An Energy Efficient Dynamic Routing Scheme for Clustered Sensor Network Using a Ubiquitous Robot

Donghoon Lee, Vishnu Kumar Kaliappan, Duckwon Chung, Dugki Min
Department of Information and Communication Engineering, Konkuk University, Seoul, South Korea
podong@konkuk.ac.kr
vishnukumar_cbe@yahoo.co.in
dwchung@konkuk.ac.kr
dkmin@konkuk.ac.kr

Abstract—Wireless sensor network have been widely used in many applications such as military, unmanned space exploration, and so on. However, the limited energy of the sensor nodes requires efficient gathering of information so that the network lifetime is increased. In literature it is proved that this efficiency can be achieved by clustering the sensor nodes in the network. The cluster heads cooperate with each other to forward their data to the base station, these cluster heads which are closer to the base station are burdened with heavier relay traffic and tend to die much faster, leaving areas of the network uncovered and causing network partitions. In this paper we propose energy efficient dynamic routing protocol (EEDR) to reduce these kind of problem by distributed way using ubiquitous robot which works like a data collecting agent and in charge of balancing the energy in the entire network. We use two kind of routing schemes, one is the reactive routing which is used for intra clustering and proactive routing for inter cluster routing. We evaluate our work by using mathematical expressions which shows the efficiency of our work is greater than that of the classic routing schemes.

I. INTRODUCTION

Wireless Sensor networks have generated much interest in the research community because they are used in wide range of applications, such as monitoring of patients for emergency medical care, environmental and wildlife habitat monitoring [1], military surveillance [2], target tracking [3], weather monitoring forecasting, etc. Furthermore, the wireless sensor network has developed tremendously because they are of cost effective, low power, and so on. Many researchers are trying to give an efficient solution for making the sensor network reliable, but only a few researchers come out with successful results.

Clustering [4] is one of the conventional protocols for wireless networks. In clustering the nodes are organized into clusters, which consist of a cluster head and several other sensor nodes called cluster members. The cluster members send the data to their respective cluster heads and only the cluster heads communicate the data to the base station or sink. This reduces the energy spent by the nodes that are away from the local base station. Hence clustering is known to be an energy efficient communication protocol.

In this paper we propose an intelligent EEDR algorithm which makes UR to assist the clustered sensor network for the balanced data collection and the data aggregation in the account to save energy. We plan to employ the UR with the sensor node which acts as the data collecting agent and control the network to maintain the constant data flow from the source to the sink node.

Most of the researches in robot assist sensor networks like [5], [6], the study has done that the robot can be used to achieve the coverage, proper navigation and localization. However we investigate the energy balance scheme which makes the network reliable.

This paper composed as follows we review some related works in Section II and present an overview of our network model in Section III. In Section IV we describe the problem statement. The Section V gives the brief explanation about our proposed work and in Section VI we introduced a mathematical model for calculating power loss of EEDR protocol and show the results. Finally, we conclude the paper in Section VI.

II. RELATED WORKS

LEACH protocol developed by Heinzelman in [4] is a cluster based protocol. Cluster heads are elected in a probabilistic fashion and they rotate between each other in order to ensure the good local energy balancing. Cluster heads collect the information which arrives from the nodes of their cluster and realize the data aggregation and the data fusion before transmitting to the base station. The data are collected periodically in a centralized fashion. Thus, LEACH is particularly adapted for the applications which are in need of a constant monitoring by the sensor network. Even though LEACH is able to increase
the network lifetime, but there are still a number of issues to be considered about the assumptions used in this protocol. LEACH assumes that all the nodes can transmit with enough power to reach the Base Station (BS) if needed. Therefore, it is not applicable to networks deployed in large regions.

