An Energy-Efficient Cluster-Based Routing in Wireless Sensor Networks

Seongsoo Cho[1], Bhanu Shrestha[1], Keuk-Hwan La[1],
Bong-Hwa Hong[2], and Jongsup Lee[3]

[1] Department of Electronic Engineering, Kwangwoon University, 26 Kwangwoon–gil, Nowon-gu, Seoul, 139-701, Korea
{css,bnu,Khra}@kw.ac.kr
[2] Department of Information Communication, Kyunghee Cyber University, Dongdaemun-gu, Seoul, 130-701, Korea
bhhong@khcu.ac.kr
[3] SK C&C, SK u-Tow4er, 25-1, Jeongia-dong, Bundang-gu, Seongnam-si, 463-844, Korea
jsleearmy@sk.com

Abstract. In Wireless Sensor Networks (WSNs), sensor nodes depend on batteries for energy source. The ability to use limited energy efficiently is the key to determining the lifetime of networks and the amount of information transmitted. Low Energy Adaptive Clustering Hierarchy (LEACH) is a representative cluster-based routing protocol designed to ensure energy use efficiency. In this paper, a protocol scheme was proposed wherein member nodes (lower-level nodes) are designed to compare the currently sensed data with the previously sensed one and to switch to sleep mode when a match is achieved. The design is to help improve the transmission energy efficiency. The proposed scheme was tested via simulations and was compared with two existing cluster-based algorithms, i.e., LEACH and Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN). Performance evaluation was conducted based on the number of surviving nodes in each of the three networks (i.e., LEACH, TEEN, and proposed scheme) over time. The results indicated that the scheme contributed to greater energy efficiency by helping to increase the lifetime of the LEACH network by a maximum of 27%.

Keywords: WSN, LEACH, TEEN, Clustering Algorithm, Energy Efficiency.

1 Introduction

A Wireless Sensor Network (WSN) consists of sensor nodes, each of which includes a microcontroller, a radio transceiver, and a sensing module. Data collected by the sensor nodes are sent to the sink node (the data aggregator) mostly through the multi-hop wireless mesh network. The WSN, deploying a large number of sensor nodes in a specific area, had first started out as the monitoring and patrol application as well as military application for missions involving areas to which humans have limited access. Since then, the network has expanded its application gradually, which now includes environmental monitoring, building hazard diagnosis, and patient monitoring

T.-h. Kim et al. (Eds.): FGCN 2011, Part II, CCIS 266, pp. 57–64, 2011.
© Springer-Verlag Berlin Heidelberg 2011

as well as health care service applications [1]. In the sensor networks, MANET (Mobile Ad Hoc Network)-like environment wherein no AP (Access Point) or other fixed infrastructure exists is used, wherein a relatively large number of sensor nodes are deployed throughout a sensor field covering a large area, resulting in various, dynamic topology. Also, autonomous and independent networks are formed between the sensor nodes [2-3]. One of the most important issues about WSN is ensuring the efficiency in energy use, which arises from the energy resource constraints imposed on sensor nodes. For sensor nodes, batteries are the main source of energy, but their operation characteristics do not allow the replacement or charge of batteries. There are three items to evaluate the performance of WSNs: energy efficiency; accuracy of the data; and service quality. Among these items, energy efficiency is the most important one. It acts as a factor that indicates the lifetime of the sensors, as they function, consume energy, and wear out over time [4].

The sensor nodes comprising a WSN are often small and have limited battery capacity. Moreover, the batteries, in most cases, are not replaceable or chargeable due to the characteristics of their operating environment. It is thus crucial that the sensor nodes be designed in such a way that they maximize the efficiency of their energy use and that the process involved be run effectively. One of the solutions to the energy problem is clustering [3]. Networks adopting clustering are hierarchical, and consist of upper-level and lower-level nodes. Because forwarding of data to a remote base station (BS) requires a tremendous amount of energy, transmitting is carried out by only a few upper-level nodes (cluster heads) selected from all the cluster nodes. A big energy spender, upper-level nodes are designed to make sure that each node have an equal chance of becoming a cluster head according to the set probability and transmit data. Taking turns helps extend the lifetime of the sensor network [4]. Low Energy Adaptive Clustering Hierarchy (LEACH), a representative cluster-based routing protocol, assumes that each lower-level node always has data to transmit [5]. The assumption means that in some cases data that were sensed previously may also be sensed afresh, which is a drawback. Under LEACH, nodes react immediately to changes in the sensed data. Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN), on the other hand, uses threshold values which help prohibit data sensed previously from being sensed afresh or from being sent to upper-level nodes [6]. But this feature can be a drawback to TEEN, since the sensed data failing to meet the thresholds will not be sent to upper-level nodes. Therefore, in this paper, an energy-efficient clustering technique taking into account the way lower-level nodes collect data was proposed.

