# Efficient Dual-layered Hierarchical Routing Scheme for Wireless Sensor Networks

**Mahn-Suk Yoon[a], Hyun-Sung Kim[1a] and Sung-Woon Lee[b]**

[a] *School of Computer Engineering, Kyungil University*
*Buhori, Hayangup, Kyungsan, Kyungbuk, 712-701, Korea*
*Tel: +82-53-850-7288, Fax: +82-53-850-7609, E-mail:zigira1211@nate.com*
[b] *Dept. of Information Security, Tongmyong University*
*Busan, 608-711, Korea*
*Tel: +82-51-610-8751, E-mail:staroun@tu.ac.kr*

**Abstract**

*Supporting energy efficiency and load balancing in wireless sensor network is the most important issue in devising the hierarchical routing protocols. Recently, the dual layered clustering scheme with GPS was proposed for the supporting of load balancing for cluster heads but there would be many collided messages in the overlapped area between two layers. Thereby, the purpose of this paper is to reduce the collision rate in the overlapped layer by concisely distinguish them with the same number of nodes in them. For the layer partition, this paper uses an equation* $x^2 + y^2 \le (\frac{R}{\sqrt{2\pi}})^2$ *to distinguish layers. By using it, the scheme could efficiently distinguish two layers and gets the balanced number of elements in them. Therefore, the proposed routing scheme could prolong the overall network life cycle about 10% compared to the previous two layered clustering scheme.*

**Keywords:**

Wireless sensor network; Routing protocol; Energy efficiency; Clustering scheme

## 1. Introduction

The development of a reliable and energy-efficient protocol stack is important for supporting various wireless sensor network (WSN) applications. Depending on the application, a network may consist of hundreds to thousands of nodes. Each sensor node uses the protocol stack to communicate with one another and to the sink. The network layer handles routing of data across the network from the source to the destination. The routing protocol should meet network resource constraints such as limited energy, communication bandwidth, memory, and computation capabilities. By meeting these constraints, a sensor network's lifetime can be prolonged [1]. Two categories of routing approaches are prominent in the literature : location-based routing and cluster-based (or hierarchical) routing. Location-based routing considers node location to route data [2]. Cluster-based routing employs cluster heads to do data aggregation and relay the information to the base station [3]. Cluster-based routing can aid in reducing useful energy consumption. We will only consider the cluster-based routing protocols in the later of this paper.

Supporting the energy efficiency and the load balancing in WSN is the most important issue in devising the cluster-based routing protocols. Many protocols proposed in the literature to minimize energy consumption on routing paths. LEACH is an application-specific data dissemination protocol that uses clustering to prolong the network lifetime [4]. In LEACH, the nodes organize themselves into local clusters, with one node acting as the cluster head. All non-cluster head nodes transmit their data to the cluster head, while the cluster head node receives data from all the cluster members, performs signal processing functions on the data, and transmits data to the remote sink. Therefore, being a cluster head node is much more energy intensive than being a non cluster head node. To solve the problem in LEACH, Younis and Fahmy proposed HEED that periodically selects cluster heads according to a hybrid of their residual energy and a secondary parameter, such as node proximity to its neighbors or node degree [5]. HEED does not make any assumption about the distribution or density of nodes, or about node capabilities, e.g., location-awareness. However, HEED also has the same cluster heads severe energy consumption problem as the same as in LEACH. Recently, Yeo et al. proposed the dual layered clustering scheme with GPS for the supporting of load balancing for cluster heads [6]. There would be many collided messages in the overlapped area between two layers, a transmission later and a collection layer.

Thereby, the purpose of this paper is to devise an efficient dual-layered hierarchical routing scheme for WSNs to reduce the collision rate in the previous scheme. This scheme concisely distinguishes two layers with the considerations of almost the same number of nodes in them

[1] Corresponding author : Hyun-Sung Kim. kim@kiu.ac.kr. This research was supported by Ministry of Knowledge and Economy, Republic of Korea, under the ITRC(Information Technology Research Center) support program supervised by IITA(Institute for Information Technology Advancement)(IITA-2008-C1090-0801-0004)

by using a unique equation. By using it, the scheme could efficiently prolong the overall network life cycle about 10% compared to the previous two layered clustering scheme.