In [7], an enhancement over the LEACH protocol was proposed. The protocol, called Power-Efficient Gathering in Sensor Information Systems (PEGASIS), is a near optimal chain based protocol. The basic idea of the protocol is that, in order to extend the network lifetime, the nodes need only to communicate with their closest neighbors, and they take turns in communicating with the BS. When the round of all nodes communicating with the BS ends, a new round starts, and so on. This reduces the power required to transmit the data per round as the power draining is spread uniformly over all nodes. Unlike LEACH, the PEGASIS avoids the cluster formation and uses only one node in a chain to transmit to the BS instead of multiple nodes. Here the method by which the node locations are obtained is not outlined. Note also that PEGASIS introduces excessive delay for distant nodes on the chain. In addition, the single leader can become a bottleneck problem or domino effect.

HEED [8] introduces a variable known as cluster radius which defines the transmission power to be used for intra cluster broadcast. The initial probability for each node to become a tentative cluster head depends on its residual energy, and final heads are selected according to the intra cluster communication cost. HEED terminates within a constant number of iterations, and achieves fairly uniform distribution of cluster heads across the network.

Kyungmi Kim [5] has developed a zone based clustering method for ubiquitous robots based on wireless sensor networks. Their scheme has some attractive features: First, a high density node having good many neighbor nodes can be selected as a cluster head in a zone. Second, reconfiguration of cluster can be carried out in a single zone, not all over network field, to reduce the number of nodes that participate in changing cluster heads. Third, multiple-hop transmissions between nodes or between cluster heads are possible. Finally, their method can be applicable to various ubiquitous computing services including the ubiquitous robot (UR) based on wireless sensor networks. The drawback of their scheme is it cannot be applied for the wide area due to energy constrains. The solution for balancing energy consumption of entire network has not been determined.

In [9] Guihai Chen has developed an unequal cluster based routing protocol in wireless sensor networks. The author has developed unequal based clustering protocol (UCR) protocol. It groups the nodes into clusters of unequal sizes. Cluster heads closer to the base station have smaller cluster size than those farther from the base station, thus they can preserve some energy for the inter-cluster data forwarding. For inter cluster communication, they use the greedy geographic routing algorithm which used for transfer the data via inter clustering. The problem of this protocol is even if the cluster size is decreased, the load to the node nearer to the BS will not reduce.

In this paper, we study the unbalanced energy consumption problem existing in the cluster based wireless sensor networks. The advantages of the EEDR are as follows. EEDR is the first protocol which uses the u-robot for balancing the energy; the EEDR doesn’t need any pre-deployment stage which makes the deployment much faster compare to other sensor networks. Beside this we also present a heuristic table driven algorithm for inter cluster routing by considering the energy efficiency and the balanced energy distribution.

III. NETWORK MODEL

In this paper we use the EEDR scheme in which N number of nodes are scatted uniformly in a vast area, where the set of nodes deployed is $S = \{s_1, s_2, s_3, \ldots, s_n\}$. First we use the clustering algorithm to select some sensors as Cluster Heads (CHs), and then we further organize those CHs into a shortest path tree topology which acts as a back bone network. In Fig.1, the initial nodes are formed clusters and the CHs are linked to transfer the data by shortest path tree topology. We make some assumptions beneath our network model:

1) There is a mobile base station (u-robot) deployed without any prior knowledge of the network into the field. All the other sensor nodes are stationary after deployment and they have the same power level.
2) Sensors are homogeneous and have the same capabilities. Each node is assigned with a unique identifier (ID).
3) Sensors are capable of operating in an active mode or a low-power sleeping mode.
4) A node can compute the approximate distance to another node based on the received signal strength, if the transmitting power is known.

IV. PROBLEM STATEMENT

The cluster heads forms a backbone for the network to forward the collected data and to reach the base station by multihop routing method. The reason to do this, because the multihop communication is more realistic; where the nodes
V. AN ENERGY EFFICIENT DYNAMIC ROUTING PROTOCOL

The EEDR consists of four parts namely: the first stage is cluster setup stage in which we use dynamic clustering algorithm (DCA), the second stage is routing stage where we use table driven algorithm (TDA) for routing data to base station, the third stage is data aggregation stage for aggregating the data from cluster heads to base station, the last stage is localization and navigation stage where we use a technique for balancing the network energy consumption by intelligently navigating the robot into the network.