2 Related Studies

2.1 Overview of Routing Protocols for Wireless Sensor Networks

A WSN is comprised of nodes that are connected to sensors detecting changes in the data under monitoring. Figure 1 illustrates the architecture of the network.

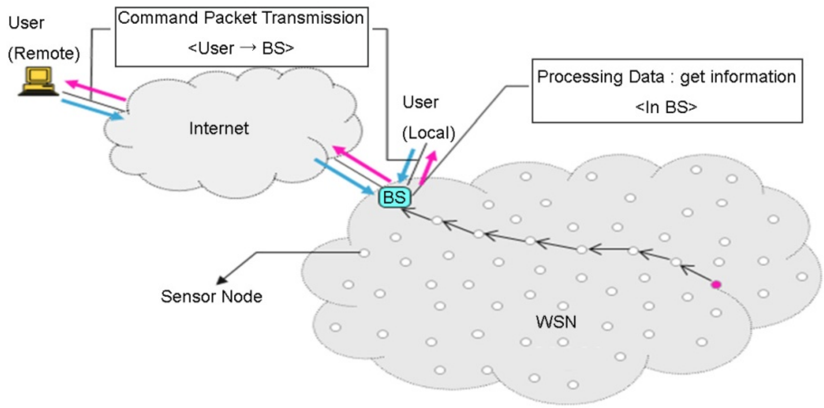

Fig. 1. Wireless sensor network architecture

Depending on network configuration, routing protocols for WSNs are divided into flat routing protocol and cluster-based hierarchical routing protocol. In flat routing protocol, the entire network is considered a unit, and all the nodes therein participate in routing function with equal probability. In comparison, a cluster-based hierarchical routing protocol uses various clustering processes to divide the network into a number of clusters (units) which group the nodes into a hierarchy according to their roles [4]. In this protocol, lower-level nodes collect sensed changes in data and send them to upper-level nodes. The upper-level nodes then aggregate the data and forward them to BS. Some of the best-known cluster-based hierarchical routing protocols are LEACH, LEACH-C (LEACH-Centralized), and TEEN [7].

The routing protocols can also be divided into proactive network protocol and reactive network protocol depending on the network's mode of functioning and type of target application. In the proactive network protocol, the nodes in the field periodically switch on their sensors and transmitters but do so only during the time slots assigned to them. The nodes sense changes in the data and transmit them to the upper-level nodes. The proactive network protocol is suitable for applications that require periodic monitoring of data. LEACH and LEACH-C are among the examples of this protocol. In the reactive network protocol, all the nodes in the field are engaged constantly in sensing changes in the data. The nodes react immediately to the changes, and the data are transmitted immediately to the upper-level nodes. It is better suited for time-critical applications. TEEN is included in this protocol.

2.2 LEACH

A WSN using LEACH is built with several clusters, each of which has a cluster head (CH) and non cluster heads (Non-CHs). The CH controls all the sensor nodes within the cluster, fuses data sent by the sensor nodes, and forwards them to BS. Non-CHs, on the other hand, collect data and send them to the CH. Since it is in charge of aggregating data transmitted from Non-CHs and forwarding them to a remote BS, the CH consumes a lot of energy. Thus, the CH is selected from all the nodes at the beginning of a new round, according to the set probability. This taking turns allows each node to have an equal opportunity to become the CH [5].

