An Enhanced Sorting Tree Energy-Efficient Routing Scheme for Wireless Sensor Networks with Mobile Sink

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ABSTRACT

Wireless sensor networks with mobile sink are expected to increase the flexibility for gathering information in the large-scale sensing and detecting environments. The sink can randomly move within the sensing area to collect the sensing data. Energy saving becomes one of the most important features for the sensor nodes to extend their lifetime in such networks. To provide reasonable energy consumption and to improve the network lifetime for the wireless sensor network systems, new and efficient energy saving schemes must be developed. A tree based energy-efficient routing scheme is proposed in this paper to reduce the energy consumption in wireless sensor networks with mobile sink. The main goal of this scheme is to reduce the data transmission distances of sensor nodes by using the tree structure and multi-hop concepts. Based on the location of mobile sink, the distances between the sensor nodes, and the residual energy of each sensor node, the proposed scheme makes an adaptive decision for creating the routing structure. Simulation results show that the proposed scheme outperforms the previously known schemes in terms of the energy consumption and network lifetime for the wireless sensor networks with mobile sink.

Keywords: wireless sensor networks, mobile sink, tree structure, multi-hop, lifetime.

I. INTRODUCTION

Recently, wireless sensor networks have been widely considered as supplementary technology in wireless and mobile systems. Powerful, inexpensive, and low-power wireless micro-sensors are designed and used in the various monitoring environments [1-3]. Wireless sensor networks have been pervasive in various applications including health care systems, battlefield surveillance systems, environment monitoring systems, and so on. A wireless sensor network consists of a large number of sensor nodes. Each sensor node has sensing, computing, and wireless communication capability. All of the sensor nodes play the role of an event detector and the data router. Sensor nodes are deployed in the sensing area to monitor specific targets and collect data. Then, the sensor nodes send the data to a sink or a base station (BS) by using the wireless transmission techniques. Wireless sensor networks with mobile sink are expected to increase the flexibility for gathering information in the large-scale sensing and detecting environments. The sink can randomly move within the sensing area to collect the sensing data. The sink mobility improves the accuracy of data transmission and reduces the energy consumption for the sensor nodes because the distances from the sensor nodes to the sink may be reduced. Fig. 1 shows the direct communication protocol in wireless sensor networks with mobile sink, where each sensor node directly transmits its sensing data to the sink. Energy saving is one of the most important features for the sensor nodes to prolong their lifetime in wireless sensor networks. A sensor node consumes mostly its energy in transmitting and receiving packets. In wireless sensor networks, the main power supply of the sensor node is battery. However, in most application scenarios, users are usually difficult to reach the location of sensor nodes. Due to a large number of sensor nodes, the replacement of batteries might be impossible. However, the battery energy is finite in a sensor node and a sensor node draining of its battery may make sensing area uncovered. Hence the energy conservation becomes a critical concern in wireless sensor networks. In order to reduce the energy consumption and prolong the network lifetime, new and efficient energy saving schemes must be developed [4], [5].

Several researches on the energy saving issues have been conducted in wireless sensor networks. With regard to the chain-based energy saving methods, analytical models have been proposed in [6], [7]. Fig. 2 shows the chain-based routing structure in wireless sensor networks. The main concept is that all of the sensor nodes are interconnected into a chain for all of the sensor networks. For each round, a chain head is selected from the chain structure. Two nodes at the end of the chain structure will send data through the neighboring nodes to the chain head (CH), and each sensor node receives data from its neighboring node for data aggregation. Finally, a chain head sends data to the BS. Power-efficient gathering in sensor information systems (PEGASIS) is proposed to create a chain structure in wireless sensor networks by using the greedy approach [6]. The main goal of this scheme is to shorten the data transmission distance between two sensor nodes, and thereby, the energy consumption of each node is reduced. In [7], the authors propose a Grid-Cluster-Hilbert-Chain tree (GCHC-Tree) scheme as an improvement of PEGASIS in wireless sensor networks. This scheme uses grid structure to divide into several clusters. For each cluster, a sensor node is selected as a grid manner based on a predetermined probability. The grid manners and the non-grid manners organize the tree structure in its cluster. All of the grid manners will interconnect into a chain by using Hilbert chain concepts. The critical problem of the chain-based routing protocol is the long latency for data transmission because the sensor node must take several hops to transmit its data to the BS. Additionally, some sensor nodes must transfer data through a longer distance, and a reasonable energy savings is not obtained in wireless sensor networks.

