# A Regional Cell Routing in Wireless Sensor Networks

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## ABSTRACT

Among routing protocols of wireless sensor networks, hierarchical routing protocols are more efficient, in general, because they involve less sensor nodes for data transmission. However, when events happen regionally and dynamically, unnecessary overheads occur in hierarchical routing protocols. In this paper, we propose a regional cell routing protocol to overcome the overheads of conventional hierarchical routing protocols: The protocol organizes cells with sensor nodes which have sensed similar events and it selects representative nodes in the cells. The representative nodes collects data in the cells and then the nodes compress data and deliver them to the sink node. Our simulation results show that the proposed routing protocol has improved its performance in terms of energy and latency by comparing with other routing protocols of wireless sensor networks.

## Categories and Subject Descriptors

C.2.2 [**Network Protocols**]: Routing protocols.

## General Terms

Algorithm, Design.

## Keywords

Wireless sensor networks, Hierarchical routing, Multi-hop routing.

## 1. INTRODUCTION

Wireless sensor networks are composed of numerous tiny sensor nodes that are densely deployed. The sensor nodes are smaller and cheaper and they have multiple functions and low-power properties by advances of embedded systems [1]. Nevertheless since sensor nodes have scarce computing resources, considering energy efficiency to design systems of wireless sensor networks is very important. Especially since data transmission and reception have major portion of energy consumption in sensor nodes, energy-efficient routing protocols are required in wireless sensor networks. The routing protocols should provide the following properties:

- *Low-power communication*: Sensor nodes which depend on battery have limited energy and data communication among sensor nodes consumes a lot of energy.
- *Short transmission delay*: Sensor nodes are deployed in large area and time sensitive data occur frequently.
- *Long system lifetime*: Due to energy constraint, sensor networks should have efficient routing protocols for long system lifetime and the protocols should balance loads of sensor nodes together with low-power communication.

In general, routing protocols for sensor networks are classified into non-location based and location based protocols. Non-location based protocols can be classified again into flat routing protocols and hierarchical routing protocols [2]. Since hierarchical routing protocols have less data transmission than flat routing protocols and each representative node compress data from its cluster, the hierarchical routing protocols exhibit better performance.

However there occur several overheads in the hierarchical routing protocols when events happen in partial area of a sensor field. Although the event area is small, they periodically construct clusters in a total sensor field and manage the clusters. If cluster-heads somewhat collect information of the events, the cluster-heads which gather the information should deliver the data. In this case, the hierarchical routing protocols can involve more energy consumption and long delay to transmit the information. For example, we can monitor habitat of rare wild animals in national park. The animals live regional area in the park and change their habitat per season. In this scenario, the hierarchical routing protocols can provide efficiency but they inherently have the overheads by characteristics of the protocol operations.

Therefore we require new routing protocol which differs from existing routing protocols of sensor networks. The protocol should operate on sensor nodes in the region where events occur. In addition, collected data from the region should be delivered to sink node efficiently. In this paper, we propose such a routing protocol which removes unnecessary overheads of the existing hierarchical routing protocols.

The remainder of this paper is organized as follows: In Section 2, we introduce routing protocols for sensor networks as related work. Section 3 describes the proposed routing

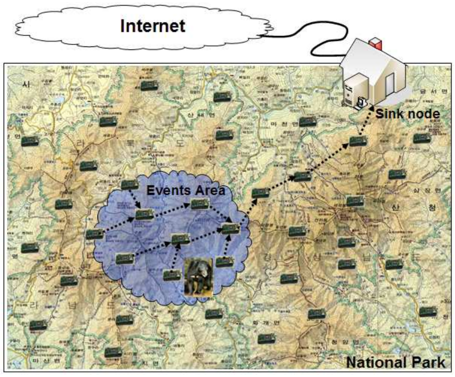



Figure 1: Example: Monitoring habitat of rare wild animals

protocol. Next, we evaluate its performance through extensive simulations in Section 4 and conclude the paper in Section 5.

# 2. RELATED WORK

Wireless sensor nodes are equipped with an "insufficient power" source and contend for a share of limited bandwidth [1]. Hence communication among these sensor nodes has been emphasized in wireless sensor networks and there have been a lot of work on efficient routing protocols.

