An Energy Efficient Load-Balanced Routing Protocol for Small Display Devices

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Current clustering algorithms usually utilize two techniques; selecting cluster heads with more residual energy, and rotating cluster heads periodically to distribute the energy consumption among nodes in each cluster and extend the network lifetime. However, they rarely consider the hot spot problems in multi-hop sensor networks. When cluster heads cooperate with each other to forward their data to the base station, the cluster heads closer to the base station are burdened with heavier relay traffic and tend to die much faster. In this paper, an improved algorithm based on the weighted clustering algorithm and a base station initiated dynamic routing protocol is proposed with additional constraints for the selection of cluster heads in wireless sensor networks. ELBRP (Energy Efficient Load-balanced Routing Protocol) groups nodes into unequal sized clusters, which become smaller the closer they are to the base station. Then, the base station chooses cluster heads based on weight metrics. Experimental results show that the proposed algorithm behaves better than previous protocols in providing a system with a long lifetime.

Key Words: Wireless Sensor Networks, Routing Protocol, Clustering, Load-Balancing.

1. INTRODUCTION

Wireless sensor networks (WSNs) have gained worldwide attention in recent years, particularly with the proliferation in Micro-Electro-Mechanical Systems (MEMS) technology which has facilitated the development of smart sensors. These sensors are small, with limited processing and computing resources, and they are inexpensive compared to traditional sensors. These sensor nodes can sense, measure, and gather information from the environment and, based on some local decision process, they can transmit the sensed data to the user.

Wireless sensor networks are, however, a little different from traditional networks due to some more constraints. The former, in particular, must usually take the energy factor into consideration in order to prolong the network lifetime. Efficiently utilizing energy in wireless sensor networks thus becomes an important research topic in this area. Good algorithms for allocation of base stations and sensor nodes were then proposed to reduce power consumption. Sensors in a wireless sensor network can not only collect data from an environment but can also process data and transmit information. Recently, a two-tiered architecture of wireless sensor was proposed and has become popular. It is motivated by the latest advances in distributed signal processing and source coding and can offer a more flexible balance among reliability, redundancy and scalability of wireless sensor networks.

Clustering provides an effective way for prolonging the lifetime of a wireless sensor network. Current clustering algorithms usually utilize two techniques—selecting cluster heads with more residual energy and rotating cluster heads periodically—to distribute the energy consumption among nodes in each cluster and extend the network lifetime. However, they rarely consider the hot spots problem in multi-hop wireless sensor networks. When cluster heads cooperate with each other to forward their data to the base station, the cluster heads closer to the base station are burdened with heavy relay traffic and tend to die early, leaving areas of the network uncovered and causing network partition.

To address the problem, Energy-Efficient Unequal Clustering (EEUC) mechanism for periodical data gathering in wireless sensor networks partitions the nodes into clusters of unequal size with clusters closer to the base station smaller in size than those farther away from the base station. Thus, cluster heads closer to the base station can preserve some energy for inter-cluster data forwarding.

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It proposes an energy-aware multi-hop routing protocol for inter-cluster communication. Since EEUC uses only residual energy and the relative location of clusters to the base station in choosing cluster heads, a clear solution to hot spot problems still needs to be found.

In this paper, we present an idea to solve the hot spot problem in wireless sensor network—we combine EEUC\textsuperscript{5,6} and the weighted clustering algorithm\textsuperscript{7} but introduce a better routing construction mechanism. The network is partitioned into clusters and levels which are proportional to the distance to the base station. Data transmission can be done in several stages: member nodes (non-cluster heads) send their data to the cluster heads; cluster heads send data to the level heads; level heads send data to a leader node; and then the leader node sends data to the base station. Clusters close to the base station are expected to be smaller in size in order to facilitate lower energy consumption during the intra cluster data processing, and the preservation of some amount of energy for inter cluster relay traffic.\textsuperscript{8,9} The weight of a node is defined based on the distance to the base station, the residual energy of the node, the degree difference of the node and the number of neighbor nodes in a partitioned level. Nodes are selected as cluster heads, level heads and the leader node according to their weight values. The advantage of ELBRP is that it can better assign roles to nodes than any other protocols. Hence, this method, which puts into consideration both the distance to the base station and the different weights altogether, can solve hot spot problems.