Motivated by the above discussion, we propose an enhanced sorting tree energy-efficient routing scheme to reduce the energy consumption and to prolong the network lifetime in wireless sensor networks with mobile sink. The main goal of this scheme is to reduce the data transmission distances of sensor nodes by using the sorting tree and multi-hop concepts. Based on the location of mobile sink and the distances between the sensor nodes, the proposed scheme makes an adaptive decision for creating the routing structure. The energy consumption is reduced and the lifetime of wireless sensor networks is extended by balancing the network load. The main benefits of our proposed scheme are that the energy consumption is reduced and better network lifetime can be carried out.

The rest of this paper is organized as follows. In Section II, we present the system model of wireless sensor networks with mobile sink. In Section III, we illustrate the proposed scheme in detail. In Section IV, we present our simulation model and analyze the comparative evaluation results of the proposed scheme through the simulations. Finally, some conclusions are given in Section V.

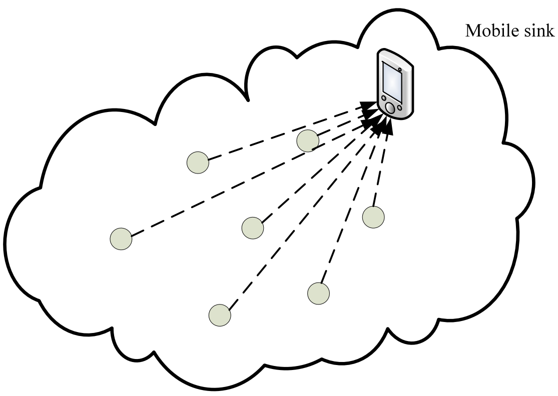

Fig. 1 The direct communication protocol

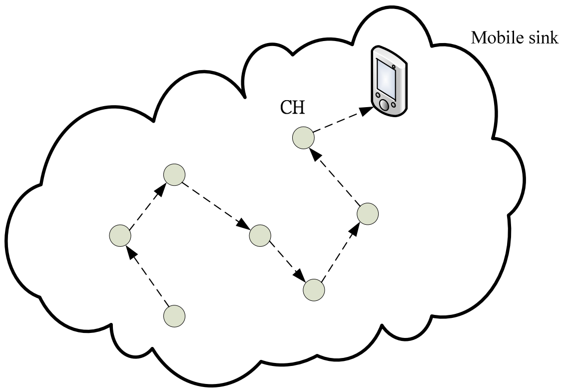

Fig. 2 The chain-based routing structure

II. System Model

The system infrastructure is composed of a mobile sink and some fixed sensor nodes. The sink can randomly move within the sensing area to collect the sensing data. We assume that the moving situation of the mobile sink is a slow movement such that a user employs the gathering device to collect the sensing data. We classify all of the sensor nodes into the non-CH nodes and CH nodes. The non-CH nodes operate in sensing mode to monitor the environment information and transmit data to the CH node by using multi-hop approach. Also, the sensor node becomes a CH to gather data, compress it and forward to the mobile sink in CH mode. All of the sensor nodes in the network are homogeneous and energy constrained. For each sensor node, the transmission power is adjustable according to the data transmission distance.

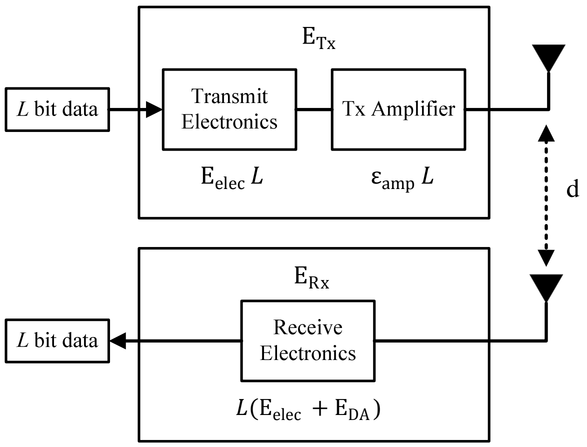

Fig. 3 Radio energy dissipation model

In wireless sensor networks, data communications consume a large amount of energy. The total energy consumption consists of the energy dissipated by data transmission of the non-CH nodes and the CH nodes. In addition, the energy consumption for data collection and aggregation of CH nodes is considered. Fig. 3 illustrates the radio energy dissipation model in the wireless sensor networks [6-7]. In this model, to transmit a L-bit message between the two sensor nodes, the energy consumption can be calculated by