First, given location of sensor nodes, efficient routing protocols can be designed because it is possible that accurate estimation of distance and energy consumption between two sensor nodes. GPSR (Greedy Perimeter Stateless Routing) is the typical location based routing protocol and it employs greedy algorithm for selecting distances between sensor nodes to decide a path [3]. To recognize the location of sensor nodes in GPSR, sensor nodes should include a GPS device. To route data without a GPS device, query based data-centric routing protocols are used as flat routing protocols. The representative protocol is DD (Directed Diffusion). In DD, sink node sends *interest* as query message to sensor nodes and then sensor nodes respond if they have the corresponding data [4].

The representative protocol of hierarchical routing protocols is LEACH (Low-Energy Adaptive Clustering Hierarchy) [5] which selects cluster-heads by probability and provides uniform opportunity to be a cluster-head to each sensor node. LEACH has efficiency in densely deployed sensor networks however they need several modifications to apply them to practical environments. Another hierarchical routing protocol, HEED (Hybrid Energy-Efficient Distributed clustering) improves LEACH by considering residual energy of each node in cluster-head selection [6] and it also need the modifications for practical environments. IEEE 802.15.4 (LR-WPAN) which is one of transmission standards in wireless sensor networks is focused on POS [1] (Personal Operating Space) that typically extends up to 10m in all directions [7]. In practical environments, both LEACH and HEED should be modified to allow multi-hop routing because they cannot transmit data over POS.

When events occur regionally and dynamically in a sensor field, the operation of the routing protocols in wireless sensor networks is the same as Figure 2. The routing protocols perform data transmission for sink node when the events happen. Since a number of nodes to transmit the event is determined according to event area, more energy is consumed in large event area. In case of small event area, conventional hierarchical routing protocols periodically reconstruct clusters within a whole sensor field regardless of events occurrence and they involve more cluster to transmit data for regional events as shown in Figure 3.

[1]POS means a space around person or object

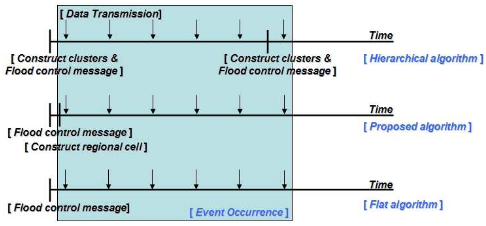



Figure 2: Operations of routing protocols

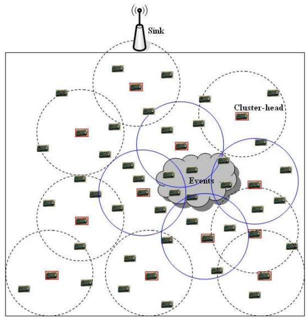



Figure 3: Overheads of hierarchical protocols

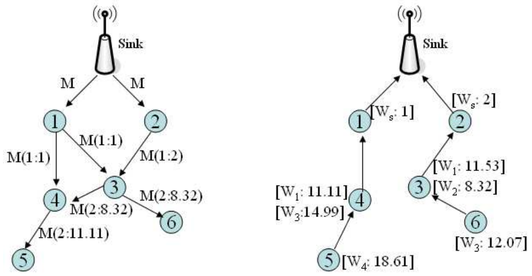
# 3. THE PROPOSED ROUTING PROTOCOL

We propose a hybrid routing protocol between hierarchical routing protocols and flat routing protocols. As shown in Figure 2, the proposed routing protocol organizes a cell within the region that events occur and decides root node, which is the representative nodes of the cell, and then aggregated information in root node is delivered to sink node. The root node performs similar roles of the cluster-heads in hierarchical routing protocols.

## 3.1 Lowest-Weight Routing

As we mentioned earlier, routing protocols in wireless sensor networks should provide multi-hop routing to transmit data into far away sink node in practical environment thus we describe LWR (Lowest-Weight Routing) in this section as the multi-hop routing protocol. As shown in Figure 4(a), a sink node broadcasts a control message ($M$) to update routing table of sensor nodes. The message includes *weight* computed by a sensor node and a sensor node sends the message to its neighbor nodes which do not receive it. With the flooded control message, each sensor node updates status (i.e., *weight*) of neighbor nodes in routing table to transmit data.

