An Enhanced Cluster Based Routing Algorithm for Wireless Sensor Networks

Uk-Pyo Han*, Sang-Eon Park**, Seung-Nam Kim*, Young-Jun Chung*

* Computer Science Department, Kangwon National University, Chunchon, Korea

**Computer Science Department, California State Polytechnic University, Pomona, USA

{mania2k, colors95, ychung}@mail.kangwon.ac.kr, sangeonpark@csupomona.edu

Abstract

The efficient node-energy utilization is one of important performance factors in wireless sensor networks because sensor nodes operate with limited battery power. In this paper, we proposed a cluster based routing algorithm to extend the lifetime of the networks and to maintain a balanced energy consumption of nodes. To obtain it, we add a tiny slot in a round frame, which enables to exchange the residual energy messages between the base station (BS), cluster heads, and nodes. The slot is used in the Pre-setup phase. The performance of the proposed protocol has been examined and evaluated with the NS-2 simulator. As a result of simulation, we have confirmed that our proposed algorithm shows the better performance in terms of lifetime than LEACH. Also if we use a simulation mode of the large number of nodes (or 1000 or more), we expect that our protocol will clearly make network lifetime much longer compared to LEACH. Consequently, our proposed protocol can effectively extend the network lifetime without other critical overheads and performance degradation.

<**Keywords**: wireless sensor networks, LEACH, cluster-based routing, cluster formation>

1. Introduction

Advances in wireless sensor network technologies have made it possible to develop low-cost, low-powered tiny sensor nodes. The sensor node consists of small sensors able to detect light, sound, temperature, and motion, an intelligent computing device that enables the processing of raw data collected from the sensors, and communication capabilities with other nodes through wireless networks.

A wireless sensor network is an ad hoc wireless telecommunication networks deployed in a wide area with tiny, low-powered smart sensor nodes. The wireless sensor network integrates all raw data sent from sensor devices for context recognition under wire/wireless telecommunication infrastructures deployed in a wide range of area, and makes a set of sensed environmental data to associate with real application services. Such a wireless sensor network - an essential element in this ubiquitous environment - is expected to be utilized in various information and telecommunication applications. A wireless sensor network is typically made of many sensor nodes used to detect accuracy and scalability of sensing areas. In such a large scale networking environment, one of the most important networking factors is the self-organizing capability for adaptation to dynamic situation changes and interoperating capability between sensor nodes [1]. Many studies have shown that there are a variety of sensors used for gathering sensing information and efficiently transferring the information to the sink nodes.

The major issues stemming from these studies are protocol design in regards to battery energy efficiency, localization scheme, synchronization, data aggregation and security technologies for wireless sensor networks. In particular, researchers have shown great interest in the routing protocols in the network layer, which considers self-organization capabilities, limited battery power, and data aggregation schemes [2, 3].

A wireless sensor network is densely deployed with a large number of sensor nodes, each of which operates with limited battery power, while working with the self-organizing capability in the multi-hop environment. Since each node in the network plays both terminal node and routing node roles, a node cannot participate in the network once its battery power runs out. Increases in dead nodes generate network partitions and consequently, normal communication becomes impossible as a sensor network. Thus, the development of an efficient batter-power management to increase the life cycle of the wireless sensor network is of significant importance [1-4].

The routing protocol of sensor networks is typically partitioned into two sub routings: (1) flat routing protocol and (2) hierarchical routing protocol. The sensor node performs a data aggregation process to avoid duplicated data transfers. Such a sequence of processes favors the hierarchical routing protocol based upon clusters due to the fact that efficient selection of cluster heads can reduce the usage of consumption power and maximize the life time of the networks [4].

In this paper, we proposed an enhanced cluster reconfiguration algorithm for a routing protocol of wireless sensor networks based upon the LEACH (Low-Energy Adaptive Clustering Hierarchy) routing protocol. The proposed algorithm extends the survival time of sensor networks by properly choosing cluster heads with consideration to node residual energy.

In section 2 of this paper, we survey existing cluster based routing protocols and describes some problems. In section 3, we propose an enhanced cluster reconfiguration algorithm which determines cluster heads by considering the node residual battery power while extending the life time of the network. Finally, in Section 4, we discuss the NS-2 simulation performance analysis of the routing protocols along with final conclusions and future studies.

2. Related Study and Problems defined

In a cluster based routing protocol, sensor nodes are partitioned into many groups (clusters), which integrates information data collected from sensor nodes and transmits them to the sink node of the network. In each of the many clusters in this network resides a cluster head which collects data from sensor nodes within its group, completes data aggregation, and sends them to the sink node of the network. Such data aggregation can reduce the consumption of node energy and the transmission delay as compared to multi-hop routing protocols [4].