The rest of this paper is organized as follows: Chapter 2 introduces related works in this area. Chapter 3 proposes the ELBRP (Energy Efficient Load-balanced Routing Protocol). Chapter 4 presents simulation results. Finally, chapter 5 concludes the paper.

2. RELATED WORKS

Many clustering algorithms have been proposed for sensor networks and in recent years, new ideas on clustering have been emerging.\textsuperscript{1} In this section, we review some of the relevant papers. In LEACH,\textsuperscript{9} randomized rotation of the cluster-head is used to evenly distribute the energy load among the sensor nodes in the network. Each node has certain probability of becoming a cluster head per round, and a cluster head’s function is to send an aggregated and packed data to the base station through a single hop. In PEGASIS,\textsuperscript{7} further improvement on energy conservation is suggested by connecting the sensors into a chain. HEED\textsuperscript{6} extends LEACH by incorporating communication range limits and intra cluster communication cost information. The initial probability for each node to become a tentative head depends on its residual energy and a head is finally selected according to the cost. In the implementation of HEED,\textsuperscript{3} multi-hop routing is used when cluster heads deliver the data to sink. All methods require doing the re-clustering mechanism after a period of time because cluster heads use more energy due to their higher workload.

In Ref. [2], an unequal cluster based routing (UCR) protocol in wireless sensor network is proposed; it groups nodes into clusters of unequal size. Cluster close to the base station are smaller in size than those farther from the base station, enabling Cluster heads to preserve some energy for inter cluster data forwarding. The UCR protocol consists of an energy-efficient unequal clustering algorithm and an inter cluster greedy geographic and energy-aware routing protocol. At the network deployment stage, the base station broadcasts a beacon signal to all sensors at a fixed power level. Therefore, each sensor node can compute the approximate distance to the base station based on the received signal strength. UCR, however, has a weakness when choosing a cluster head after some operating time. It usually considers only the distance between the node and the base station but does not consider the energy status of the nodes. This makes it difficult to choose a node with the most energy as the cluster head if it is located farther away. Furthermore, the hot spot problem still remains to be solved. We can see the overview of a UCR protocol in Figure 1.

In this paper, we study about a new protocol named ELBRP (Energy Efficient Load-balanced Routing Protocol). ELBRP utilizes the base station which has enough energy and computing power to construct the clusters and decide the roles of the nodes, which are the member node, the cluster head, the level head, and the leader node. EBBRP divides the sensor area with equal sized partition levels and unequal sized clusters using a weight-based (WCR) method. To select the roles of the nodes, ELBRP considers several factors that allow it to efficiently choose better cluster heads, level heads and a leader node using less energy for data transmission.

3. SYSTEM MODEL

3.1. Network Model

(1) The base station is located far from the sensing field. Sensors and the base station are stationary after all deployment.

(2) Sensors are homogeneous and have the same capabilities; each node is assigned a unique identifier (ID).

(3) Sensors are capable of operating in an active node or low power sleeping mode.

(3) Sensors can use power control to vary the amount of transmission power according to the distance to the desired recipient.

3.2. Energy Model

The energy model used in this paper is similar to that used by most existing energy-efficient clustering algorithms and can be seen in Ref. [10]. The radio model consists of three parts: the transmitter, the power amplifier, and the receiver. There are two propagation models: free space model and two-ray ground propagation model. Both of the
free space (d2 power loss and two gray propagating) and the multi path fading (d4 power loss) channel model are used depending on the distance between the transmitter and the receiver. The energy for transmission of a 1-bit packed from the transmitter to the receiver at distance $d$ is defined as:

$$E_{Tx}(l, d) = lE_{elec} + l/\varepsilon_f d^2, \quad d < d_0$$
$$E_{Tx}(l, d) = lE_{elec} + l/\varepsilon_g d^4, \quad d \geq d_0$$

$E_{Tx}$ is energy dissipated in the transmitter of the source node and the electronic energy $E_{elec}$ is the per bit energy dissipation for running the transceiver circuitry, whereas the amplifier energy, $\varepsilon_f d^2$ or $\varepsilon_g d^4$, depend on transmission distance and acceptable bit-error rate.

