A Base Station Centralized Simple Clustering Protocol for Sensor Networks

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Abstract. Sensor nodes in wireless sensor network are severely energy-constrained. This has been a key factor to limit its performance. So far, many energy-efficient routing protocols have been proposed. Cluster-based routing protocols have been paid much attention because of their advantages. However, the cluster-based routing protocols require information on the locations of the sensor nodes in the network to construct clusters. Due to cost, it is not feasible to know the locations of all sensor nodes in the network. In this paper, we propose *a base station centralized simple clustering protocol* (BCSP) which requires no location information of the sensor nodes. Instead, BCSP utilizes information on the remaining energy of each sensor node and the number of cluster heads which is changed depending on the circumstance of the sensor network. From performance experiments, BCSP shows better performance than *low-energy adaptive clustering hierarchy* (LEACH).

1 Introduction

Recent advances in wireless communication and electronics have enabled developing low cost, low power, and multi-functional sensor nodes, which are small and can communicate with neighbor nodes within short distances. *Wireless sensor network* (WSN) usually consists of a base station and many sensor nodes. The sensor nodes are randomly distributed in the sensor network field and monitor temperature, air pressure, motion, and so on. After sensing, the sensor nodes send the sensing data to the base station. Here, the base station acts as a gateway to deliver the data from the sensor nodes to users who need it. In WSN, the number of the sensor nodes can be tens of thousands. Therefore, it could be difficult to initialize the sensor nodes and to manage the sensor network. This is why self-configuring the sensor nodes and saving energy via an efficient routing protocol [1] are desirable in WSN.

Conventionally two protocols have been used in WSN. One is direct communication protocol and the other is multi-hop communication protocol such as the *Minimum Transmission Energy* (MTE) routing protocol. In the direct communication protocol, the distant sensor nodes from the base station dissipate their energy faster than others because they send their data to the base station directly. In the MTE routing protocol, each node acts as a router for other sensor nodes. Therefore, energy is consumed faster if more sensor nodes are adjacent to the base station [4]. To overcome the problems in the conventional protocols, data centric protocols such as *the Sensor Protocols for Information via Negotiation* (SPIN) [5] and *the directed diffusion* (DD) [6] have been proposed. As far as data transmission and data collection are concerned, the data centric protocols are more efficient than the conventional transmission methods. However, the data centric protocols require many control messages and thus cause long latency to set routing paths. On the other hand, cluster-based routing protocols involve reduced control messages. In addition, the cluster-based routing protocols have bandwidth reusability, enhanced resource allocation, and improved power control. One disadvantage in the cluster-based routing protocols is that cluster heads are fixed, carry out more energy-intensive processes, and therefore their energy consumption is greater than non-cluster head nodes. As a result, network lifetime is short.

In this paper, we propose *a base station centralized simple clustering protocol* (BCSP) for sensor networks which is energy-efficient. Some related works on cluster-based routing protocols for sensor networks will be presented in Section 2. In Section 3, we explain BCSP in detail. In Section 4, we present performance results of BCSP and comparison with original LEACH and LEACH-C protocol. Finally, we conclude with some conclusions and future works.

2 Related Works

Low-energy adaptive clustering hierarchy(LEACH) was proposed to solve the prob-ems in the cluster-based protocols. LEACH is based on hierarchical clustering structure model. In order to increase the lifetime of the sensor network, LEACH changes cluster heads periodically. LEACH involves two main steps; the setup phase and the steady state phase. The setup phase involves cluster head selection part and cluster construction part. After cluster heads are chosen from sensor nodes, the cluster head sensor nodes broadcast advertisement message. The message contains cluster head ID which is the sensor node ID. Based on the advertisement message, non-cluster head sensor nodes know which nodes are new cluster heads in the sensor network. The new cluster head nodes use *the carrier-sense multiple access* (CSMA) *medium access control* (MAC) protocol to transmit it. Non-cluster head sensor nodes then select most relevant cluster head node according to the signal strength of the advertisement message from the cluster head nodes and send join request message back to the selected cluster head node for registration. Once the selected cluster head node receives join message, the cluster head nodes make *a time division multiple-access* (TDMA) schedule to exchange data with non-cluster sensor nodes without collision. The cluster head node broadcasts the schedule to its member nodes, and then the member sensor nodes start sending their data to the base station through their cluster head node during the steady state phase.