There have been many studies presented for configuration and operation algorithms of a cluster based network topology in ad hoc networks. Advantages to a clustering network are the reduction of an overhead of routing establishment, minimization of the size of the routing table, and stabilization of the network topology. The clustering network can make resource management and bandwidth allocation more efficient and make node positioning management and transmitting power management possible.

In addition, the clustering scheme in a wireless sensor network enables an aggregate data of cluster member nodes at the cluster head and can easily provide the network scalability due to node increase. Consequently, in a huge sensor network that is several hundred ~ hundred thousand times bigger than ad hoc networks, the clustering based routing algorithm is a possible approach to maintain network configuration management and to make data aggregation.

In the clustering algorithm, all nodes in a sensor network can become a cluster head but must belong to only one cluster. The algorithm should minimize the overhead of clustering setup messages and establishing times. Additionally, the algorithm must maintain a stable network configuration, routing, network efficiency, with a minimization of energy consumption [4].

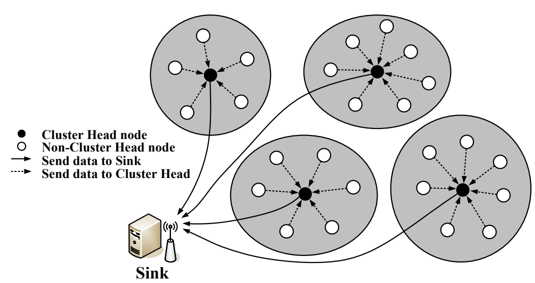

Figure 1. A basic operation of the cluster based routing algorithm

Many clustering algorithms have been proposed, most of which are based upon node identifier, node connectivity, and node weights. Some of better-known cluster based hierarchical routing protocol are LEACH, LEACH-Centralized, and

Chain-based 3 level PEGASIS (Power Efficiency Gathering in Sensor Information Systems). Figure 1 shows the basic operational diagram of a cluster based routing protocol.

2.1 LEACH (Low Energy Adaptive Clustering Hierarchy)

LEACH [5] is a clustering routing protocol in which a cluster head collects data from sensor nodes belonging to the cluster and sends the data to the sink node after data aggregation process. To make all sensor nodes in this network consume their node energy equally and extend the life time of the network, this algorithm randomly changes the cluster head, which in turn uses more energy than any other node belong to the cluster, every time period. To reduce overall communication costs, the cluster head performs data aggregation and then send the data to the sink node.

The cluster head is determined by the following function (1):

$$T(n) = \begin{cases} \dfrac{P_t}{1 - P_t \cdot (r \cdot \bmod \frac{1}{P_t})}, & \textit{if } n \in G \\ 0, & \textit{otherwise} \end{cases} \quad (1)$$

where P_t is the desired percentage of cluster heads, r is the current round number, G is the set of nodes that have not been cluster-heads in the last $1/P_t$ rounds.

A round consists of two phases; a set-up phase and a steady state phase. The former is a stage for configuration of a cluster head and a cluster, and the latter is a stage for data transfer by the TDMA schedule.

When a new round starts, each sensor node generates a random number in the range of 0 and 1, computes a threshold value by using equation (1), and compares the two numbers. If the generated number is smaller than the threshold value, the node is nominated as a cluster head; otherwise it neglects the number and remains a plain node.

The nominated cluster head broadcasts advertisement messages over neighbor nodes. The neighbor node that receives the advertisement messages selects one of broadcasting nodes that transmits the strongest broadcasting signal as its head cluster node, and sends a "Join-REQ" message to the head cluster. After receiving the "Join- REQ" message, the head cluster registers the node onto its own member node table. The cluster head makes a TDMA schedule for data transfer within the cluster network and broadcasts the schedule to its member nodes. It is at this point that the setup phase to select a cluster head has completed.

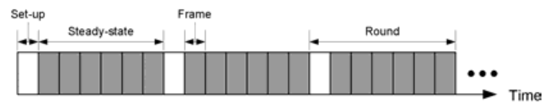

Figure 2. The Time line of LEACH

In the next steady state phase, each node in a cluster network sends information data to its cluster head by the TDMA schedule. The cluster head send the aggregated data to the sink node, called its base station. To reduce the overhead of the cluster head selection once a cluster head has been selected, many rounds of data frame transfer aree performed followed by a repeat of the cluster reconfiguration procedure.

Since LEACH uses a probability in selection of cluster heads, its advantage is that all nodes have a chance to becoming a cluster head. But the stochastic process brings unbalance of node energy consumption which ultimately shortens the life time of the sensor network.