Figure 5 represents the algorithm to set routing table of




(a) Flood control message (b) Route data to sink node

**Figure 4: Lowest-Weight Routing**

$SET - TABLE(u, v, RT_v, M_u)$

1. $M_{u,hc} \leftarrow M_{u,hc} + 1$
2. Compute *weight* $(f_w)$
3. if $RT_v = \emptyset$ then
4. do $RT_v[u] \leftarrow f_w$
5. else
6. do if $u \notin RT_v$ then
7. do $RT_v[u] \leftarrow f_w$
8. if $HC[v] > M_{u,hc}$ then
9. do $HC[v] \leftarrow M_{u,hc}$

**Figure 5: Algorithm to set routing table in LWR**

each sensor node. When node $v$ receives control message ($M_u$) from node $u$, the node $v$ increases hop count and computes *weight* ($f_w$) using information of the message and then the node sets the *weight* about the node $u$ to routing table ($RT_v[u]$). The node $v$ sets the smallest hop count from hop count information ($M_{u,hc}$) of control message $M_u$ as its hop count.

To compute the *weight*, we use a utility function which consists of signal level ($l$) depicted by $k$ steps, residual energy ($e$) presented by percent, and hop count ($h$),

$$f_w = \frac{l \cdot h}{e\ (\%)} + f_u \tag{1}$$

where $f_u$ is the communication load by the previous node $u$. For example in node 3 which receives control message from node 2 in Figure 4(a), the *weight* is 8.32 when signal level is 3, hop count is 2, residual energy is 95% and previous communication load is 2. The *weight* from the utility function accumulates in each node and it becomes communication load from a current node to sink node on a selected path. After sensor nodes construct their routing table they search their routing table to find next node with the lowest communication load as shown in Figure 4(b) when they want to deliver data. Since LWR considers the communication load to a sink node, there is not any routing loop while sensor nodes transmit data toward a sink node.

**Table 1: Notations**

| Notation | Definition |
|---|---|
| $G$ | graph of total network |
| $N_{RC}$ | number of nodes in regional cell |
| $u$ | previous vertex |
| $v$ | current vertex |
| $V[G]$ | set of vertices of $G$ |
| $Nb[v]$ | neighbors of vertex $v$ |
| $Nb_s[v]$ | neighbors who sent message |
| $M_v$ | message which vertex $v$ sends |
| $RT_v^{RC}$ | routing table for regional cell |
| $SN[G]$ | set of sensed vertices |
| $EP[G]$ | entry point in regional cell |
| $MK[v]$ | maker of vertex $v$ |
| ADV | entry points send to members |
| JOIN | child nodes send to parent |
| $THR_{split}$ | threshold to split the cell |

## 3.2 Regional Cell-LWR

We define Regional Cell-LWR (RCLWR), which is based on LWR, to transmit data about regional events occurrence. As shown in Figure 2, RCLWR does not construct the regional cell periodically but constructs the cell when events happen. To construct the cell, a root node should be elected. To select a root node, several nodes sensed events exchange their communication load with neighbors. The nodes in event area generate another routing table for data transmission within the regional cell.

After the information exchange, each node in event area sends JOIN message to a neighbor with the lowest communication load in order to find an entry point in the regional cell. Then at final step a node that its communication load is less than the lowest communication load among neighbors which receive JOIN message becomes an entry point to enter the event area from the outside. By transmission of JOIN message in each hop, relay nodes is counted as member nodes of an entry point and the entry point is a candidate of root node.

Several entry points can be generated in the events area. In this case, each entry point includes its information about identification, communication load and number of member nodes into ADV message, which is a control message to construct routing table to use in regional cell, and the entry points locally broadcast the message to the regional cell where the events occur: *line 5-6* in Figure 6. Each sensor node which receives ADV message computes communication load and updates routing table for data transmission within the regional cell: *line 10-11* in Figure 6. Then the sensor nodes decide its root node by status information (communication load, number of member nodes) of the entry points in ADV messages: *line 12* in Figure 6. The root node collects data from regional cell and processes the data and then it delivers the data to sink node through LWR.