This paper is consisted as follows. Section 2 describes the basic characteristics of cluster-based routing protocols. An efficient dual-layered hierarchical routing scheme is proposed to solve the problems from the related schemes in section 3 and it is analyzed with the previous well known schemes in section 4. Finally, section 5 gives conclusions.

## 2. Related Works

This section abbreviates the advantages of cluster-based approaches and some basic representative cluster-based routing protocols including LEACH, HEED, and the dual-layered scheme [4-7].

### 2.1 Necessity of Clustering

Clustering can be extremely effective in one-to-many, many-to-one, one-to-any, or one-to-all (broadcast) communication. The essential operation in sensor node clustering is to select a set of cluster heads among the nodes in the network, and cluster the rest of the nodes with these heads. Cluster heads are responsible for coordination among the nodes within their clusters, and communication with each other with external observers on behalf of their clusters [5].

### 2.2 Cluster-based Routing Schemes

LEACH and HEED are representative cluster-based routing schemes that use clustering to prolong the network lifetime. However, they both have the same problem of that a cluster head node is much more energy intensive than being a non cluster head node. To solve the problem, the dual-layered clustering scheme was proposed.

**[LEACH]** The operation of LEACH is divided into rounds [7]. Each round begins with a set-up phase when the clusters are organized, followed by a steady-state phase when data are transferred from the nodes to the cluster head and on to the sink. LEACH is consisted with three phases, i.e., cluster head selection phase, cluster formation phase, and steady-state phase. The abstracts of these phases are as follows : *Cluster Head Selection Phase*-Each sensor node $i$ elects itself to be a cluster head at the beginning of round $r+1$ with the probability, which is chosen such that the expected number of cluster head nodes for this round is $k$. Ensuring that all nodes are cluster heads the same number of times requires each node to be a cluster head once in $N/k$, where $N$ represents the number of nodes in a network. *Cluster Formation Phase*-Once the nodes have elected themselves to be cluster heads, they must let all the other nodes in the network know that they have chosen this role for the current round. To do this, each cluster head node broadcasts an advertisement message. This message is a small message containing the node's ID and a header that distinguishes this message as an announcement message. Each non-cluster head node determines its cluster for this round by choosing the cluster head based on the received signal strength of the advertisement heard from each cluster head. After each node has decided to which cluster it belongs, it transmits a join-request message back to the chosen cluster head. *Steady-state Phase*-The steady-state operation is broken into frames, where nodes send their data to the cluster head at most once per frame during their allocated transmission slot. Once the cluster head receives all the data, it performs data aggregation to enhance the common signal and reduce the uncorrelated noise among the signals.

LEACH clustering terminates in a constant number of iterations, but it does not guarantee good cluster head distribution and assumes uniform energy consumption for cluster heads.

**[HEED]** Younis and Fahmy proposed HEED that periodically selects cluster heads according to a hybrid of their residual energy and a secondary parameter, such as node proximity to its neighbors or node degree. In HEED, cluster heads are randomly selected based on their residual energy, and nodes join clusters such that communication cost is minimized. The scheme terminates in a constant number of iterations, independent of the network diameter. HEED operates in quasi-stationary networks where nodes are location-unaware and have equal significance. No assumptions were made about the node dispersion or density in the field. However, HEED also has the same cluster heads severe energy consumption problem as the same as in LEACH.

**[Dual-layered Scheme]** To solve the problem, Yeo et al. proposed the dual layered clustering scheme with GPS for the supporting of load balancing for cluster heads. It halves the severe energy consumption of cluster heads using two headers, which each performs a different role in the previous cluster heads'. The dual-layered scheme divides a cluster heads role into two parts, i.e., data transmission and data aggregation and layered it as a transmission layer and a collection layer. After it sets a cluster, it sets a dual-layer and chooses a head in them, each. After that, the head in the collection layer collects and merges data and sends it to the head in the transmission layer and then it resends the data to sink. The heads decides their role to be continued or not depending on their remainder energy level. The dual-layered scheme solves the problem in LEACH but there are still some problems in it. There would be many collided messages and thereby data losses are happened in the overlapped area between two layers, the transmission layer and the collection layer. The main reason of the problems is that the scheme used both of a diameter of a cluster and a relative constant $\delta$ but not considered the range of each cluster heads and additional parameters.