2.2 LEACH-C (LEACH – Centralized)

As previously mentioned, the disadvantage to LEACH is that the number of cluster head nodes is little ambiguous to count. LEACH-C [6] , has been proposed to clarify this problem. LEACH-C provides an efficient clustering configuration algorithm, in which an optimum cluster head is selected with minimization of data transmission energy between a cluster head and other nodes in a cluster.

In LEACH-C, the base station receives information about residual node energy and node positions at the set up phase of each round. The received data can compute an average residual energy for all nodes. The nodes with less than average energy are excluded in selection of cluster heads.

Among the nodes that have more than average energy, cluster heads are selected with use of the simulated annealing algorithm. The base station sends all nodes a message of the optimum cluster head IDs (Identifiers). The node, the ID of which is the same as the optimum cluster head ID, is nominated as a cluster head and prepares a TDMA schedule for data transfer. Other nodes wait for the TDMA schedule from their cluster heads.

3. Proposed Routing Protocol

In this paper, we describe a cluster based routing protocol based upon the LEACH algorithm, which considers a residual energy of sensor nodes to avoid unbalanced energy consumption of the sensor nodes. Without additional overhead of LEACH, this proposed protocol can lead to node energy consumption balance and extend overall network lifetime without performance degradation.

To increase the lifetime of the networks, the proposed algorithm uses a probability function while considering use of node residual energy for cluster configuration; in contrast, LEACH only utilizes a probability function. The following formula shows the computation of the threshold value for a cluster head selection.

$$T(n) = \begin{cases} \dfrac{P_t}{1 - P_t \cdot (r \cdot \bmod \frac{1}{P_t})} \cdot \dfrac{E_{res}}{E_{\max}}, & if\ n \in G \\ 0, & otherwise \end{cases} \qquad (2)$$

where P_t is the desired percentage of cluster heads, r is the current round number, G is the set of nodes that have not been cluster-heads in the last $1/P_t$ rounds, E_{res} is the current residual energy of node, E_{max} is the maximum residual energy of entire network.

As shown in Figure 3, a round in the proposed algorithm consists of three phases: (1) a set-up phase, (2) a steady state phase, and (3) a pre-setup phase. The former is a stage for configuration of a cluster head and a cluster, and the latter is a stage for data transfer by the TDMA schedule.

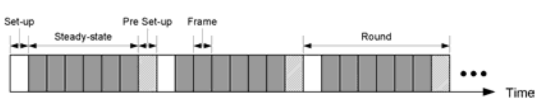

Figure 3. The Time line of the proposed routing algorithm

The algorithm works as follows:

- In the set-up phase,
  1) Each node generates a random probability(p) at the beginning of a new round and computes the threshold value(T(n)) with the use of equation(2). If r = 1 (i.e. the first round), let E_{max} of all nodes be 1.
  2) In case of p < Pt, the node is selected as a cluster head.
  3) A selected cluster head broadcasts an advertised message over neighbor nodes.
  4) The neighbor nodes collect advertised messages during a given time interval and then send a “join-REQ” message to the nearest cluster head.
  5) The cluster head receives the “join-REQ” messages and builds a cluster member list and a TDMA schedule. Then broadcast them over neighbor nodes.
  6) The member node receives and save the message for data transfer.

- In the steady state phase,
  1) After the cluster selection process completes, each member sends data and its residual energy information to the cluster head by the given TDMA schedule.
  2) The cluster head maintains residual energy information of member nodes.

- In the Pre-setup phase,
  1) Before the last frame of a round completes, the cluster head sends BS the maximum residual energy value of nodes belong to its own cluster.
  2) BS collects all maximum residual energy values from cluster heads, finds the maximum residual energy value (E_{max}) of the network, and sends E_{max} back to cluster heads.
  3) The cluster head broadcasts E_{max} over cluster nodes.
  4) Each node save the value of E_{max} for the next computation of T(n) and the current round is terminated.

From equation (2), assume that the initial energy of nodes is E_{max}, the overhead for initial settings can be reduced since the computation of E_{max} of the network is unnecessary.

4. Performance Evaluation

The performance analysis of routing protocols is evaluated with the NS-2 simulator [7]. Then our proposed protocol is compared to the LEACH algorithm in terms of the network lifetime.

4.1. Simulation Environment

In this simulation, our experiment model performed on 100 nodes which were randomly deployed and distributed in a 100×100 square meter area. We assume that all nodes have no mobility since the nodes are fixed in applications of most wireless sensor networks. Our simulation model uses the same parameters in [6] as shown in table 1.