If the region where events occur is relatively large, several problems happen because single root node cares the region. All data packets are concentrated on the root node and the root node receives all the data from the region and then processes and delivers them. Hence when the regional cell is large, the cell should be split efficiently. Since the root node

```
RC − LWR(G)
1.  for each vertex v ∈ SN[G]
2.     do MK[v] ← FALSE
3.  select EP[G]
4.  for each vertex v ∈ EP[G]
5.     do ADV_v ← status information of the entry point v
6.         sendADV_v to Nb[v]
7.         MK[v] ← TRUE
8.  for each vertex v ∈ SN[G] and v ∉ EP[G]
9.     do if MK[v] = FALSE then
10.        do ADV_v ← update communication load
11.            SET − TABLE(u, v, RT_v^RC, ADV_v)
12.            decide root node from ADV_v
13.            send ADV_v to Nb[v] − Nb_s[v]
14.            MK[v] ← TRUE
15. At vertex v = root
16. if N_RC > THR_split then
17.    do M_v ← N_RC
18.        send M_v to SN[G]
19.        elect cluster-heads
20.        construct regional clusters
```

**Figure 6: Algorithm for RCLWR in the regional cell**

has already known the number of member nodes within the regional cell through entry points selection, if the number of member nodes greater than threshold to split the cell, clustering is performed in the regional cell: *line 15-20* in Figure 6.

For cluster-head selection we propose the threshold calculation to elect cluster-heads. The computation method is represented by Eq.(2)

$$THR_{CH} = \frac{E^i_{residual}}{E^i_{init}} \cdot \frac{N^i_{neighbor}}{N^{\max}_{neighbor}} \cdot (p \cdot \frac{N_{RC}}{N}). \qquad (2)$$

$E^i_{init}$ is initial energy and $E^i_{residual}$ is residual energy of each node. $N^i_{neighbor}$ is number of neighbors and $N^{\max}_{neighbor}$ is the maximum number of nodes which a cluster-head has. $p$ is the ratio of cluster-heads. Through control message of entry points, each node in event area has known the number of sensor nodes ($N_{RC}$) within the regional cell. The number of clusters can be controlled by the ratio of $N_{RC}$ and total number of sensor nodes ($N$).

After building clusters, sensed node in regional cell deliver data to its cluster-head and each cluster-head transmits collected data to sink node through LWR.

**Table 2: Environment parameters for performance evaluation**

| Environment Parameters | Value |
|---|---|
| Network size | 100m x 100m |
| Data packet size | 100 bytes |
| Query packet size | 25 bytes |
| Header packet size | 25 bytes |
| $E_{elec}$ | 50 $nJ/bit$ |
| $\varepsilon_{amp}$ | 10 $pJ/bit/m^2$ |
| $E_{init}$ | 1 $J$ |
| Positions of sink node | (50, 101) |

# 4. PERFORMANCE EVALUATION

## 4.1 Simulation model

In the experiment, we assume the number of sensor nodes in network is 300. The sensor nodes are randomly deployed and each sensor node has 1 joule as initial energy. Events with radius 15 to 40m happen at random area of network. Interarrival time of the events is 20sec and their duration is 10sec. In addition, a control message from sink node issues every 10sec. At that time routing tables of all sensor nodes are updated. Since all sensor nodes are applied to POS of IEEE 802.15.4, ratio of each sensor node reaches up to 10m. Hence we modified that LEACH and HEED transmits data through multi-hop routing which finds a node with the lowest communication load as next hop. GPSR includes a GPS module and it consumes more energy [2]. Table 2 summarizes the experiment parameters and both $E_{elec}$ and $\varepsilon_{amp}$ are used in energy consumption model.

To represent energy consumption of sensor nodes, we assume the radio model of LEACH [5] as wireless channel: $E_{TX}(n, l) = E_{elec} \times n + \varepsilon_{fs} \times n \times l^2$, $E_{RX}(n) = E_{elec} \times n$. Given $n$-bit message and distance $l$, a sender consumes energy as $E_{TX}$ and a receiver spends energy as $E_{RX}$. Since we consider only free space model for data transmission, $\varepsilon_{amp}$ in Table 2 can be $\varepsilon_{fs}$.

