Cluster-Based Multi-Path Routing Algorithm in Wireless Sensor Networks

Si-Gwan Kim

***Abstract*—**Small-size and low-power sensors with sensing, signal processing and wireless communication capabilities is suitable for the wireless sensor networks. Due to the limited resources and battery constraints, complex routing algorithms used for the ad-hoc networks cannot be employed in sensor networks. In this paper, we propose node-disjoint multi-path hexagon-based routing algorithms in wireless sensor networks. We suggest the details of the algorithm and compare it with other works. Simulation results show that the proposed scheme achieves better performance in terms of efficiency and message delivery ratio.

***Keywords*—**Clustering, multi-path, routing protocol, sensor network.

I. Introduction

COMPOSED of tens and thousands of sensor nodes, sensor network can work in the environment to which human cannot easily access [1]-[3]. As sensor nodes have limited battery capacity unlike mobile phone, PDA, or laptop computer, it is difficult to replace or recharge battery and the computing capability of each node is severely limited. Thus, the operation of sensor node with low power is intensively studied recently. Since neighboring sensor nodes generally have similar data, energy waste is incurred if redundant delivery of similar information is used. With these properties in mind, clustering technique is a good solution that minimizes the battery energy consumptions [4]. By using many available paths, multi-path routing algorithms [5], [6] increase the reliability of the network. If the path between the source node and the sink fails, then the source node can choose the path from the available paths.

The rest of the paper is organized as follows. In Section II, we introduce the related works. In Section III, we describe multi-path routing algorithm. In Section IV, we present the results of our simulations. Finally, we summarize our results in Section V.

II. Related Works

Typical sensor networks applications include a variety of military, medical, and environmental applications. In these applications, the tasks performed by the sensors include sensing the environment, processing the data, and sending data to the base station.

Routing in wireless sensor network is intensively studied these days. The hierarchical protocol, which is based on cluster, prevents unnecessary energy waste caused by redundant transmission of similar data of adjacent node and to reduce load on the intermediate node. As routing technique operated on the cluster, LEACH protocol is the typical example of hierarchical protocol. The operation of LEACH protocol is composed of two stages called round and it is formed of the repetition of such round. As adjacent sensor nodes usually have similar data, cluster head collects data from cluster member node to reduce energy waste caused by redundant transmission of information. Then, they are combined to be directly transmitted to sink node [7]-[9].

Multi-path routing can be used to balance the traffic load and to increase the data transfer rate in a wireless sensor network; thus, improving the usage of the reserved energy of sensor nodes. By traffic balancing, we mean that for a given total energy consumption in the network, every node should have spent the same amount of energy on the average. The objective is to assign more loads to under-utilized paths and less load to over-utilized paths so that uniform resource utilization of all available paths can be ensured as much as possible. Multi-path routing is cost effective for heavy load applications, while a single path routing scheme with a lower complexity may otherwise be more desirable.

The multi-path routing algorithm is usually composed of two phases: multi-path construction phase and data transmission phase. In data transmission phase, route request message and route reply message are used. Route Request message is transmitted when a node enters in the network to execute the neighbor discovery process during the network startup. Also it is used to establish a route to the destination. Route Reply message is initiated when the given source node is reached and to create a new entry in the local neighbor table. In the previous works, multi-path routing has been studied for two reasons. The first one is load balancing: traffic between the source and destination is evenly distributed across multiple (partially or fully) paths as much as possible. The second use of multi-path routing is to increase the probability of reliable data delivery. In these approaches, multiple copies of the data are sent along different paths allowing for resilience to failure of a certain number of paths.

Multi-path routing is suitable for multimedia applications by providing necessary bandwidth using non-interfering disjoint paths while increasing the network life time. To achieve these goals, an incremental approach is applied where only one path is built at once for a given session. Additional paths are built when path congestions or lack of bandwidth occur. When a given path is chosen, all nodes interfering with it are put in a passive state. Passive nodes do not further take part in the routing process so they could not be used to form a new path,

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which will not interfere with previously built ones [10].