The cross over distance $d_0$ can be obtained from:

$$d_0 = \sqrt{(e_f/e_g)}$$

To receive the message, the radio expends energy:

$$E_{Rx}(l) = lE_{elec}$$

It is assumed that the sensed information is highly correlated, thus the cluster head can always aggregate the data gathered from its member into a single length-fixed packet. $E_{DA}$ (nJ/bit/signal) is the energy consumed for data aggregation cluster head. Explanation of all parameters is given in Table I.

4. ELBRP (ENERGY EFFICIENT LOAD-BALANCED ROUTING PROTOCOL)

4.1. Clustering and Partitioning the Sensing Field

The role of a cluster head is rotated among the sensors in each round to distribute the energy consumption across the network. EEUC or UCR are competitive algorithms where the cluster head selection is primarily based on the residual energy of the cluster head for the mitigation of hot spot problems. They are at a disadvantage, however, when a node that contains higher residual energy than other nodes, is located farther away from the base station. The UCR cannot handle this situation.

So we propose ELBRP (Energy Efficient Load-balanced Routing Protocol) to mitigate the hot spot problem. It does not just use the residual energy, but also considers the distance to the base station, the degree difference of a node and the number of neighbor nodes. All constraints make weight metrics to choose a cluster head, a level head and a leader node in each cluster and level.

In ELBRP, the sensing field is first divided into unequal sized clusters—clusters close to the base station are smaller than others. Then, one cluster head (CH) is chosen in each cluster after calculating the weight of each node as described in Section 4.2. CH collects data from member nodes in that cluster as shown in Figure 2.
The sensing field is also divided into equal sized partition level as shown in Figure 3. There is one level head (CH10, CH5, CH1 in Fig. 4) in each partition level; the level head (CH1) collects integrated data from the CHs in that partition level and these level heads relay the data to the base station. One of the level heads becomes a leader node and this leader node finally sends the data to the base station. The weight of a node is defined based on the residual energy, the distance of the node to the base station, the degree difference of the node, and the number of neighbor nodes. Using these weight metrics, better cluster heads, level heads and a leader node can be chosen. After a period of time, the weights of nodes are recalculated and roles re-assigned.

### 4.2. Calculation of Weights and Selection of Head Nodes

The weight of each node has to be calculated. Based on these calculations, a cluster head is chosen in each cluster, a level head in each partition level and one leader node for the entire sensing field. A cluster head collects data in its cluster; the level head relay the data coming from cluster heads in its partition level; and the leader node sends all integrated data to the base station. The weight of node $v$ can be defined as follows:

In this formula, $w_1$, $w_2$, $w_3$, $w_4$ are the coefficient values where the summation of the weights is equal to 1 (i.e., $w_1 = 0.4$, $w_2 = 0.2$, $w_3 = 0.1$, $w_4 = 0.5$) degree; $d_v$ is the number of the neighbors of $v$; $\delta$ is the predefined ideal number of neighbor nodes; $N(v)$ are the neighbor nodes of $v$; $T(v)$ is the time in which a node $v$ has been the cluster-head from the time the system started working; $E_0$ is the initial energy of node $v$; and $E_{\text{residual}}$ is the residual energy of node $v$. Weight factors $w_1$, $w_2$, $w_3$, $w_4$ vary according to the situation and should be adjusted close to the optimal values.

The node with the minimum weight value in a cluster becomes the cluster head (dark and big nodes in Fig. 3). In the same manner, a head node (level head node) is chosen for each partition level among cluster heads based on the above minimum weight criterion. The leader node is also chosen based on the same criterion among the level heads.