Parameters	Values
Network size	100m x 100m
Location of the sink node	(20,175)
The number of nodes	100
The number of clusters	5
The initial energy of nodes	2 J
Data packet length	512bytes

Table 1. Simulation parameters

4.2. Simulation Results

To compare to the network lifetime of the two algorithms, we investigated the residual energy of nodes every 10 seconds during simulation and measured the number of nodes alive which maintained residual energy.

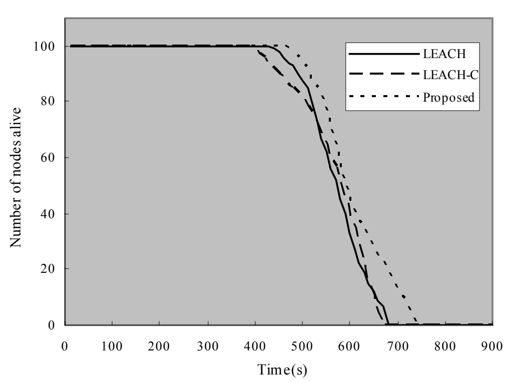

Figure 4. The number of nodes alive vs. the elapsed time

As shown in Figure 4, our algorithm leads to balanced energy consumption of nodes in process of cluster head selection. Based upon the simulation results, we confirmed that our proposed protocol can control the residual node energy and effectively extend the network lifetime without performance degradation.

Figure 5 presents a comparison of the number of received data packets in respect with consumed node energy. The proposed algorithm has better throughput than LEACH, but worse than LEACH-C. Since LEACH-C configures an optimum cluster topology, its throughput is the best of three algorithms in case that nodes initially have equal energy. However, since LEACH-C requires more energy consumption in cluster configuration, its network lifetime is shorter than the proposed algorithm.

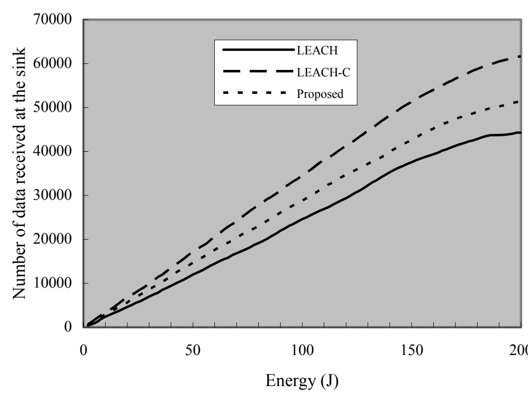

Figure 5. The number of received data vs. consumed node energy

5. Conclusions

In this work, we proposed a cluster based routing protocol that considers the residual energy of nodes to extend the lifetime of sensor networks. Based upon the NS-2 simulation, the protocol has confirmed that it provides a longer network lifetime than LEACH. The consideration of node residual energy during cluster head selection processing can maintain the balanced energy consumption of the sensor network. Additionally, if we used a simulation mode of the large number of nodes (or 1000 or more), our protocol clearly makes network lifetime much longer than the LEACH protocol. Consequently, it is our belief that our proposed protocol can effectively extend the network lifetime without other critical overheads and performance degradation

Acknowledgement

This study has been supported by Kangwon National University, Korea and California State Polytechnic University, Pomona, USA.

References

[1] Ian F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "A survey on sensor networks," IEEE Communications Magazine, Vol. 40, Issue 8, pp. 102-114, Aug. 2002.

[2] K. Akkaya and M. Younis, "A Survey of Routing Protocols in Wireless Sensor Networks, " in the Elsevier Ad Hoc Network Journal, Vol 3/3, pp. 325-349, 2005.

[3] Q. Jiang and D. Manivannan, "Routing protocols for sensor networks," Proceedings of CCNC 2004, pp.93-98, Jan. 2004.

[4] J. Ibriq and I. mahgoub, "Cluster-Based Routing in Wireless Sensor Networks: Issues and Challenges", Proceedings of the 2004 Symposium on Performance Evaluation of Computer Telecommunication Systems, pp.759-766, Jul. 2004.

[5] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Microsensor Networks," proc. Hawaii International Conference on System Sciences, Vol. 8, pp. 1-10, Jan. 2000.

[6] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "An Application-Specific Protocol Architecture for Wireless Microsensor Networks," IEEE Transactions on Wireless Communications, Vol. 1, No. 4, pp. 660-670, Oct. 2002.

[7] Information Sciences Institute, "The Network Simulator ns-2" http://www.isi.edu/nanam/ns/, University of Southern California.