## 3. Dual-layered Hierarchical Routing Scheme

This section proposes an efficient dual-layered hierarchical routing scheme (DHRS) for WSNs to solve both of the clusters overlay problem and the inefficient energy consumption problem by reducing the collision rate in the network. The previous dual-layered clustering scheme suffered from collided messages in the overlapped area between two layers. To solve the problem, DHRS concisely distinguishes two layers with the considerations of almost the same number of nodes in them by using a unique dual-layering method (DLM). The main goal of DHRS is to efficiently prolong the overall network life cycle. This section describes DLM first to distinctly diversify two layers which is the very important method in this paper then proposes DHRS using DLM.

This paper assumes that each node uses GPS to know their location and nodes are uniformly distributed over the WSN.

### 3.1 Dual-layering Method

Dual-layering method (DLM) sets up two layers in a cluster to halve the traditional clusters roles into two, i.e., data transmission and data aggregation. DLM divides a cluster into two layers in 1:1 ratio. This is for the balance of energy consumption in two layers and thereby it could lengthen the overall network life cycle. Additionally, by considering the range between heads it could removes collided area in them. For the consideration of these two parameters, DLM uses the equation 1 for the aggregation layer and the equation 2 for the transmission layer.

$$x^2 + y^2 \le (\frac{L}{\sqrt{2\pi}})^2 \quad (1)$$

$$x^2 + y^2 > (\frac{L}{\sqrt{2\pi}})^2 \quad (2)$$

, where $L$ is a diameter of a cluster and $\pi$ represents the phi. Figure 1 shows the established layer in a cluster by using DLM. The size of a circle inside of a cluster divides the cluster into two areas by using the equations 1 and 2. Thereby, each layer could have the same number of nodes in a cluster.

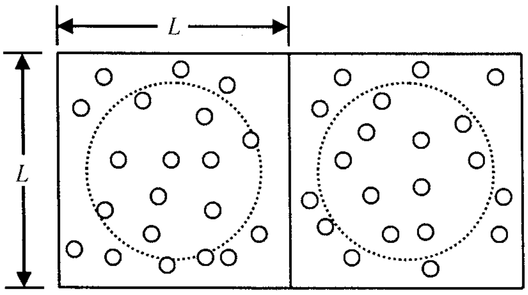



Figure 1 – An example of dual-layering by DLM

### 3.2 DHRS

The purpose of an efficient dual-layered hierarchical routing scheme (DHRS) is to solve both of the clusters overlay problem and the inefficient energy consumption problem in the previous scheme. It is consisted with a cluster setup phase, a data collection and aggregation phase, and a data transmission phase. Especially in the cluster setup phase, DLM is used for the dual-layering after the setting of the range of a cluster.

#### 3.2.1 Cluster Setup Phase

The very important consideration to setup clusters is the uniform energy consumption over the network. The cluster setup phase establishes clusters by considering both of energy remainders of nodes and head nodes distances. This phase is processed in the sequences of setting up a cluster range, dual-layering, head selection, joining, and TDMA scheduling. DLM is used for setting up dual-layering. The overall steps for the cluster setup phase are as follows :

Step 1 : It sets up cluster range by using GPS based on the lattice formation. This ranging is really affected to the performance of WSNs and the established square area by set up $L$ is used as a clusters' work area.

Step 2 : If the cluster range is settled up, the dual-layering is performed by using DLM based on the equations 1 and 2. This is for the balance of energy consumptions in two layers and thereby it could lengthen the overall network life cycle.

Step 3 : Cluster heads are selected after the dual-layering. A head is chosen in each layer, one in outer layer for the transmission role and one in inner layer for the aggregation role. For this, each node sets up a predetermined delay by the equation 3 and waits in that term.

$$delay \leftarrow Duration_{adv} \times (1 - \frac{E_{residual}}{E_{max}}) \quad (3)$$

, where $Duration_{adv}$, $E_{residual}$, and $E_{max}$ represent the duration of the head advertisement message, the nodes remainder energy level, and the nodes initial energy level, respectively. $Duration_{adv}$ is initially initialized by the consideration of the size of WSN but after the first head try it updates the value with the real duration. When it finishes the delaying, it broadcasts a cluster head set-up message to others that it is a head in that layer. If it receives the set-up message before it finishes the delaying, it gives up becoming a head.

