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An energy-saving routing architecture with a uniform clustering algorithm for wireless body sensor networks

Jau-Yang Chang *, Pei-Hao Ju

Department of Computer Science and Information Engineering, National Formosa University, Hu-Wei, Yun-Lin, Taiwan

HIGHLIGHTS

- We adopt the uniform cluster algorithm to create the routing structure.
- We balance the traffic loading of wireless body sensor networks among the cluster.
- The data transmission distance is reduced by using the adaptive multi-hop approach.
- The energy consumption is reduced in the wireless body sensor networks.
- The lifetime of wireless body sensor networks is extended.

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ABSTRACT

Wireless body sensor networks are expected to extend human-centered applications in large-scale sensing and detecting environments. Energy savings has become one of the most important features of the sensor nodes to prolong their lifetime in such networks. To provide reasonable energy consumption and to improve the network lifetime of wireless body sensor network systems, new and efficient energy-saving schemes must be developed. An energy-saving routing architecture with a uniform clustering algorithm is proposed in this paper to reduce the energy consumption in wireless body sensor networks. We adopted centralized and cluster-based techniques to create a cluster-tree routing structure for the sensor nodes. The main goal of this scheme is to reduce the data transmission distances of the sensor nodes by using the uniform cluster structure concepts. To make an ideal cluster distribution, the distances between the sensor nodes are calculated, and the residual energy of each sensor node is accounted for when selecting the appropriate cluster head nodes. On the basis of the uniform cluster location, the data transmission distances between the sensor nodes can be reduced by employing an adaptive multi-hop approach. The energy consumption is reduced, and the lifetime is extended for the sensor nodes by balancing the network load among the clusters. Simulation results show that the proposed scheme outperforms the previously known schemes in terms of the energy consumption and the network lifetime for the wireless body sensor networks.

1. Introduction

Recently, there has been rapid advancement in the field of Internet techniques. The Internet is moving quickly toward the interaction of objects, sensors, and computing devices, which are usually indicated as the Internet of things (IoT) systems. An IoT system is expected to integrate sensing, communication, Internet, and cloud computing technologies in large-scale monitoring environments [1]. The main monitoring infrastructure of IoT systems is wireless sensor networks. A wireless sensor network is composed 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 a data router. The 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 wireless transmission techniques [2–6]. The BS is connected to a switching center that acts as a gateway from the wireless network to the Internet. Fig. 1 shows a direct communication protocol in the wireless sensor networks, where each sensor node directly transmits its sensing data to the BS. Wireless sensor networks have been pervasive in various applications, including health care systems, battlefield surveillance systems, and environment monitoring systems, among others.

A wireless body sensor network is one of the specific classes of wireless sensor networks. Wireless body sensor networks are expected to extend human-centered applications in large-scale sensing and detecting environments [7–9]. However, body sensor

* Corresponding author. Tel.: +886 56315589; fax: +886 56330456.
E-mail address: jychang@nfu.edu.tw (J.-Y. Chang).

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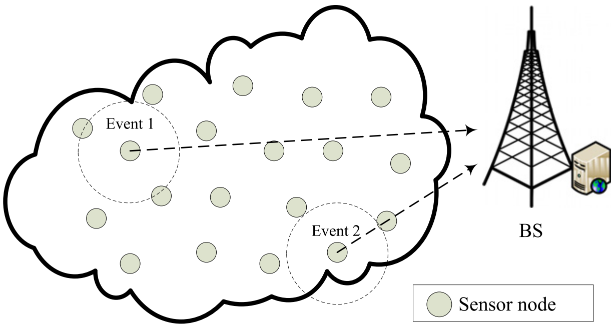

Fig. 1. Direct communication protocol in the wireless sensor networks.

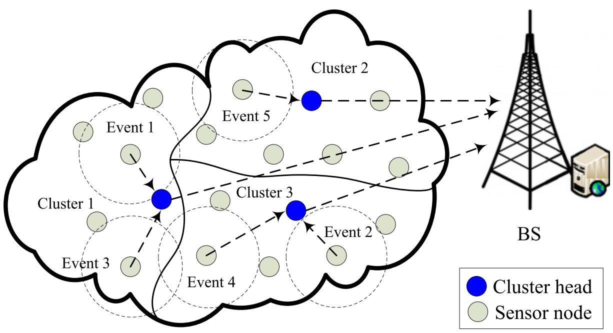

Fig. 2. Cluster-based routing protocol in wireless sensor networks.

network systems require powerful networking infrastructure and suitable routing structure. To prolong the lifetime of sensor nodes, energy consumption and routing design issues must be accounted for. Energy saving becomes one of the most important features for the sensor nodes to prolong their lifetime. In the wireless body sensor networks, the main power supply of a sensor node is a battery, and a sensor node consumes most of its energy in transmitting and receiving packets. However, the battery energy is finite in a sensor node, and a sensor node that has its battery drained could make the sensing area uncovered. Hence, energy conservation becomes a critical concern in wireless body sensor networks. To reduce the energy consumption and to prolong the network lifetime, new and efficient energy saving routing architectures must be developed.