$$\mathrm{E}_{\mathrm{Tx}}(L,d) = L(\mathrm{E}_{\mathrm{elec}} + \varepsilon_{\mathrm{amp}}), \quad (1)$$
$$\mathrm{E}_{\mathrm{Rx}}(L) = L(\mathrm{E}_{\mathrm{elec}} + \mathrm{E}_{\mathrm{DA}}), \quad (2)$$

where d is the distance between the two sensor nodes, $\mathrm{E}_{\mathrm{Tx}}(L,d)$ is the total energy consumption in the transmitting sensor node, and $\mathrm{E}_{\mathrm{Rx}}(L)$ is the total energy consumption in the receiving sensor node. $\mathrm{E}_{\mathrm{elec}}$ is the electronics energy consumption per bit in the transmitting and receiving sensor nodes. E_{DA} is the energy for data aggregation.$\varepsilon_{\mathrm{amp}}$ is the amplifier energy consumption in the transmitting sensor nodes, which can be calculated by

$$\varepsilon_{\mathrm{amp}} = \begin{cases} \varepsilon_{fs} d^2, & \text{when } d \le d_0 \\ \varepsilon_{mp} d^4, & \text{when } d > d_0 \end{cases}, \quad (3)$$

where ε_{fs} and ε_{mp} are communication energy parameters, and d_0 is a threshold value. If the distance d is less than d_0, the free-space propagation model is used. Otherwise, the multipath fading channel model is used.

It is obvious that the data transmission takes most of the energy consumption for the sensor nodes in wireless sensor networks. Taking into account the energy consumption of sensor nodes, the data transmission distance must be reduced and hop number should be set reasonably. Hence, the energy consumption and routing design become an important issue in wireless sensor networks with mobile sink.

III. Proposed Energy-Efficient Routing Scheme

In order to reduce the energy consumption and extend the lifetime for the sensor nodes in the wireless sensor networks with mobile sink, efficient energy saving scheme must be developed and designed. Based on the centralized sorting and tree architecture, we propose an enhanced sorting tree routing scheme (ESTRS) to provide efficient energy utilization and better network lifetime in wireless sensor networks. In the proposed scheme, for each round, we assume that the mobile sink receives the information of location and the residual energy for all of the sensor nodes. The CH selecting principle is based on the distance from a sensor node to the mobile sink and the residual energy. In this scheme, the operation includes two phases: set-up and steady-state phases.

3.1 Set-up phase

The main goal of this phase is to create a tree structure and find the CH nodes. During the set-up phase, the mobile sink collects the position information and the energy from all of the sensor nodes in the networks. Then the mobile sink calculates the distances between the mobile sink and the sensor nodes. The distances are sorted in ascending order. Additionally, the average residual energy of all of the sensor nodes is calculated.

Let $\mathrm{E}_{average}$ be the average residual energy of all of the sensor nodes. If there are N nodes in wireless sensor networks, then the average residual energy of all of the sensor nodes can be calculated by

$$\mathrm{E}_{average} = \frac{\sum_{n=1}^{N} E_{energy,n}}{N}, \quad (4)$$

where $\mathrm{E}_{energy,n}$ is the residual energy of the sensor node n. Let $d_{\alpha,MS}$ be the distance between the sensor node α and the mobile sink. Let $d_{\alpha,\beta}$ be the distance between sensor node α and sensor node β. The sorting tree routing structure is established according to $d_{\alpha,MS}$ in ascending order, and then $d_{\alpha,MS}$ is compared with $d_{\alpha,\beta}$. If $d_{\alpha,MS}$ is minimal, sensor node α directly connects to the mobile sink and becomes a CH when its residual energy is higher than $\mathrm{E}_{average}$. Otherwise, sensor node α connects to the mobile sink via sensor node β where $d_{\alpha,\beta}$ is minimal and $d_{\beta,MS}$ is smaller than $d_{\alpha,MS}$. The expression of routing establishment for the sensor node α is given by

$$min.\{d_{\alpha,MS}, d_{\alpha,\beta}\}, \;\; for \; d_{\beta,MS} < d_{\alpha,MS}. \quad (5)$$