In LEACH, a cluster head node is selected according to sensor nodes probability value. As far as optimal energy consumption is concerned, it is not desirable to select a cluster head node randomly and construct clusters. However, repeating round can improve total energy dissipation and performance in the sensor network. In spite of these advantages, LEACH has some shortcomings: remaining energy of sensor nodes is not considered to construct clusters, and LEACH protocol fixes the number of cluster head nodes in the sensor network which is a parameter used in the setup phase. Therefore, it is difficult to increase and decrease the size of the sensor network. Moreover, LEACH does not guarantee the number of cluster head nodes and their distribution because the cluster head nodes are selected stochastically by the value of probability [4]. To overcome the shortcomings in LEACH, various cluster-based protocols such as *LEACH-centralized* (LEACH-C) and *Base-Station Controlled Dynamic Clustering Protocol* (BCDCP) have been proposed. In these protocols, cluster head nodes are selected by the base station in the sensor network.

LEACH-C is the extended version of LEACH. It is the same as LEACH except the setup phase. In cluster construction step, all sensor nodes in the sensor network send their information, which includes their ID, remaining energy level, and position information to the base station. Then, the base station calculates average energy of the sensor network and chooses a candidate set of cluster head nodes that have more energy than the average in the sensor network. Here, the base station executes *annealing algorithm* to find the most optimized and energy-efficient number of clusters with the candidate set of cluster head nodes. After clusters are constructed, the base station transmits information about cluster head nodes, their members, and their TDMA schedule to all sensor nodes. Then, non-cluster head sensor nodes decide own TDMA slot and come in sleep state until their own data transmission turn [3].

In BCDCP, the base station randomly changes cluster head nodes as in LEACH, constructs *cluster-to-cluster* (CH-to-CH) routing paths, and carries out other energy-intensive tasks such as data aggregation, compression, and fusion. BCDCP constructs balanced clusters where each cluster head has approximately equal number of member nodes to avoid overload, and cluster head nodes are uniformly distributed in the sensor field. It uses CH-to-CH routing to transfer data to the base station. Similar to LEACH-C, energy information sent by all sensor nodes is used to construct clusters in the setup phase. The base station uses *balanced clustering technique* for distributing load of cluster head nodes, and *iterative cluster splitting algorithm* to find optimal number of clusters. After this setup phase, the base station makes a multiple CH-to-CH routing paths, creates a schedule for each cluster, and then broadcasts schedule in-formation to the sensor network. In the data communication phase, the cluster head nodes transfer data from sensor nodes to the base station through the CH-to-CH routing paths [7].

3 Proposed Protocol

In this section, we explain the proposed protocol, BCSP in detail. LEACH-C and BCDCP use the base station and location information of the sensor nodes to increase lifetime of the sensor network. As mentioned previously, it is however difficult to know locations of all sensor nodes due to cost. There are also network overhead for all sensor nodes to send their information to the base station at the same time every setup phase due to the number of sensor nodes involved in the sensor network.

In BCSP, the base station uses the remaining energy of each sensor node and the number of sensor nodes alive in the sensor network. Therefore, the protocol does not need location information of the sensor nodes. In addition, the base station can select cluster head nodes with desirable number depending on sensor network and use this information in constructing clusters. The base station selects cluster head nodes by considering the remaining energy of sensor nodes, and broadcasts the list of the new cluster head nodes to the sensor network in the cluster construction phase. In the data communication phase, sensor nodes transmit their energy information together with their own sensing data. Therefore, BCSP can keep away from overhead originated by directly sending setup information of sensor nodes to the base station during the cluster construction phase.

3.1 Network Model

In this paper, we assume a sensor network model, similar to those used in LEACH, with the following properties.

- Sensor nodes are energy-constrained.
- The base station is supplied by power outside, and has enough memory and computing capability for energy intensive tasks.
- Each sensor node always has data to transmit it to the base station at a fixed rate.
- Each sensor node can directly communicate with other sensor nodes by varying their transmission power in the sensor network.
- The location of each sensor node is fixed.
- System lifetime is defined as the time when last sensor node dies in the senor net-work.