By discovering multiple node-disjoint paths between source node and sink node, this protocol is designed to improve packet delivery ratio, lifetime and latency. LIEMRO includes a load balancing algorithm to distribute source node's traffic over multiple paths based on the relative quality of each path. A set of node-disjoint paths are established from the source node to the sink node, while these paths impose minimum interference over each other to minimize route coupling effect. In addition, extra routes are only established if they do not decrease data reception rate at the sink node [11].

III. Our Algorithms

In this section, we propose our algorithms based on multi-path routes. Our routing algorithm is based on LEACH, and works in rounds. Each round is divided into two stages: the setup stage and the steady State stage.

In our system, we employ grid-based and hexagon-based coordinate schemes. Since signal ranges in hexagon-based one would form a circle around its deployment location and equal distance between two neighboring sensor nodes, hexagon-based coordinate system has more advantages over a grid-based one in wireless sensor networks. In a grid-based coordinate system, the distance between two neighboring sensor nodes differs. When the neighboring node is located directly adjacent or diagonally in the grid-based system, its distance is one unit and square root of two units, respectively.

In our systems, nodes are place in the grid form n x n as in Fig. 1. We assume that transmission range is two hops for each node. Therefore, the number of neighbor nodes within transmission range for each node is 16. Nodes within transmission range for node S is shown in black nodes in Fig. 1. Label of each node is numbered using two dimensional matrixes.

$$\{N(i,j) \mid i=0,1,2, \ldots, n-1, j=0,1,2, \ldots, n-1\},$$

where, n is the size of the network.

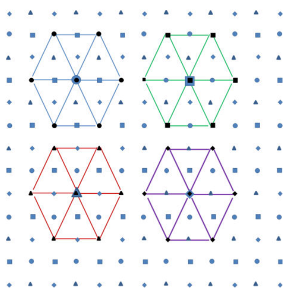


Fig. 1 Example of source nodes

With our scheme, four overlapping networks, in G_0, G_1, G_2 and G_3, can be organized using the hexagon-based scheme as:

- $G_0 = \{N(i,j) \mid i=0,2,4, \ldots, 2m\text{-}2, j=0,2,4, \ldots, 2m\text{-}2\}$
- $G_1 = \{N(i,j) \mid i=0,2,4, \ldots, 2m\text{-}2, j=1,3,7, \ldots, 2m\text{-}1\}$
- $G_2 = \{N(i,j) \mid i=1,3,7, \ldots, 2m\text{-}1, j=0,2,4, \ldots, 2m\text{-}2\}$
- $G_3 = \{N(i,j) \mid i=1,3,7, \ldots, 2m\text{-}1, j=1,3,5, \ldots, 2m\text{-}1\}$

In Fig. 1, example source nodes of four networks are shown. An example member node in G_0, G_1, G_2 and G_3 is drawn as circle, rectangle, triangle and diamond, respectively. In this figure, an example of hexagon-based routing path is shown for each in G_0, G_1, G_2 and G_3, with each source node drawn as big circle, big rectangle, big triangle and big diamond, respectively.

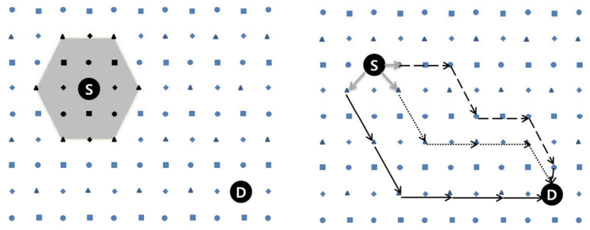
Our scheme uses two kinds of hops, one-hop delivery and two-hop delivery. Hexagon-based two-hop delivery is used for the routing where a destination node is more than three hops away. On the other hand, one-hop delivery is used for the distribution of message segments to the neighbor nodes, or final hop of the segments to the destination node. This one-hop is routed using grid-based coordinates.