Step 4 : The nodes, which failed to become heads, joins to a cluster in that layer.

Step 5 : Each head in the transmission layer sets the TDMA schedule with the considerations of the number of members in it and broadcasts the schedule to members.

By distinctively separate each layer in a cluster, DHRS could efficiently reduce the overlapped area by using DLM. In step 3, *delay* is to be getting smaller by the energy consumption increases. This delay is very necessary to choose a head node with higher energy level than others. Each layer computes its own delay using the equation 5.

Steps 1 and 2 are only performed at the initial clustering. However, if clustering is established and there is a necessity to change cluster head nodes, only steps 3 to 5 are performed regularly.

#### 3.2.2 Data Collection and Aggregation Phase

After the clustering, each member node in a cluster sends collected data to the aggregation head node. It aggregates the collected data. The steps for the data collection and aggregation phase are as follows :

Step 1 : Each member node senses its environment and collect data and sends the data to the aggregation head node considered with its own TDMA schedule.

Step 2 : The aggregation head node does some operation for data aggregation by performing compress, add, or average collected data depending on the application area and the characteristics of the data.

Especially in the data transmissions, there would be some problems including data retransmission and data loss due to the over hearing from other clusters or wireless signal collision problem. However, the proposed scheme could efficiently minimize the possibilities by using the equation 3.

### 3.2.3 Data Transmission Phase

After the aggregation head finishes data collection, it sends the data to the transmission head in the cluster regularly. The transmission head re-transmits the received data to the sink regularly. The steps for the data transmission phase are as follows :

Step 1 : The aggregation head sends the collected data to the transmission head in the same cluster regularly. At this time, all member nodes in the cluster except the transmission head fall in a sleep mode for the energy considerations.

Step 2 : When the aggregation head receives the aggregated data from the other head, it re-transmits the received data to the sink. It sleeps after the re-transmission.

Each node only wakes up and does its own behavior in the pre-established time schedule. However, there should be asynchronously scheduled between the transmission head node and the aggregation head node but synchronously scheduled between the aggregation head node and all the other member nodes. Thereby, DHRS could get a maximized network life cycle and halve the cluster heads severe energy consumption overheads. So the energy consumption would be uniformly distributed in two layers.

## 4. Comparison and Analysis

This section presents the simulation results of the proposed scheme and analyzes it by comparing with the previous schemes including LEACH, HEED, and the dual-layered scheme (DLS). This section analyzes DHRS in the perspectives of the number of overlapped between clusters , the number of live node in each layer by varying rounds, and the number of live node by varying rounds.

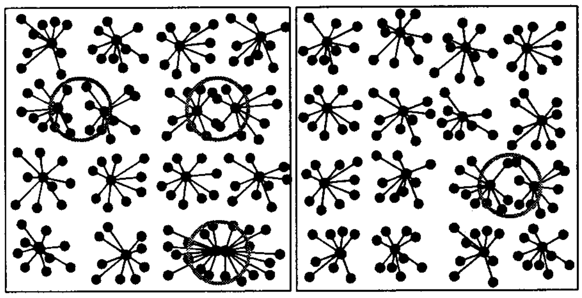
Table 1 shows the network configurations for the simulation and it is assumed that each node uses GPS to know their location and nodes are uniformly distributed over the WSN.

Table 1 – Network configuration

| Item | Value |
|---|---|
| Size of network field | 120m × 120m |
| The number of nodes | 200 nodes |
| The position of a sink node | (60, 240) |
| The size of advertisement message | 400 bits |
| The size of join message | 200 bits |
| The size of sensed data | 1000 bits |
| $E_{elec}(nJ/bit)$ | 50 nJ/bit |
| $\varepsilon_{fs}(pJ/bit/m^2)$ | 10 pJ/bit/$m^4$ |
| $\varepsilon_{mp}(pJ/bit/m^4)$ | 0.013 pJ/bit/$m^4$ |
| Energy consumptions for data aggregation | 5 nJ/signal |

### 4.1 Number of Overlapped Clusters

This sub-section gives a comparison between the proposed scheme, DHRS and the previous scheme, DLS. For the easy simulation, we tested two schemes to evaluate the average by repeating 100 times and counted the number of overlapped clusters and got an average. Figure 2 shows a snapshot to show the average overlapped numbers and we could notice that DHRS could halve of the number of overlapped clusters compared to DLS.