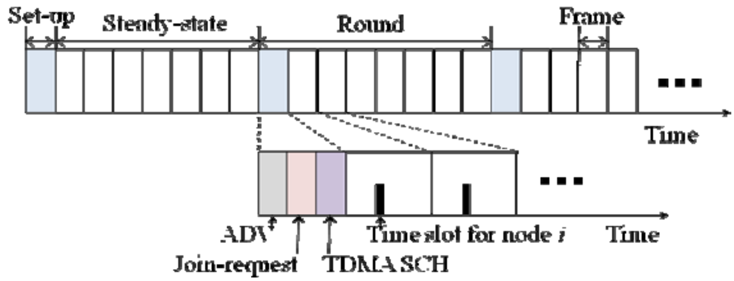

Fig. 2. Timeline showing operation of LEACH

As shown in Figure 2, the operation and structure of LEACH schedule are based on rounds. At each round, Non-CH nodes select their respective CHs (i.e., the set-up stage); data are then transmitted from Non-CHs to the CHs and to BS (i.e., the steady-state stage).[5] Unless it is their time slot, Non-CH nodes remain in sleep mode to save energy. Upon the completion of the current round, a new round begins, with new CHs selected, repeating the aforesaid process all over again. Under this protocol, Non-CH nodes send sensed data to the CHs even if they were the same as the ones sensed previously. In other words, the nodes transmit unnecessary data while consuming energy of the member nodes. Also, in LEACH, CHs are selected based on probability; and clusters are formed based on the location of the selected CHs. This system, therefore, could lead to clusters with non-favorable topology.

2.3 TEEN

Though its cluster structure is basically the same as that of LEACH (proactive network protocol), TEEN is a reactive network protocol where all nodes sense data continuously by reacting immediately to the changes occurring in the data. The reactive network protocol uses two types of threshold in sensing data: hard threshold (HT) and soft threshold (ST).[6] HT is the absolute value of the sensed data. When the value of the data collected by Non-CH nodes is either the same as or less than HT, the data get to be transmitted to the CHs. ST, on the other hand, is a small change in the value of the sensed data. When this value matches or exceeds data collected by Non-CH nodes, the data will get to be sent to the CHs. Once the network starts operating and when the sensed data reach their HT value, Non-CH nodes send the data to the CHs. (The value of the sensed data is stored in the Non-CH nodes.) Next, at the current cluster period, nodes will transmit data only when the current value of the sensed data exceeds HT and at the same time matches or exceeds ST. The purpose of using HT then is to have nodes transmit only the data of importance and to help reduce the number of transmissions conducted by them. In comparison, ST is set to detect minor changes in data when the value of the sensed data is greater than HT. A drawback to TEEN is that the use of thresholds leads to other problem, i.e., Unless the sensed data reach thresholds, communication with upper-level nodes will never occur.

3 An Energy-Efficient Clustering Technique Taking into Account Data Collection Practice

LEACH assumes that each lower-level node always has data to transmit. When each new cluster is created, Non-CH nodes select the closest CH based on the strength of the ADV (Advertisement) signal information transmitted by the CH. By selecting the closest CH, Non-CH nodes are expected to consume the least amount of energy during the transmission. Nevertheless, the consumed energy is still large compared to the one spent during the nodes' sleep mode. Moreover, non-favorable cluster topology, where the distance between Non-CHs and their CHs is far, can result from the LEACH protocol's use of probability in selecting CHs. Previous research on LEACH focuses extensively on how to improve the energy efficiency of CHs, the biggest energy spender, based on the aforesaid assumption of the protocol. In this paper, a method for extending the lifetime of a WSN was explored by focusing on how to reduce the energy consumption at Non-CH nodes, the majority that makes up the cluster. The proposed scheme offers an alternative to help improve the energy efficiency of the entire network while taking into account the data collection occurring at Non-CH level in cluster-based routing protocols. When applied to the current LEACH protocol, the proposed scheme undergoes the process illustrated in Figure 3. In the process, the set-up stage, during which the cluster is created, ends and then triggers a new period, during which Non-CH nodes at once sense data in the environment and compare them with the ones stored in their internal memory during their time slot. In the initial period, no previously collected data exist, and hence no match between data sets. The non-match will next allow the data to be stored in the nodes' internal memory and at the same time to be transmitted to the CHs. Upon the completion of the transmission, Non-CH nodes switch to sleep mode, just as their counterparts in the current LEACH protocol do.