Fig. 4 shows an example of wireless sensor networks with a mobile sink. Fig. 5 shows an example of routing architectures for our proposed ESTRS. It is obvious that the transmission distance between two sensor nodes is shortened by using the proposed scheme. The non-CH nodes play both the role of sensing the environment as well as receiving sensed data from other non-CH nodes, aggregating them and sending them to the CH node as a hop. This result may increase the energy consumption of those non-CH hop nodes. However, the network load is balanced, and the energy consumption of the sensor node is shared by using our proposed ESTRS. Hence, the total energy consumption is reduced in the systems, and the network lifetime is extended for the sensor nodes.

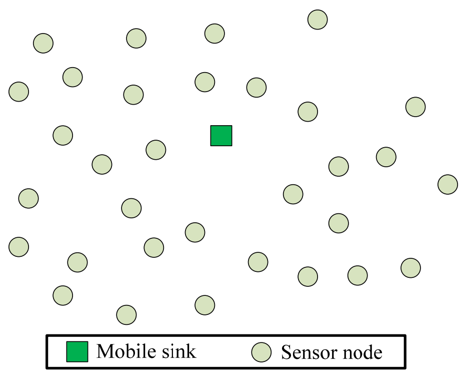

Fig. 4 Example of wireless sensor networks with a mobile sink

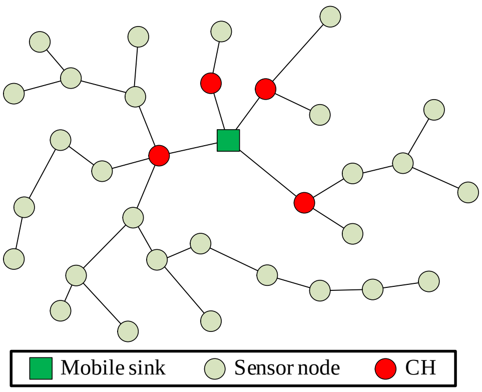

Fig. 5 Example of routing architectures for our proposed ESTRS

When the tree routing structure is created, the mobile sink broadcasts the routing information to all of the sensor nodes. Hence, each sensor node has its own routing table and knows its task (e.g. CH or non-CH). Also, each sensor node knows the distances from any other sensor node and thereby calculates the transmission power. According to the number of the sensor nodes within the tree, the CH node creates a schedule based on time division multiple access (TDMA) to allocate the time for all of the sub members.

3.2 Steady-state phase

Once the sorting tree routing is created and the TDMA schedule is fixed, data transmission can begin. The non-CH nodes can send data with each other, and the data will be transmitted to the CH during their allocated transmission time. When all of the data has been received, the CH node performs signal processing to compress the data into a single signal. Then, this signal is sent to the mobile sink. The amount of information is reduced because the data aggregation is performed at the CH or non-CH hop nodes. This round is done and the next round begins with set-up phase and steady-state phase repeatedly. In order to avoid unnecessary nodes controlling the messages transmission and control overhead of the mobile sink, the tree is re-created only when the sensor node cannot work in a certain round. So the calculating overhead is only the CH selecting in the most set-up phases.

IV. Performance Analysis

In this section, we evaluate the performance of our proposed ESTRS by using a simulation model. We describe our simulation model and illustrate the simulation results, and compare our scheme with PEGASIS [6] and GCHC-Tree [7] schemes. We assume that the moving situation of the mobile sink is a slow movement such that a user employs the gathering device to collect the sensing data. To prove that our proposed scheme is promising, we design a visual interface simulator by using C# and implement several existing schemes for fair comparison. The assumptions for our simulation study are as follows.

