor networks (WSNs). Providing full sensing coverage in a security-sensitive area is necessary for practical applications such as security surveillances or military investigations. In order to prolong the duration of full sensing coverage, we propose an Energy-aware and Coverage-presenting Hierarchical Routing (ECHR) protocol for randomly deployed WSNs. The ECHR protocol accommodates energy-balancing and coverage-preserving while selecting one cluster head for each round. The power consumption of radio transmission and residual energy over the network are taken into account when determining an optimal route for a packet. The simulation results show that ECHR prolongs the duration with full sensing coverage, which provides up to 85% extra lifetime comparing with other protocols.

1 INTRODUCTION

Wireless sensor networks (WSNs) consist of a large number of wireless sensor nodes. For the secure and military applications (Stojmenović, 2005), maintaining sensing coverage is extremely important, because any coverage hole in a wireless sensor network is not tolerable. Most of the previous proposed routing protocols were designed to prolong the lifetime of the network (Lindsey et al., 2002; Al-Karaki et al., 2004). However, the sensor network could become useless when the network fails to maintain full coverage.

Usually, routing protocols were proposed to prolong the lifetime of the network or enhance the Quality of Service (QoS) (Mollanoori and Charkari, 2008). In order to decrease the energy consumption of radio transmission, a Low-Energy Adaptive Clustering Hierarchy (LEACH) routing protocol was proposed by Heinzelman et al. (2002). Cluster heads of the LEACH protocol provide data fusion in each hop to reduce energy consumption, and then transmit the sensing data to the base station (denotes as BS). Therefore, energy consumption of sensor node can be greatly reduced by preventing it from transmitting the sensing data directly to the BS. In addition, Tasi (2007) proposed a coverage-preserving routing protocol, which was modified from LEACH protocol and entitled it as LEACH-Coverage-U protocol. The LEACH-Coverage-U protocol calculates the overlap sensing areas of all sensor nodes, and then uses this feature to select cluster head. The simulation result shows that the LEACH-Coverage-U protocol can prolong the operational time when the sensing coverage is greater than 50%. However, it produces large amount of coverage holes during network operation.

Because of the random deployment, some locations of nodes might be very close to each other that causes overlapped sensing area. If these overlapping nodes run out of energy earlier, the full sensing coverage of the network can be maintained. Hence, in this study, we present this study proposes an Energy-aware and Coverage-preserving Hierarchical Routing (referred as ECHR) protocol to increase the duration of maintaining the full sensing coverage in a WSN. The proposed ECHR protocol

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always chooses one of the overlapping nodes to be the cluster head in each round. In addition, we applied the energy-aware hierarchical routing mechanism to find out an optimal route for the data measured by each node. Comparing with the previous protocols, the ECHR protocol can effectively prolong the duration of maintaining the full sensing coverage in a WSN.

The rest of the paper is organized as follows: Section 2 illustrates the radio transmission model and coverage model of sensor nodes. The ECHR protocol is presented in Section 3. Simulation results are demonstrated in Section 4. Finally, concluding remarks are given in Section 5.

2 PRELIMINARIES

In this work, assume that there are n sensor nodes (denoted as S_1, S_2, …, S_n) randomly deployed in a $L \times L$ sensing field and the sensing field has m points of interest (abbreviated as POI). The definition of POI (denoted as P_1, P_2, …, P_m) and the related point coverage problem can be referred to the reference (Cardei and Wu, 2005). Some assumptions for the network model are also made: 1) All sensor nodes and BS are all stationary after deployment. 2) The BS is located far away from the sensing area. 3) Each node has power control ability which can be adjusted according to the transmission distance.

2.1 Radio Transmission Model of Sensor Node

The first order radio model, which is the same as that used in LEACH-Coverage-U protocol, was adopted in this study (Tasi, 2007). There two parameters, E_{elec} and ε_{amp}, involved in the energy consumption model. E_{elec}, the energy dissipations per bit by the transmitter or receiver circuits, is set to 50 nJ/bit. ε_{amp}, the energy dissipations per bit by the transmitter amplifier, is set to 0.1 nJ/bit/m$^{\alpha}$. The energy consumption for transmitting/receiving k-bit data message under a given distance d, modelled in Tasi (2007), is formulated by:

$$\begin{aligned} E_{Tx}(k,d) &= k(E_{elec} + \varepsilon_{amp} d^{\alpha}) \\ E_{Rx}(k) &= kE_{elec} \end{aligned} . \quad (1)$$

where E_{Tx} is the energy consumption for transmitting data, E_{Rx} denotes the energy dissipation by receiving data, and α is the pass loss exponent. The pass loss exponent α is set to 2 for the transmission from each node, and α is set to 2.5 for the transmission from a cluster head to BS.