BCSP is composed of a base station and 100 sensor nodes and has following char-acteristics.

- The base station can change the desirable number of cluster head nodes regarding the variation of the sensor network size.
- The base station decides cluster head nodes based on the amount of remaining energy of both each sensor node and the sensor network. It also reflects the number of cluster head nodes changed by the sensor network size.
- Sensor nodes transmit energy information to the base station in the data communication phase together with their own sensing data.

3.2 Energy Model

Energy model of BCSP is based on energy model of LEACH [3]. Energy consumption can be mainly divided into two parts: receiving and transmitting message. In transmission, it needs additional energy to amplify signal depending on the distance to the destination. In this paper, we suppose that power attenuation depends on distance between a transmission node and a reception node. The propagation loss is assumed to be inversely proportional to d^2 while it is assumed to be inversely proportional to d^4 at long distances. To transmit a k-bit message a distance d, the radio expends the following energy:

$$\begin{aligned} E_{T_x}(k,d) &= E_{T_{x-elec}}(k) + E_{T_{x-amp}}(k,d) \\ &= \begin{cases} E_{elec} \times k + \epsilon_{friss-amp} \times k \times d^2 & \text{if } d < d_{crossover} \\ E_{elec} \times k + \epsilon_{two-way-amp} \times k \times d^4 & \text{if } d \geq d_{crossover} \end{cases} . \end{aligned} \quad (1)$$

At reception, exhausted energy is given by

$$E_{R_x}(k,d) = E_{R_{x-elec}}(k) = E_{elec} \times k. \quad (2)$$

Here, E_{elec}, $\epsilon_{friss-amp}$ and $\epsilon_{two-way-amp}$ are identical to those of LEACH.

3.3 Cluster Construction Phase

In the cluster construction phase, the base station broadcasts advertisement message, which includes a list of new cluster head nodes selected by the base station according to the amount of remaining energy of each sensor node (BS_ADV). At first cluster construction phase, however, the base station sends cluster information as zero, because the base station cannot recognize energy level of each sensor node and the number of sensor nodes in the sensor network.

If a sensor node is found to be a new cluster head node according to the advertisement message, the sensor node broadcasts new advertisement message that includes its own information (CH_ADV). Otherwise, non-cluster head nodes discard advertisement message from the base station and wait new advertisement message from new cluster head nodes. When non-cluster head nodes receive messages from cluster head nodes, the non-cluster head nodes choose their own cluster head node using the strength of signal, and then send join message to the cluster head node (JOIN).

In the first cluster construction phase, since the advertisement message from the base station includes just null value, sensor nodes carry out cluster head selection algorithm (3) of LEACH. Otherwise, sensor nodes carry out the operations explained above. The other operations in the cluster construction phase are identical to those of LEACH. As the cluster construction ends, cluster head nodes make a schedule for their own sensor nodes and broadcast it to their own sensor nodes (CH_SCHE). N is the number of sensor nodes in the sensor network, and k is the desirable number of cluster head nodes. The $P_i(t)$ represents the probability that a sensor node i is a cluster head node. It is identical to the formation of LEACH.

$$P_i(t) = \begin{cases} \frac{k}{N - k \times (r \bmod \frac{N}{k})} & C_i(t) = 1 \\ 0 & C_i(t) = 0 \end{cases} . \tag{3}$$

3.4 Data Communication Phase

In the data communication phase, each sensor node transmits sensing data to its own cluster head node according to communication schedule (SN_DATA). Cluster head nodes gather data sent by sensor nodes and do aggregation, fusion and compression. After that, cluster head nodes transmit processed data that include remaining energy level of each sensor node to the base station (CH_DATA).

The base station passes raw data through the Internet or other networks, and it stores information of remaining energy of each sensor node for the next cluster construction phase. Now, the base station can know the amount of energy of each sensor node and the number of sensor nodes in the sensor network. The base station can use various kinds of algorithms to calculate the suitable number of cluster heads considering size of the sensor network as well as the number of sensor nodes. In this paper, we use 5 percent of the number of sensor nodes as the optimum number of cluster head nodes that was found from the experiment in LEACH. Therefore, the base station decides 5 percent of sensor nodes as new cluster head nodes in descendant order of the amount of remaining energy every cluster construction phase.