- The simulation environment is composed of a mobile sink and some sensor nodes.
- The sink can randomly move within the sensing area to collect the sensing data.
- The speed of mobile sink is uniformly distributed between 0 and 5 km/h.
- The location of each sensor node is randomly distributed in the sensing area.
- All of the sensor nodes can send data to the mobile sink.
- All of the sensor nodes in the network are homogeneous and energy constrained.
- All of the nodes can gather, compress and forward the data to the mobile sink or hop node.
- All of the sensor nodes are stationary and the initial energy is the same for each sensor node.
- The energy of the sensor node cannot be recharged. The sensor node continues to sense and transfer data until its energy is depleted.
- All of the parameters used in our simulation are listed in Table I [6-7].

TABLE I. Parameters used in simulation mode

Parameter	value
Electronics energy (E_{elec})	50 nJ/bit
Energy for data aggregation (E_{DA})	5 nJ/bit/signal
Initial energy of node (E_{init})	0.25 J
Communication energy (ε_{fs})	10 pJ/bit/m^2
Communication energy (ε_{mp})	0.0013 pJ/bit/m^4
Threshold value of distance (d_0)	87 m
Packet size	2000 bits
Sensing area (M × M)	100 × 100, 200 × 200, 500 × 500
Number of nodes (N)	100