In addition, when an intermediate node receives n k-bit message data, the node consumes energy of $k \times E_{DA}$ units to compress the data into a packet with $\mu \times (n \times k)$ bits, where μ is the compression coefficient, and E_{DA}, the energy consumption per bit by data aggregation, is set to 5 nJ/bit.

2.2 Coverage Model of Sensor Node

Each sensor node has sensing range r_s and location $\{x_i, y_i\}$, $i \in [1, n]$. The location of each POI is $\{x_j, y_j\}$, $j \in [1, m]$. Then, we denote a coverage set of a sensor node S_i by CS_i. The set of POIs that are covered by multiple CS_i can be determined by the following equation:

$$\begin{aligned} O_i = CS_i \cap (&CS_1 \cup CS_2 \cup \ldots \\ &\cup CS_{i-1} \cup CS_{i+1} \cup \ldots \cup CS_n) \end{aligned} , \quad (2)$$

where O_i is the set of POIs that are covered by multiple sensor nodes. In addition, we define the coverage ratio C of the network as

$$C = \frac{\left\| CS_1 \cup CS_2 \cup \ldots \cup CS_{n-1} \cup CS_n \right\|}{m} . \quad (3)$$

If a node S_1 runs out of energy, CS_1 in equation (3) will be an empty set.

3 THE PROPOSED ECHR ROUTING PROTOCOL

In order to prolong the lifetime of the network with full sensing coverage, a cluster head selection mechanism based on energy-balancing and coverage-preserving was developed and used in the ECHR protocol. We also apply the energy-aware hierarchy routing mechanism to determine an optimal route for packets generated by each node. The detail functions about these mechanisms will be described in subsection 3.1 and 3.2. The flowchart of the proposed ECHR protocol is shown in Figure 1.

3.1 Cluster Head Selection Mechanism

According to the radio model described in the subsection 2.1, the transmission between a cluster head and the BS could consume a great deal of energy. In the ECHR protocol, there is only one cluster head in each round. Therefore, the cluster head selection mechanism is essential. The head-weight H_i for selecting node S_i as a cluster head is defined as

$$H_i = \left(\frac{\|O_i\|}{\|CS_i\|} \right)^c \times (RE_i) , \quad (4)$$

where the RE_i is defined as residual energy, and c is weight adjustment exponent.

After calculating head-weight of each node, the node with the maximum head-weight will be chosen to be a cluster head in one round. Then, the cluster head broadcasts a beacon message to other sensor nodes in the network. According to the message contained in the beacon message, each node can not only acquire the information of the cluster head, but also obtain the information of the neighboring nodes.

The beacon message contains information that consists of ID, residual energy, and hop count. The information is updated when the sensor nodes receive messages from other nodes.

3.2 Energy-aware Hierarchy Routing Mechanism

In order to reduce the power consumption of data transmission, we adjust communication range of each node. Thus, all sensing data of sensor nodes will be transmitted by multi-hop mechanism. Each node uses the hop count of received information in a neighbor table. Thus, each sensor node knows which nodes are closer to the cluster head, and these nodes could be its parent node. However, a node S_i might have multiple parent nodes available for choosing. Therefore, we calculate the parent node factor Φ_k for the parent node S_k by:

$$\Phi_k = (1/d_k) \times (RE_k) , \quad (5)$$

where the d_k is the distance between the node S_i and the parent node S_k. According to equation (5), each node calculates the parent node factor according to its parent nodes and values saved in the neighbor table. After calculating the parent node factor, each node starts to transmit sensing data to its parent node.

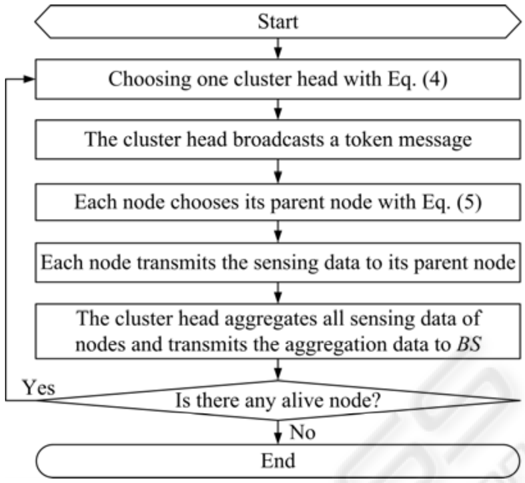

Figure 1: Flowchart of the proposed ECHR protocol.