At the initial state the u-robot send a broadcast beacon signal to all the sensors at a fixed power level. Therefore each sensor node can compute the approximate distance from the mobile base station, whether the node is far from the base station (BS) or near to BS. It does not only helps to know about the distance but also for dynamic clustering. Detailed discussions of DCA, TDA are in the following subsections. Figure 2 gives an overview of the EEDR protocol where the conceptual flow starting from cluster formation to navigation is shown.

A. Cluster setup phase

Clustering is nothing but splitting the entire network into subblocks in which single node is elected as a cluster head and others as a members. The operation of clustering technique is divided into rounds. Each round is divided into two phases, the setup phase and steady state phase. During the setup phase, a predetermined fraction of nodes elect themselves as cluster heads as follows. Each sensor node chooses a random number, \( r \), between 0 and 1. If this random number is less than a threshold value, \( T(n) \), the node becomes a cluster heads for the current round.

We use the model shown in [4], the threshold value is calculated based on an equation that incorporates the desired percentage to become a cluster heads, the current round, and the set of nodes that have not been selected as a cluster heads in the last \( (1/P) \) rounds, denoted \( G \). It is given by:

\[
T(n) = \frac{P}{1 - p(r \mod (1/p))}, \text{ if } n \in G
\]  

(1)

Where \( G \) is the set of nodes that are involved in the cluster heads election.

B. Routing setup phase

To route the data we use a heuristic algorithm known as table driven algorithm. The TDA is used to find the location of the u-robot which acts as a base station. The typical example for table driven algorithm is illustrated in figure 3 (c).

When routing announcement is given from u-robot, the current cluster head will check for the table and finalize which cluster head is nearer to the base station. The announcement of the mobile base station is illustrated in figure 3 (a) in which the u-robot sends the routing announcement to all the nodes and the cluster head elects the node that is nearer to the base station by checking the table and sends the announcement to all the nodes in the cluster.

Consequently, they will die much faster than the other cluster heads, possibly reducing the coverage sensing and leading to the network partitioning.

The basic issue in wireless sensor networks is to maximize the life time. To achieve this goal, the energy consumption should be balanced among the nodes. In classic clustered networks, the cluster heads are rotated periodically among the nodes to make balanced energy consumption. However we cannot reduce the energy dissipation of cluster heads near the base station. The main aim of rotating the cluster heads is to balance the energy consumption among the sensor nodes, but it is hard to balance the energy consumption for inter cluster multihop routing. We also investigated about using nodes residual energy to select the cluster head, but it doesn’t solve the problem like energy loss of cluster head near the base station.

Considering the energy balancing as a main issue, we introduce a heuristic energy efficient dynamic routing protocol. We choose the cluster head and the cluster head rotation together with clustering algorithm. It organizes the cluster head based on the power threshold level and table driven algorithm called TDA and is used to detect the cluster which has the limited power. The TDA makes the network to identify the location of the u-robot in order to route the data.

\[
G = \{ n | n \in G \}
\]

\[
\text{Threshold value, } T(n) = \frac{P}{1 - p(r \mod (1/p))}, \text{ if } n \in G
\]

\[
T(n) = \frac{P}{1 - p(r \mod (1/p))}, \text{ if } n \in G
\]  

(1)

Where \( G \) is the set of nodes that are involved in the cluster heads election.

\[
T(n) = \frac{P}{1 - p(r \mod (1/p))}, \text{ if } n \in G
\]  

(1)

Where \( G \) is the set of nodes that are involved in the cluster heads election.

\[
T(n) = \frac{P}{1 - p(r \mod (1/p))}, \text{ if } n \in G
\]  

(1)

Where \( G \) is the set of nodes that are involved in the cluster heads election.
up to its reaching circle. When the message is received, the head will update the table whether the base station is far from the data sink or close to data sync. Once the table is updated then the nearer cluster head sends the data to the base station as illustrated in figure 3 (b).