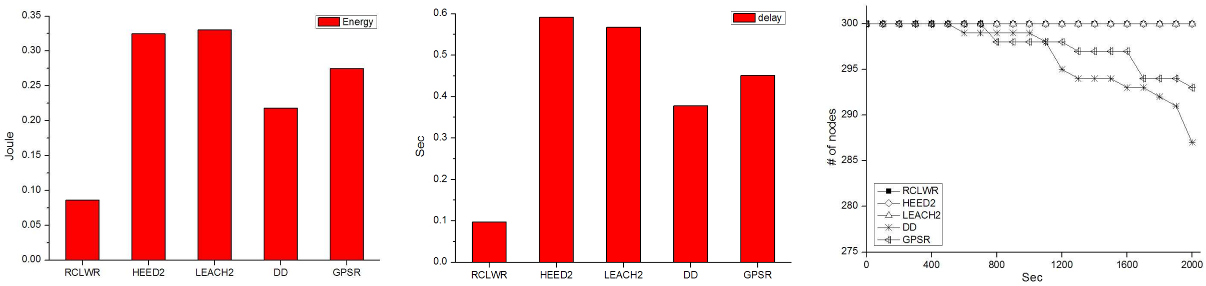
## 4.2 Simulation results

In this section, we compare the proposed protocol, RCLWR, to the representative routing protocols in sensor networks through the requirements as metrics. For hierarchical routing protocols we set 5% to ratio of cluster-heads such such as LEACH.

Figure 7(a) shows average energy consumption. When events happen in regional area, hierarchical routing protocols (i.e., HEED2 and LEACH2) consume more energy than flat/location based routing protocols (i.e., DD and GPSR) because the hierarchical routing protocols experience overheads for construction and management of clusters. However since RCLWR builds clusters in only events area, it consumes the lowest energy.

In average transmission delay, generally flat/location based routing protocols have more delay because they involve every

[2]Generally a small GPS device for sensor nodes expends energy more three times than a RF module.
http://www.leadtek.com/newGPS/GPS9546_1.htm.
http://www.chipcon.com/index.cfm?kat_id=2&subkat_id=12&dok_id=115.htm.




(a) Average energy consumption (b) Average transmission delay (c) Change of number of alive nodes

**Figure 7: Simulation results: Events occur in random area**

sensor nodes with information about the events to transmit data. In Figure 7(b), the reason why LEACH2 and HEED2 have longer transmission delay than flat/location based routing protocols is that they creates numerous clusters in a total sensor field and manages the whole clusters as we mentioned in Section 1. As hybrid type between hierarchical and flat routing protocols, RCLWR reduces number of nodes to involve data transmission by building hierarchy in the event area hence it can reduce the average transmission delay.

Figure 7(c) shows change of number of alive nodes in proportion to time. Hierarchical routing protocols maintain alive nodes constantly. They prevent concentrating on certain nodes by re-constructing clusters periodically. However flat routing protocols do not prevent the concentration nevertheless they consume less energy than the hierarchical routing protocols. RCLWR can prevent the concentration by reducing number of nodes to join data transmission in events area and constructing clusters such as the hierarchical routing protocols.

# 5. CONCLUSION

Sensor nodes are densely deployed and events occur regionally. In addition, generally events appear dynamically. Hierarchical routing protocols are efficient in wireless sensor networks however they are not appropriate for the events and present several overheads. Although flat routing protocols are useful to sense the events, they consume lots of energy. In this paper, we have proposed the RCLWR which takes benefits of both hierarchical routing and flat routing protocols.

Simulation results show that the RCLWR can improve performance in terms of energy consumption, transmission delay and load balancing in the application that events present regionally and dynamically. Especially the RCLWR maintained the lowest delay regardless of the size of regional cell.

# 6. ACKNOWLEDGMENTS

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# APPENDIX

LEMMA 1. *LWR does not have any loop.*

PROOF. Let us assume that path $p = n_s \rightarrow \cdots \rightarrow n_i \rightarrow \cdots \rightarrow n_i \rightarrow \cdots \rightarrow n_d$ and the path has one more loop. When communication load of $n_s$ is $c$, communication load of $n_{s+1}$ which is neighbor of $n_s$ is $c-l_1$. If the path has same relay node $n_i$ after two hops, the communication load ($w_2$) of second $n_i$ is $w = c - l_i - l_{i+1} - l_{i+2}$ where communication load ($w_1$) of first $n_i$ is $c - l_i$. Since $w_1 \neq w_2$, the assumption is wrong and LWR does not have any loop. $\square$