DLS(about 2.8 times) DLS(about 1.3 times)

Figure 2 – Snapshot for the average overlapped clusters

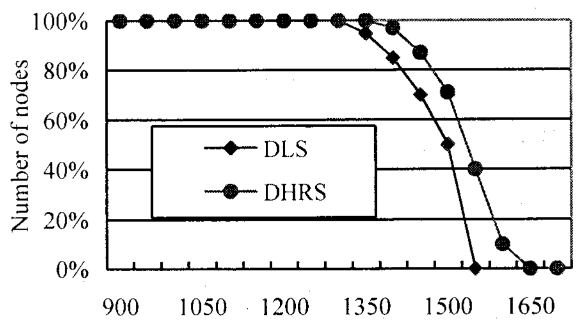



Figure 3 – Live node numbers in the transmission layer

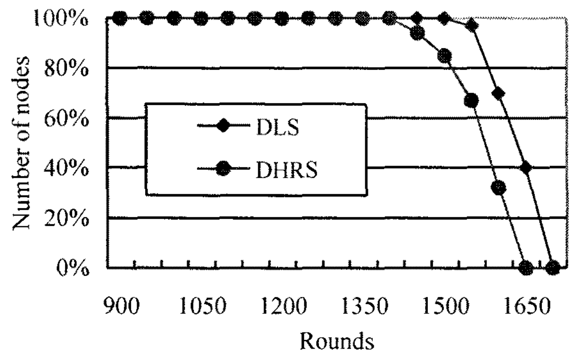



Figure 4 – Live node numbers in the aggregation layer

### 4.2 Number of Live Nodes in Each Layer

This sub-section gives a comparison between DHRS and DLS again to check the uniform energy consumption between layers. The uniformly consumed scheme in layers would get the similar decrement of live nodes in two layers.

Figure 3 and 4 show the simulation result of the number of live nodes in the transmission layer and the aggregation layer, respectively. As shown in Figures, we could know that the proposed scheme is more efficient in the energy consumption than the previous scheme because the result of DHRS gets similar tendencies between two layers. However, Figures show that of the in-balance in DLS due to the lack of considerations of node distributions in two layers.

### 4.3 Number of Live Nodes by Varying Rounds

This sub-section gives a comparison between LEACH, HEED, DLS and DHRS to check the uniform energy consumption over the network. Figure 5 shows the simulation result of the number of live nodes by varying rounds over the network. As we could see the result in Figure 5, DHRS gets better energy consumption than LEACH about 20%, HEED about 15%, and DLS about 10%.

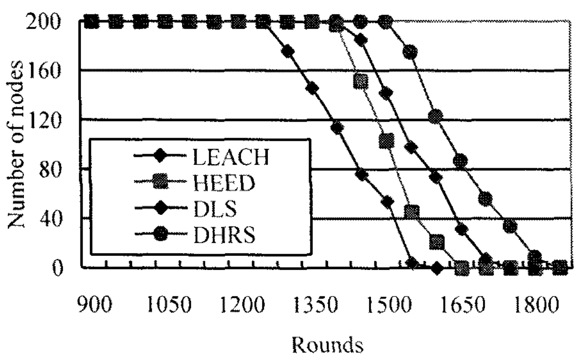



Figure 5 – Live node numbers over the network

This tendency could be achieved because DHRS considered both of the clusters overlay problem and the inefficient energy consumption problem by reducing the collision rate in the network.

## 5. Conclusion

This paper has proposed an efficient dual-layered hierarchical routing scheme over wireless sensor networks. Supporting energy efficiency and load balancing in wireless sensor network is the most important issue in devising the hierarchical routing protocols. To support it, the proposed scheme used an equation for the layer partition into two to get a balanced number of elements in them. By using two layers, the proposed routing scheme could prolong the overall network life cycle about 10% compared to the previous two layered clustering scheme.

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