4 SIMULATION RESULTS

In this section, the performance of the ECHR protocol is compared with those of LEACH and LEACH-Coverage-U via numerical simulation. The simulation environment is a network with 100 nodes randomly distributed in an area of 50 × 50 m^2. This monitoring area consists of 2500 POIs, and the BS is located at (25, –50). The initial energy of all nodes is assumed to be 1 joule, and the sensing range r_s is set to be 7.5 m. Furthermore, the compression coefficient μ is set to 0.05, and the data packet size k is set to 2000 bits. We set the weight adjustment exponent c to 8.5 in equation (4) with experience obtained in priori.

Figure 2 shows the number of alive sensor nodes versus the simulation rounds. LEACH protocol and LEACH-Coverage-U protocol lose the first node at about the 700th round. On the other hand, the proposed ECHR protocol is able to maintain all sensor nodes surviving till the 1620th round. After the first node of the ECHR protocol runs out of energy, the number of the alive nodes falls rapidly. It is because the proposed ECHR protocol is able to equalize the energy consumption over the entire network. Figure 3 shows the coverage ratio versus the simulation rounds. The proposed ECHR protocol maintains 100% coverage ratio until the 1680th round, but the LEACH protocol and LEACH-Coverage-U protocol lose full coverage ratio at the 900th and the 1000th round, respectively. In other words, the proposed ECHR protocol provides about 85% extra duration with 100% sensing coverage ratio comparing with LEACH and LEACH-Coverage-U protocols.

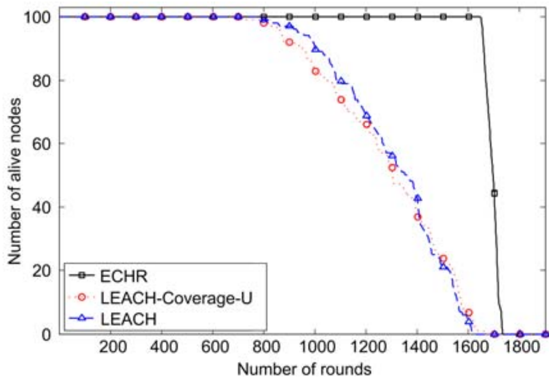

Figure 2: Comparison of the alive nodes of the proposed ECHR protocol with those of other protocols.

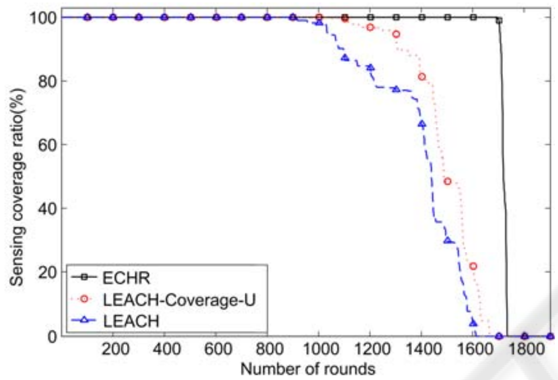

Figure 3: Comparison of the coverage ratio of the proposed ECHR protocol with those of other protocols.

Examining Figures 2 and 3, it clearly indicates that the coverage ratio of the network adopting the ECHR protocol is still maintained at 100% before the first node runs out of energy at the 1620th round. At the 1680th round, there are in total of 46 nodes that run out of their energy, and the coverage ratio of the entire network starts to fall out of 100%. This result shows that the ECHR protocol is able to prolong the duration of 100% network coverage by choosing overlapping nodes to relay sensing data in the most rounds of the simulation.

5 CONCLUSIONS

In this paper, we propose an energy-aware and coverage-presenting hierarchy routing protocol for wireless sensor networks. The goal of this study is to prolong the duration for maintaining full sensing coverage. The main idea is to combine energy-balancing and coverage-presenting mechanisms into routing protocol. Simulation results show that the proposed ECHR protocol is able to prolong the duration of the network with 100% coverage ratio, which provides up to 85% extra lifetime comparing with other protocols. We will try to evaluate the performance of the ECHR protocol with respect to transmission delay, and add some factors into our ECHR protocol based on other information in our future work.

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