When a node wants to send some messages to the destination node, we first divide given message into c segments, i.e. w_0, w_1, …, and w_{c-1}. Then each segment except w0 is delivered to c neighboring nodes. This delivery takes just one hop for each segment. Then each segment is routed to the destination node. This routing is hexagon-based coordinate system and uses two-hop delivery. Fig. 2 shows the outline of our routing algorithms.

Step 1. By transmitting hello packet to two-hop range nodes, select the first c nodes which return the hello-reply packets within predetermined time td. Maximum number of c is considered to be four, as this number is equal to the number of overlapping networks.
Step 2. A given message is divided into c segments, i.e. w_0, w_1, w_2, … , w_{c-1}.
Step 3. Each segment w_i is delivered to a neighboring node , which is one-hop or two-hop away.
Step 4. When each segment wi is arrived in the node, each segment decides its corresponding G_i (i=0,1,2,3).
Step 5. Each segment is forwarded to the destination node based on hexagon-based routing.
Step 6. When each segment is arrived at the intermediate node, each segment is routed to the next intermediate node according to the pre-determined G_i.
Step 7. As each segment gets closer to the destination node, the last hop may be one-hop or two-hop routing for the destination node depending on the position of that node.
Step 8. After receiving all the segments in the destination node, original messages can be reconstructed.

Fig. 2 Outline of the proposed routing algorithms

Fig. 3 shows an example of our routing. In this example, source node 'S' has some messages for the destination node 'D', which may be a cluster head node. Node S tries to find the neighbor nodes that return hello-reply packets within two-hop distance. There can be sixteen nodes within two-hop distance. This is shown in Fig. 3 (a). Assume the source node found that three neighbor nodes return the hello-reply packet within pre-determined time. This is shown in Fig. 3 (b). Therefore, we divide a message into three segments, and these three segments are forwarded to the neighbor nodes using one-hop or two-hop routing. These three segments are ready to be routed to the destination node using two-hop routing. For the two-hop routing, nodes that share the key are found among two-hop distant neighbor G_i nodes. As two-hop routing is based on the hexagon-based coordinates system, the maximum number of nodes that can be forwarded is six. Among these six nodes, only one node is randomly selected for further routings. The final hop to the destination node D may use one-hop delivery. This is shown in Fig. 3 (b)



(a) Finding next nodes (b) Routing

Fig. 3 Example routing

IV. Simulations

In this section, NS-2 is used to perform simulations to compare and analyze performance of our suggested clustering algorithms with that of previous studies. Our algorithm performs better than the previous schemes in message delivery ratio, the quantity of received data in comparison with the consumed.

As shown in Table I, LEACH algorithm and suggested algorithm are performed in the same condition with various simulation environments. The size of network is 100m × 100m and sink is located outside of network. Simulation environments are as follows: simulation time is 900 sec, packet size is 50 bytes, communication range is 15 m, initial energy is 2 J, aggregation energy is 5 nJ, transmitter energy is 600 mW, receiver energy is 300 mW and idle energy is 120 mW. The performance of algorithm is observed with various network densities by increasing the number of node from 100 to 600. The network node periodically reorganizes cluster and cluster head collects data by assigning same time to member node of cluster.

We have performed various experiments to evaluate our schemes for network life time and packet delivery ratio. Network life time means the number of alive nodes as time elapses and packet delivery ratio measures the percentage of packets sent by the source which reaches the sink depending on the number of source nodes.

TABLE I
Simulation Parameters

Parameter Name	Value
Network area	100 meter × 100 meter
Number of sensor nodes	100
Data packet size	512 bytes
Eelec	50 nJ/bit
Eproc	5 nJ/bit
Elow	0.2 nJ/sec
Simulation time	900 sec

A. Network Life Time

Network lifetime of WSN is very important due to the limited energy. Fig. 4 shows the results of the number of alive nodes. The proposed scheme performs better than the previous schemes for the most of the time. After 600 seconds, most of nodes die for both schemes.