The remainder of this paper is organized as follows. In Section 2, we review related work from the literature and describe the critical problems in these schemes. In Section 3, we present a system model of wireless body sensor networks. In Section 4, we illustrate the proposed scheme in detail. In Section 5, we present our simulation model and analyze the comparative evaluation results of the proposed scheme through simulations. Finally, conclusions are provided in Section 6.

2. Related work

Several studies on energy saving issues have been conducted on wireless sensor networks. With regard to cluster-based energy saving methods, analytical models have been proposed in [10–18]. Fig. 2 shows a cluster-based routing protocol in wireless sensor networks, where the cluster head (CH) node is responsible for collecting information on non-CH nodes in its cluster. Then, it processes data and sends data to the BS. The non-CH node can only monitor the environment and send data to its CH node. Because a non-CH node cannot send data directly to the BS, the data transmission distance of the sensor node is shrunk. Therefore, the energy consumption is reduced for each non-CH node.

Low-energy adaptive clustering hierarchy (LEACH) is a typical cluster-based routing protocol that uses a distributed clustering approach [10]. In LEACH, the large number of sensor nodes will be divided into several clusters. For each cluster, a sensor node is selected as a CH. The selection of CH nodes is based on a predetermined probability. Other non-CH nodes choose the nearest cluster to join by receiving the strength of the advertisement message from the CH nodes. In [11], the authors modify the CH selection approach of LEACH (LEACH-E) to improve the network lifetime by accounting for the available remaining energy level of each sensor node. In [12], the authors propose the HEED (Hybrid, Energy-Efficient, Distributed) clustering protocol to prolong the network lifetime and support scalable data aggregation. In this protocol, the CHs are probabilistically selected based on their residual energy, and the sensor nodes join the clusters according to their power level. A new clustering algorithm with cluster member (NCACM) bounds for energy dissipation avoidance in wireless sensor networks [13] is proposed to reduce the energy consumption and to extend the network lifetime. The authors determine a confidence value for any sensor node that might become a CH by using parameters such as the nodes' remaining energy, the distances between the nodes, and the distances between the CHs in each round. However, a random selection of a CH node could obtain a poor clustering setup in these previously developed schemes, and the CH nodes can be redundant for some rounds of operation. The distribution of CH nodes is not uniform; thus, a cluster can consist of a large number of sensor nodes, and some sensor nodes must transfer data through a longer distance. Additionally, a CH node consumes too much energy to receive and to aggregate data from its non-CH nodes and to transmit data to the BS. It is clear that the CH node will die quickly. Thus, a reasonable energy consumption is not obtained in the wireless sensor networks. LEACH-centralized (LEACH-C) is proposed as an improvement of LEACH that uses a centralized approach to create the clusters [14]. In LEACH-C, the BS collects the information of the position and energy level from all of the sensor nodes in the networks. On the basis of this information, the BS calculates the number of CH nodes and configures the network into the clusters. LEACH-C uses a simulated annealing algorithm to create the routing structure. The average energy consumption of LEACH-C is lower than that of the distributed clustering schemes, such as LEACH, LEACH-E, HEED, and NCACM. In [15], we propose a saving energy clustering algorithm (SECA) to provide efficient energy consumption for the sensor nodes and to prolong the lifetime of the wireless sensor networks. In accordance with the centralized operation, the uniform cluster location can be obtained by using SECA. The data transmission distance from each sensor node to the CH node is suitable. Hence, the energy consumption is reduced, and the network lifetime is extended.

The chain-based technique is one of the approaches to reducing the energy consumption in wireless sensor networks [19–21]. Fig. 3 shows the chain-based routing protocol in the wireless sensor networks. The main concept is that all of the sensing 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, and each sensing 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 the wireless sensor networks by using the greedy approach [20,21]. The main goal of this scheme is to shorten the data transmission distance between two sensing nodes, and thereby, the energy consumption of each node is reduced. The critical problem of the chain-based routing protocol is the long latency for data transmission because the sensing node must take several hops to transmit its data to the BS. This approach is unsuitable for real-time sensing and discovery applications. Additionally, some sensing nodes must transfer data through a longer distance, and a