When the second period begins, Non-CH nodes come back from sleep mode and start sensing the environment and collecting data during the second time slot assigned

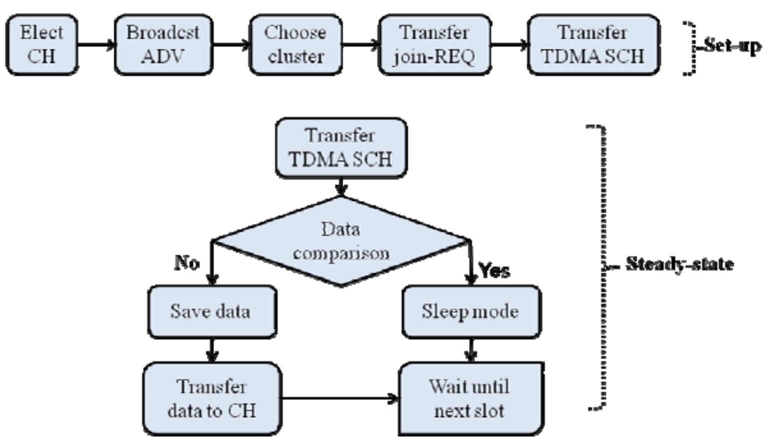

Fig. 3. Operation of the proposed scheme applied to LEACH

to them, according to the TDMA (Time Division Multiple Access) schedule created by the CH of their respective cluster. The data collected this time will be compared with the one stored previously in the internal memory of the nodes, in the same manner adopted during the first time slot. If the previous and current data achieve a match, the nodes will switch to sleep mode to save energy. If the data do not match, the nodes will store the current data in their internal memory and then transmit them to the CHs. This process will be repeated over and over again until the lifetime of the network expires. Note that with the proposed scheme, the advantage of using thresholds in TEEN (i.e., selective collection of data of interest from all the data sensed in the network field) is compromised to a certain degree, because Non-CH nodes in the proposed scheme simply compare the previously sensed data with the currently sensed one and either store and transmit or switch to sleep mode. But the proposed scheme will help solve the big problem in TEEN, i.e., the data collected by Non-CH nodes that fail to reach the thresholds will never get to be transmitted to upper-level nodes. In other words, the proposed scheme will: (a) maintain the characteristics of reactive network protocol by having Non-CH nodes continuously sense the data in the field, react immediately to changes in the data, and transmit them to upper-level nodes; and (b) simultaneously help solve the aforesaid problem of TEEN.

4 Performance Evaluation

4.1 Simulation Environment

For the simulations, it was made sure that the WSN had 100 nodes and a fixed BS. The nodes were randomly assigned to one of the three network algorithms, i.e., LEACH, TEEN, or the proposed scheme. For clustering and other issues, the parameters used in LEACH are listed in Table 1 [5, 8]. To help ease the simulation of the proposed scheme, an environmental scenario was created wherein the temperature was manipulated to fluctuate randomly between 0°C and 200°C at five-second intervals — as applied in TEEN. Regarding energy consumption, incorporating the proposed scheme into an existing routing algorithm for real-life simulation would result in energy consumption that is required for the data comparison process at Non-CH level. But the comparison concerned involves only simple comparison between the previously stored data and the currently sensed one. Thus, the amount of energy consumed for the comparison was judged to be sufficiently small, and it was ignored during the simulation of the proposed scheme.

Table 1. Simulation parameters for the proposed scheme

Parameter	Network grid	Base station coordinate	Number of sensor nodes	E_{elec}	E_{amp}	Initial energy/ node	k	E_{da}	E_{fs}	E_{mp}
Value	From (0,0) to (100,100)	(50, 175)	100	$50nJ/bit$	$100pJ/bit/m^2$	2J	5	$5nJ/bit$	$10pJ/bit/m^2$	$0.0031pJ/bit/m^4$

Another issue to consider was the variability in chances of having the same data in the provided simulation environment wherein temperature changed randomly. Thus, the validity of simulation results needed to be improved. This was achieved by conducting as many simulations as possible (i.e., at least 10 times) and combining the data to help reduce the standard deviation.