Figure 1 shows the flow of the cluster construction phase and the data communication phase, as we explained above.

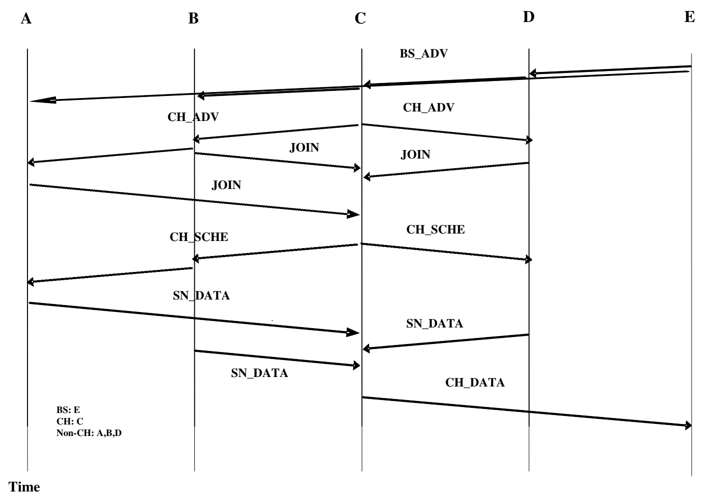

Fig. 1. The message flow of the construction phase and the data communication phase in BCSP

4 Performance Evaluation

In this section, we show performance evaluation of BCSP. We simulated with ns-2 leach extension [8] and implementation [9]. Simulation environment is equal to those of LEACH and Table 1 shows simulation parameters. We assume that sensor nodes initially have equal initial energy, $0.5J$. The area of the sensor network was set to $100m \times 100m$. The base station is located at $(50m, 50m)$ inside the sensor network. In simulation, we define system lifetime as the time when no sensor nodes send data to the base station. Performance was measured by total messages successfully delivered to the base station, system lifetime, the number of cluster head nodes per round, and average consumed energy in each simulation time. Then, we compared the simulation results with LEACH and LEACH-C.

Table 1. Parameters for simulation

Parameter	Value
Network Grid	(0, 0) × (100, 100)
BS	(50, 50)
$d_{crossover}$	$87m$
ϵ_{elec}	$50nJ/bit$
$\epsilon_{friss-amp}$	$10pJ/bit/m^2$
$\epsilon_{two-way-amp}$	$0.0013pJ/bit/m^4$
$\epsilon_{aggregation}$	$5nJ/bit$
Data packet size	$500bytes$
Packet header size	$25bytes$
Initial energy	$0.5J$
Number of nodes (N)	100
Number of clusters (k)	5 (5% of N)

Figure 2 shows the total number of received data at the base station during simulation time. We can see that BCSP stays longer and sends more data to the base station than LEACH by 7 percents. We can also see that LEACH-C sends more data than LEACH and BCSP. This is because LEACH-C uses both location and energy information of all sensor nodes.

Figure 3 shows the number of sensor nodes alive during simulation time. The figure shows that BCSP produces the longest system lifetime. The system lifetimes in BCSP and LEACH-C are longer than LEACH. This is the reason that in BCSP and LEACH-C, the base station knows remaining energy of all sensor nodes in the sensor network, and it uses the information on selecting cluster head nodes and constructing clusters. Besides, BCSP has system lifetime much longer than LEACH-C by, changing the number of cluster head nodes according to the number of the sensor nodes in the sensor network. In result, BCSP exceeds the system lifetime of LEACH by no less than 50 percent and the one of LEACH-C by 41 percent.

In Figure 4, we can see the change in the number of the cluster head nodes per simulation round. In LEACH, each sensor node uses equation 3 as a selection criterion. LEACH chooses cluster head nodes randomly regardless of the amount of energy of each sensor node. On the other hand, LEACH-C has the fixed number of the cluster head nodes by making use of the location and energy information of each sensor nodes in the sensor network. This is the reason why BCSP has system lifetime much longer than LEACH-C.