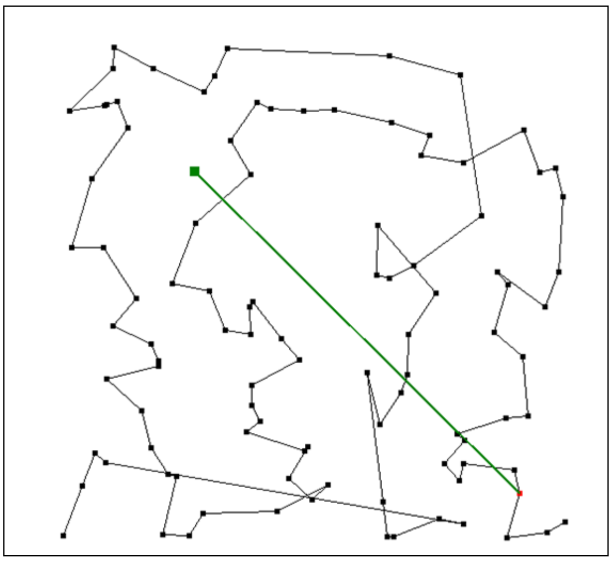

Fig.6 Routing structure of PEGASIS

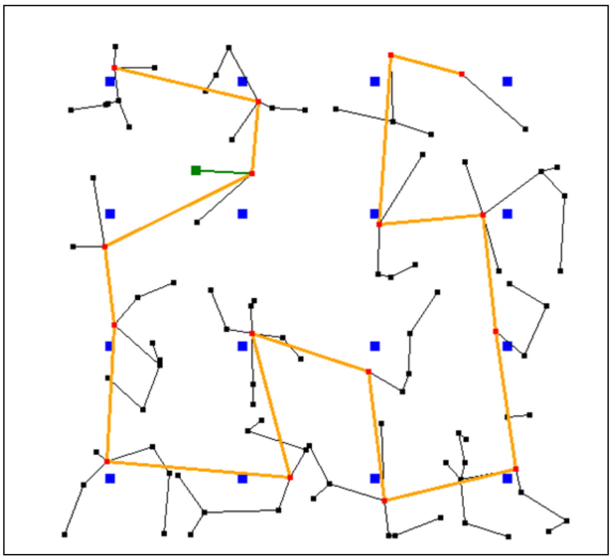
Fig.7 Routing structure of GCHC-Tree

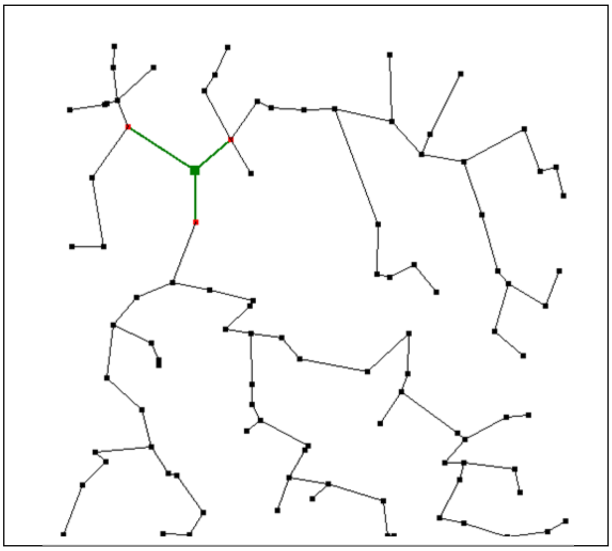
Fig.8 Routing structure of ESTRS

In order to prove our proposed scheme is well-designed, we illustrate the snapshot of the routing structures for a certain round in the simulation by using PEGASIS, GCHC-Tree, and our proposed ESTRS where the sensing area is 200 m × 200 m and the mobile sink is close to the center of the sensing area with a green node. Also, the CHs or grid manners are red nodes and non-CHs are black nodes in the sensing area. Fig. 6 shows the routing structure of PEGASIS, where we assume that the starting sensor node of the chain structure is in the bottom right of the sensing area. PEGASIS creates a chain structure in wireless sensor networks by using the greedy approach. The main goal is to shorten the transmission distance between two sensor nodes and thereby reduce the energy consumption of each node. However, some sensor nodes must transfer data through a longer distance because there is not any nearest neighbor sensor node with which to connect. Hence, reasonable energy consumption is not obtained in wireless sensor network. Fig. 7 shows the routing structure of GCHC-Tree. This scheme is an improvement of PEGASIS in wireless sensor networks by using grid, cluster, tree, and Hilbert chain concepts. It is evident that the number of hops is reduced. However, some CHs may transfer data through a longer distance. In view of Figs. 6 and 7, it observes that the PEGASIS and GCHC-Tree are unsuitable for the wireless sensor networks with mobile sink when the sensing area is extended.

Fig.8 shows the routing structure of ESTRS. It is clear that the data transmission distance between two sensor nodes is shortened while the number of hops can be maintained at an acceptable level. Hence, the energy consumption is reduced and the network lifetime is extended for the sensor nodes in wireless sensor networks with mobile sink.

The performance measures obtained on the basis of one hundred simulation runs are plotted as a function of the rounds and total network energy. A round is defined as the receiving data from all of the sensor nodes to the mobile sink. The total network energy is defined as the sum of residual energy at all of the sensor nodes. Fig. 9 shows the total network energy when the sensing area is 100 m × 100 m. It is evident that the residual energy of our ESTRS is higher than that of PEGASIS and GCHC-Tree schemes. This is because our proposed scheme provides the data transmission distance from each sensor node to the hop node is minimized. Thus the energy consumption is saved and the life time is extended for each sensor node. Also, in order to prove that our proposed scheme is promising, we extend the sensing area in the simulation environment.

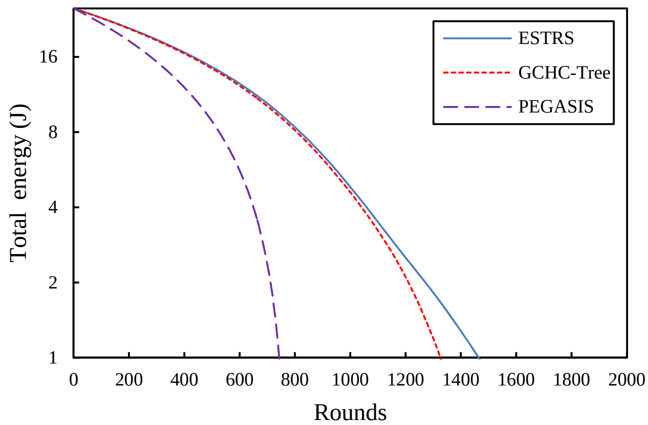

Fig. 9 Total network energy (Sensing area = 100 m × 100 m)