4.2 Results and Analysis

Simulations were carried out to compare LEACH and the proposed scheme, and the number of surviving nodes in each protocol was compared over time. As shown in Figure 4, the existing LEACH protocol had nodes that survived a maximum of 630 seconds, whereas the proposed scheme contributed to the survival of nodes for up to 800 seconds. In terms of the maximum lifetime of the network, the proposed scheme increased it by approximately 27% compared to the LEACH model. The increased lifetime is mostly contributable to the reduced energy consumption at Non-CH level. Under the proposed scheme, the CH (upper-level node) consumed less energy, too, because there were less data transmitted from the Non-CH nodes in its cluster, and hence less information to fuse and less energy to spend. This indicates that increasing energy efficiency at Non-CH level is just as important as reducing energy consumption at CH level, i.e., the focus of the majority of the previous studies. Next, simulations were conducted to compare TEEN against the proposed scheme, i.e., to compare the number of surviving nodes over time while implementing TEEN's hard mode (HT) as opposed to implementing the proposed scheme. Under TEEN, the simulation set-up including cluster configuration was mostly similar to that of LEACH. However, the radio electronics model used in LEACH had to be altered so that the model in TEEN would represent both the idle time power dissipation and the sensing power consumption. This was necessary because in TEEN algorithm all the nodes sense the environment continuously.

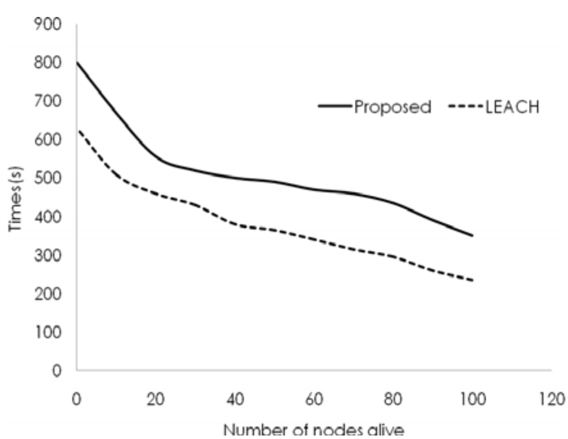

Fig. 4. Comparison of the no. of surviving nodes over time (LEACH vs. proposed scheme)

5 Conclusion

LEACH, a representative cluster-based routing algorithm, assumes that each lower-level node always has data to transmit. The assumption means that in some cases data that were sensed previously and thus need not be sent to upper-level nodes may well be being transmitted afresh. The redundancy problem was what inspired this study. In this paper, a protocol scheme was proposed to help save energy at lower-level nodes that compare the currently sensed data with the previously sensed one during their time slot and decide whether or not to send the data to upper-level nodes (CHs). The proposed scheme was compared with LEACH and TEEN through simulations. The results indicate that the use of the proposed scheme helped increase the energy efficiency of lower-level nodes as well as decrease the energy consumption required during the data aggregation by upper-level nodes (CHs). As a result, the lifetime of the entire LEACH network increased by 26% at the maximum. Compared with TEEN, the proposed scheme performed slightly better TEEN and helped solve the biggest problem it has, i.e., the backfiring of TEEN's use of thresholds to prevent redundancy in data transmission which in some cases acts to prevent communication with upper-level nodes entirely.

References

1. Ian, F., Akyildiz, F., Su, W., Sankarsubramaniam, Y., Cayirci, E.: A Survey on Sensor Networks. IEEE Communications Magazine, 102–114 (August 2002)
2. Hac, A.: Wireless Sensor Network Designs. John Wiley & Sons, Ltd. (2003)
3. Santi, P.: Topology control in wireless ad hoc and sensor networks. ACM Computing Surveys (CSUR) 37(2) (2005)
4. Heinzelman, W.B., Chandrakasan, A., Balakrishnan, H.: Energy-Efficient Communication Protocol for Wireless Microsensor Networks. In: Proc. of the Hawaii International Conference on System Science, pp. 3005–3014 (January 2000)
5. Chandrakasan, P., Heinzelman, W.B.: Application-Specific Protocol Architectures for Wireless Networks. IEEE Transactions on Wireless Communications 1, 660–670 (2000)
6. Manjeshwar, A., Agrawal, D.P.: TEEN: A Protocol for Enhanced Efficiency in Wireless Sensor Networks. In: Proc. of 1st Intl. Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile Computing, San Francisco (April 2001)
7. Heinzelman, W.B., Chandrakasan, A., Balakrishnan, H.: An Application-Specific Protocol Architecture for Wireless Microsensor Networks. IEEE Transactions on Wireless Communications 1(4), 660–670 (2002)
8. Heinzelman, W.R., Sinha, A., Wang, A., Chandrakasan, A.P.: Energy-scalable algorithms and protocols for wireless microsensor networks. In: Proc. IEEE Acoustics, Speech and Signal Processing Conf., vol. 6, pp. 3722–3725 (June 2000)