Figure 5 shows the average consumed energy per each simulation time. We can see that the number of the cluster head nodes is followed by consumed energy

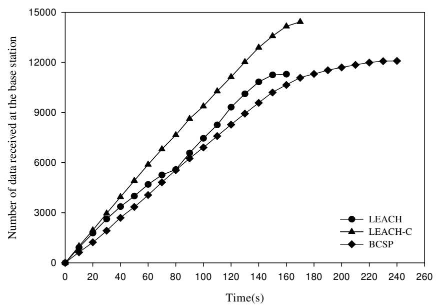

Fig. 2. Number of data received at the base station during simulation time

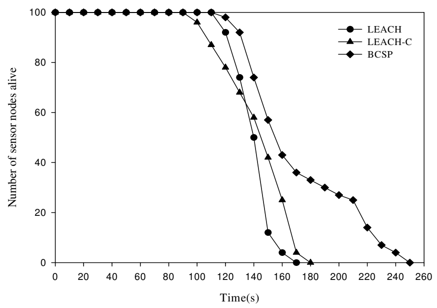

Fig. 3. Number of sensor nodes alive per simulation time

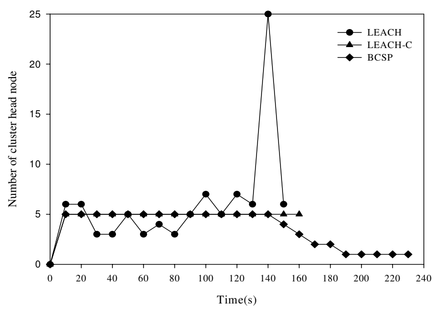

Fig. 4. Number of cluster head nodes per simulation time

linearly. Table 2 shows residual energy statistics. LEACH dissipates more energy than others, but its average data, sent to the base station, per $1J$ is the smallest, for much of consumed energy of each sensor node is used to cluster constructing and communicating with cluster head nodes. The biggest standard deviation of the average consumed energy shows the reason. The LEACH-C makes it appear that it is the most efficient among three protocols when it comes to average consumed energy and average data per $1J$.

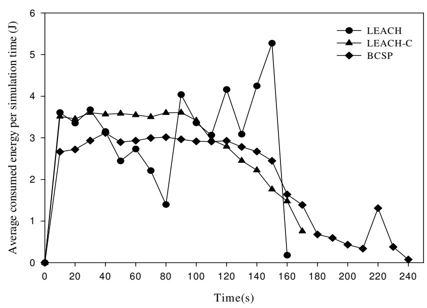

Fig. 5. Average consumed energy per simulation time

Table 2. Residual Energy Statistics

	Energy$J$		Ave. Data
Protocol	Average	Std. Dev.	(Data/J)
LEACH	3.12314	1.19851	226.01
LEACH-C	2.93060	0.89101	289.64
BCSP	2.07222	1.09602	243.11

Throughout the simulations, we can see that BCSP is better than LEACH in all simulation metrics. In that simulation, LEACH-C is a bit better than BCSP. On the other hand, BCSP is superior to LEACH-C in terms of system lifetime, since BCSP changes the number of the cluster head nodes every cluster construction phase.

5 Conclusions and Future Works

In summary, we proposed a base station centralized clustering protocol for sensor networks modified LEACH as well as very simple. We focus on the fact that it is expensive that all sensor nodes know their own location information. Moreover, to construct cluster, it is not desirable that sensor nodes send their own information every cluster construction phase, causing overhead unnecessarily. BCSP carries out cluster construction without inefficient sensor-node-broadcast to notify the base station of their information because sensor nodes send their information, necessary to construct optimal clusters, together sensing data. In addition, BCSP can change the desirable number of cluster head nodes with the sensor network size. Simulation showed that BCSP improves in all simulation metrics compared with LEACH. However, BCSP only surpasses LEACH-C in system lifetime. As we mentioned above, this is because BCSP is just concentrated in solving the problem that the number of cluster head nodes is decided irregularly.

BCSP does not still guarantee uniform distribution of cluster head nodes and the number of their member nodes. Therefore, we are now considering a better cluster based routing protocol than BCSP, which distributes cluster head nodes more uniformly and constructs similar-sized clusters without location information. When these problems are solved, it is without location information of each sensor node that our proposed protocol might have performance as good as LEACH-C or other related protocols.

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