### 4.3. Steady State Routing Mechanism

When BS (Base Station) gets all the weight information and location of each node, it chooses one CH (Cluster Head –CH1~CH12 in Fig. 4) for each cluster, one LH (Level Head –CH1, CH5, CH10) for each level and one LN (Leader Node –CH1) for the entire sensing field. CHs collect data from member nodes and relays the data to LH. LHs also gather the data from all the CHs in its level and send the data to LN. Finally, LN transmits the integrated data to BS.

This routing path and structure is sustained during a predefined time. Yet, if the energy level of CH, LH or LN becomes less than the predetermined value before that cycle time, BS ends up running the set-up phase; namely BS recalculates the weights of nodes, decides CHs, LHs, a LN and reconstruct the routing path. After the set-up phase is done, all the nodes start to sense the field and transmit the data through the reorganized routing structure.
received signal strength. To select cluster heads, we use the approximate distance to another node based on cluster data forwarding. We assume sensor nodes can communicate their location of each node, it calculates the weight of each node and chooses one CH (Cluster Head) for each cluster, one LH (Level Head) for each level and one LN (Leader Node) for the entire sensing field. CHs collect data from member nodes and relay the data to LH. LHs also gather the data from all the CHs in its level and send the data to LN. Finally, LN transmits the integrated data to BS. This routing path and structure is sustained for a predefined time. Yet, if the energy level of CH, LH or LN becomes less than the predetermined value before the defined cycle time, BS ends up running the set-up phase; namely, BS recalculates the weights of nodes, decides CHs, LHs and a LN and reconstructs the routing path. Through this, we can balance energy consumption, prolong network lifetime and solve the hot spot problem. The simulation result shows that ELBRP clearly improves the network lifetime over other schemes.

5. EXPERIMENTAL DETAILS

In this paper, simulations are given for the protocol proposed with NS, and the results compared with that of BCDCP, BIRD, EEUC protocols.

The network model in the simulation consists of 100 nodes that are uniformly and randomly distributed across an area of 100 m × 100 m with the base station located at position (150 m, 50 m). Each node is equipped 1 J (initial energy) at the beginning of the simulation. Every node transmits a 4000 bit data packet size per round. The calculation of energy dissipation in the simulation is based on (1) and (3) and parameters of radio model are the same as those in Refs. [2–12]. All these simulation parameters utilized in our simulations are summarized in the Table I.

Energy is the most important trait in WSN and the most important standard for measuring WSN is a network lifetime. Figure 5 shows that the first node died in the following order: BCDCP, BIRD, EEUC, and ELBRP. We can see that ELBRP is 10 to 30% better than other protocols.

6. CONCLUSIONS

The hot spot problem arises when employing a multi-hop routing clustered sensor network and for doing inter-cluster communication. The argument we make in this paper is that residual energy and the location of a node are not sufficient in balancing energy consumption and in prolonging network lifetime across the network. To address the problem, we propose the Energy-Efficient Unequal Clustering (EEUC). In this scheme, clusters close to the base station are smaller in size than those farther away. This permits cluster heads to use less energy for inter-cluster data forwarding. We assume sensor nodes can compute the approximate distance to another node based on received signal strength. To select cluster heads, we use four weight components—the number of neighbor nodes, the length of time a node functions as a head node, distance to the base station and residual energy.

When Base Station gets all the weight information and location of each node, it calculates the weight of each node and chooses one CH (Cluster Head) for each cluster, one LH (Level Head) for each level and one LN (Leader Node) for the entire sensing field. CHs collect data from member nodes and relay the data to LH. LHs also gather the data from all the CHs in its level and send the data to LN. Finally, LN transmits the integrated data to BS. This routing path and structure is sustained for a predefined time. Yet, if the energy level of CH, LH or LN becomes less than the predetermined value before the defined cycle time, BS ends up running the set-up phase; namely, BS recalculates the weights of nodes, decides CHs, LHs and a LN and reconstructs the routing path. Through this, we can balance energy consumption, prolong network lifetime and solve the hot spot problem. The simulation result shows that ELBRP clearly improves the network lifetime over other schemes.

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