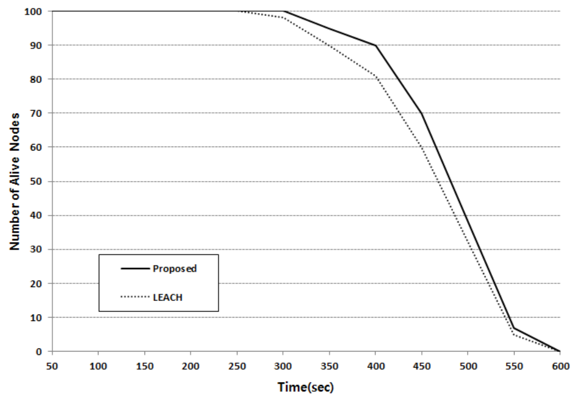


Fig. 4 Number of Alive Nodes

B. Message Delivery Ratio

Message delivery ratio of member node to sink was simulated by varying the number of sources. The message delivery ratio was measured when the number of node was 100, the number of message generating node is 30, 50 and 70 and the interval time between messages changes from 0 second to 100 seconds.

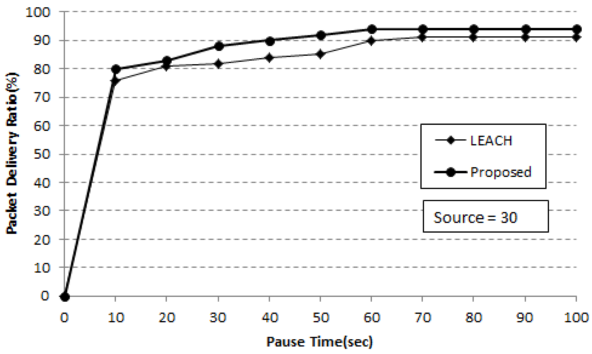


Fig. 5 Message Delivery Ratio (sources=30)

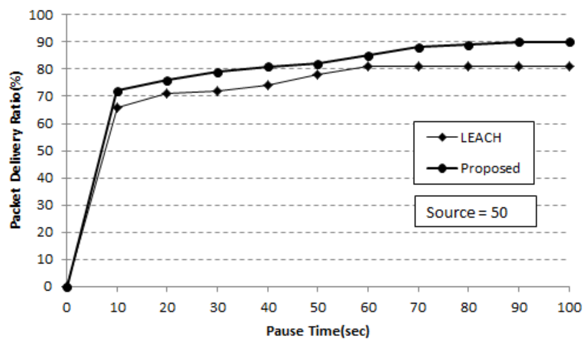


Fig. 6 Message Delivery Ratio (sources=50)

Figs. 5-7 show message delivery ratio when the number of message for each node is 30, 50 and 70 and the suggested algorithm was found to have the transmission ratio higher than that of LEACH algorithm by about 5%. This is because the shorter messages have the high probability of delivery success than the original message, which is longer than the segmented messages.

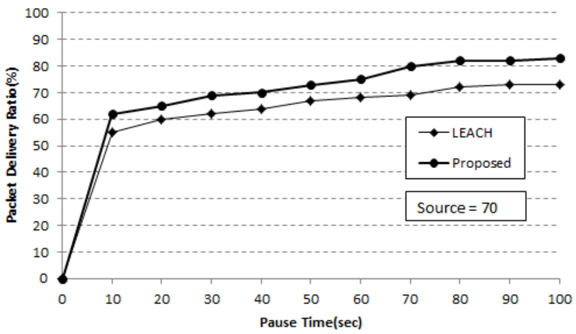


Fig. 7 Message Delivery Ratio (sources=70)

V. CONCLUSION

This paper suggests routing algorithm based on clustering that improves the probability of transmission to sink node with multi-path routes. In this paper, we have attempted that message could be transmitted with high probability using path-disjoint multi-path routes. Simulation was performed in terms of network life time and the message delivery ratio to compare the performance of suggested algorithm with that of the previous method. Suggested algorithm shows higher message transmission ratio than that of the previous method by around 5%.

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