Before the data is collected from the members by the cluster head, it should wait for the routing announcement message from the u-robot. Once the u-robot sends a routing announcement message and finalizes the routing path construction, the cluster head which received the announcement message can relay the data collected from sensor nodes. The pseudo code for updating the table for inter-cluster routing stage is shown in algorithm 1:

**Algorithm 1:** Routing table construction algorithm

```plaintext
1: Algorithm 1: Routing table construction algorithm
2: while cluster_head = true do
3:    receive a routing announcement message m
4:    if last_message_id < m.message_id then
5:      insert m.sender_node_id to close_to_data_sync
6:      last_message_id ← m.message_id
7:      clear far_from_data_sync
8:      m.pre_sender_node_id ← m.sender_node_id
9:      m.sender_node_id ← my_node_id
10:     send m
11:    else if m.pre_sender_node_id = my_node_id then
12:      insert m.sender_node_id to close_to_data_sync
13:    end if
14:  end while
```

**C. Data aggregation phase**

The data aggregation is basically used to transfer the valid sensor data to the base station. In this phase the data aggregation is divided into two parts, one is intra-clustering and the other is inter-clustering.

The intra-clustering protocol is a single hop communication protocol. After sensing the data, the member nodes will wait for the TDMA time slots from the cluster head. When the cluster head sends the TDMA time slot and the member node receive the message, they become to know the each time slot at which they can send their data. The member nodes will send the sensed data to the cluster head by single-hop communication.

In inter-cluster routing algorithm, the cluster head can detect the direction of the base station using the table. When it detects, the cluster head can decide whether he will relay the data which are sent from another cluster head or not. The pseudo code for inter-cluster routing protocol is illustrated in algorithm 2:

**Algorithm 2:** Inter-clustering data relay algorithm

```plaintext
1: Algorithm 2: Inter-clustering data relay algorithm
2: while cluster_head = true do
3:    receive a cluster data message m
4:    if m.sender_node_id in far_from_data_sync then
5:      m.sender_node_id ← my_node_id
6:      send m
7:    end if
8:  end while
```

**D. Localization and navigation of u-robot**

The issue of balancing the energy to increase the life time of the sensor nodes near the base station is rectified by navigating of the u-robot to exact position where the energy can be saved. This can be achieved by navigating protocol.

The u-robot calibrates the energy level of nearby cluster heads. When the energy level of nearby cluster heads decreases below the threshold level, the u-robot will start move to another location. This navigation is executed by an use of the information given by the cluster heads. For doing this, the u-robot first identifies the neighborhood nodes by viewing the table. The near node and far node can be identified by looking up the table which is briefly explained in last section. The u-robot will travel along the data transferred path to save the energy of the robot until he reaches the concern cluster head.

**VI. Performance Evaluation**

In this section we evaluate the performance of EEDR protocol. We simulated our work by calculating the energy loss of entire network. First we calculated the energy consumption of member node, and then we calculated the energy dissipation of the cluster head. Finally we calculated the efficiency of unbalanced network with balanced network.

**A. Energy consumption as a cluster member**

The cluster members have four types of energy consumption they are cluster announcement message, cluster join message, TDMA schedule announcement message and node data message. The length of each messages is shown in Table I.

The basic energy required for the transmitter and receiver can be defined as follows: To simplify the calculation we are limiting the number of cluster member in a single cluster to be 16. The energy need for the operating the transmitter electronics is $\varepsilon_{elec} = 50nJ/bit$ and the energy need for the operating the amplifier electronics is $\varepsilon_{amp} = 100pJ/bit/m^2$.

In the cluster member, there are 2 major steps to be processed. The first step is cluster-setup(cs) and the second step is data-aggregation(da).

Using all the above basic parameters we calculated the energy consumption of cluster members as following equations:
TABLE I
MESSAGES FOR CLUSTER MEMBERS AND HEADS