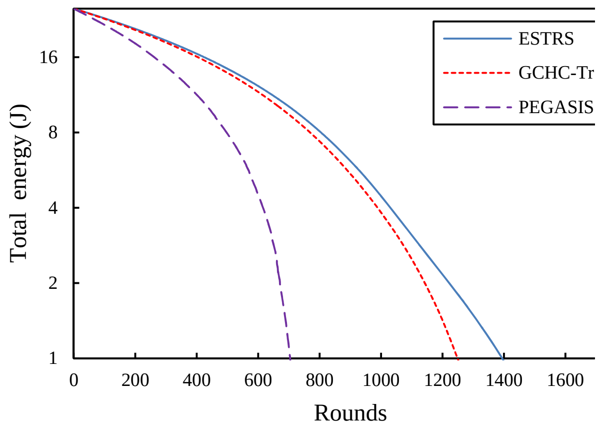

Fig. 10 Total network energy (Sensing area = 200 m × 200 m)

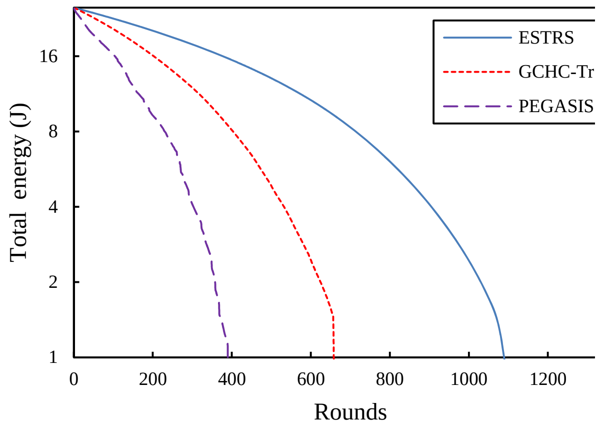

Fig. 11 Total network energy (Sensing area = 500 m × 500 m)

Figs.10 and 11 show the total network energy when the sensing areas are 200 m × 200 m and 500 m × 500 m, respectively. Due to the better energy saving approach in the proposed scheme, according to the features of ESTRS, it is intuitive that the proposed scheme results in higher residual energy than PEGASIS and GCHC-Tree schemes when the sensing area is extended.

Fig. 12 shows the average number of hops for the three schemes when the sensing area is 500 m × 500 m. The PEGASIS scheme results in long latency for data transmission because some sensor node must take several hops to transmit its data to the mobile sink. The average number of hops of ESTRS is close to that of the GCHC-Tree scheme. This result shows that the proposed scheme maintains a suitable latency for data transmission in wireless sensor networks with mobile sink. From the simulation results, it is clear that our proposed scheme not only strikes the appropriate performance in the energy consumption and network lifetime for wireless sensor networks, but is also suitable for the large-scale sensing and detecting environments.

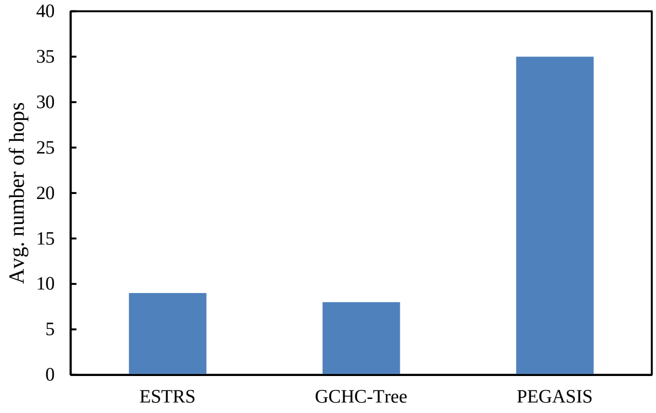

Fig. 12 Average number of hops

V. Conclusions

The energy saving is a challenging issue in wireless sensor networks with mobile sink. In order to reduce the energy consumption and extend the lifetime for the sensor nodes, new and efficient energy saving schemes must be developed. Based on the location of mobile sink, the distances between the sensor nodes, and the residual energy of each sensor node, the proposed scheme makes an adaptive decision for creating the routing structure. Simulation results indicate that our proposed algorithm achieves the low energy consumption and better network lifetime in wireless sensor networks with mobile sink.

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