<table>
<thead>
<tr>
<th>Message type</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>cluster announcement (ca)</td>
<td>32 bits</td>
</tr>
<tr>
<td>cluster join (cj)</td>
<td>32 * 2 bits</td>
</tr>
<tr>
<td>TDMA schedule announcement (sa)</td>
<td>32 * n bits</td>
</tr>
<tr>
<td>node data (nd)</td>
<td>32 bits</td>
</tr>
<tr>
<td>route announcement (ra)</td>
<td>32 * 5 bits</td>
</tr>
<tr>
<td>cluster data (cd)</td>
<td>64 + 64 * n bits</td>
</tr>
</tbody>
</table>

\[ E_{\text{member}}(f, r) = E_{\text{cs}}(r) + E_{\text{da}}(f, r) \]  \hspace{1cm} (2)

\[ E_{\text{cs}}(r) = E_{Rx-\text{ca}*r} + E_{Tx-\text{cj}*r} + E_{Rx-\text{sa}*r} \]  \hspace{1cm} (3)

\[ E_{\text{da}}(f, r) = E_{Tx-\text{nd}*f*r} \]  \hspace{1cm} (4)

Where \( f \) is the frame, \( r \) is the round, \( F \) is number of frames in one round, \( r = (f/F) + 1 \)

B. Energy consumption as a cluster head

The main role of the cluster head is to announce the route to the other heads and transfer the data to base station. The route announcement message has few fields – sync node id, sender node id, pre-sender node id, message id, message time stamp.

The data transfer module is in charge for transferring cluster data messages which consist of node id, cluster-head node id, (node id + node data) *n. The message length for the route announcement phase is 32 * 5 bits and length of data is 32(2 + n) bits.

In the cluster head, 4 steps have to be invoked: cluster-setup (cs), routing-setup (rs), data-aggregation (da), data-relay (dr)

The total energy consumption of the cluster head can be calculated as follows:

\[ E_{\text{head}}(f, r) = E_{\text{cs}}(r) + E_{\text{rs}}(r) + E_{\text{da}}(f, r) + E_{\text{dr}}(f, r) * n_{\text{relay}} \]  \hspace{1cm} (5)

\[ E_{\text{cs}}(r) = E_{Tx-\text{ca}*r} + E_{Rx-\text{cj}*r} + E_{Rx-\text{sa}*r} \]  \hspace{1cm} (6)

\[ E_{\text{rs}}(r) = E_{Rx-\text{ra}*r} + E_{Tx-\text{ra}*r} \]  \hspace{1cm} (7)

\[ E_{\text{da}}(f, r) = E_{Rx-\text{intra-da}*f*r} + E_{Tx-\text{inter-da}*f*r} \]  \hspace{1cm} (8)

\[ E_{\text{dr}}(f, r) = E_{Rx-\text{inter-da-from-ch}*f*r} + E_{Tx-\text{inter-da-to-bs}*f*r} \]  \hspace{1cm} (9)

The \( n_{\text{relay}} \) depends on the location of each node and base station. If the node is closer to base station, it has to relay more times than farer one. The upkeep of this status makes the unbalanced status, therefore the ubiquitous robot can solve by moving to a proper position.

C. Energy efficiency of unbalanced with balanced network

In this section we calculated the energy efficiency of the unbalanced network with EEDR protocol. First we calculated the efficiency of the network nodes which is nearer to base station. The calculations are done based on the frames and the rounds which mean the duration of transferring.

Figure 4 shows the amount of remained energy in the node at worst case, the node lost their entire energy at 3090th frames. The bended points in Figure 4 denotes the amount of energy spent to get the data from the neighbourhood cluster.
nodes and to transfer the data to the corresponding cluster node to reach base station.

Secondly we calculated the remained energy in the far node. The last node falls when it transmits $119200^{th}$ frames. At Fig. 6 it has been proved that the average time of the node that die after sending $44090^{th}$ frames.

VII. Conclusion

In this paper we have introduced a heuristic energy efficient dynamic clustering protocol for wireless sensor networks. The unbalanced energy dissipation problem arises when employing the multihop routing protocol in clustered sensor network. We argued about energy unbalancing problem where the cluster heads nearby the base station lose their power and finally die soon. To address the problem we first make the clustering protocol which is similar to LEACH protocol then we use a table driven algorithm to relay the data to the base station. We used the u-robot as a mobile base station which navigation to collect the data where the nodes can save their energy more. Simulation result shows that EEDR clearly improves the network lifetime than classic clustering mechanism.

REFERENCES