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A new clustering protocol for energy harvesting-wireless sensor networks☆

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ABSTRACT

Wireless Sensor Networks (WSNs) are used for environmental monitoring. In recent years, energy constraints have led us to develop sensor nodes that harvest energy from the environment. WSNs improve performances by using techniques such as routing and clustering, by harvesting energy from the environment. These networks are called Energy Harvesting Wireless Sensor Network (EH-WSN). Due to the unique features of EH-WSNs, typical WSN clustering and routing methods are inefficient for EH-WSN. In this paper, we propose a novel hybrid methodology involving static and dynamic clustering operations. It uses a distributed-centralized approach and multi-hop routing and considers criteria, such as the energy level, the amount of harvested energy and the number of neighbors in the clustering process. Simulation results show that the proposed method improves the network stability and efficiency, comparing to other methods.

1. Introduction

Wireless Sensor Networks (WSNs) is a set of wireless sensor nodes distributed over an environment. In recent years, with the development and progress of technology, sensor networks have been used in various applications [1,2] and in different domains such as medicine, environmental control, industrial management, military, etc. [3].

A WSN consists of small, low cost and low power sensor nodes, deployed for monitoring different aspects of the environment. Generally, a sensor node is made of four basic components [4] with additional units being added, depending of the application requirements [5].

WSN are limited in terms of energy. As the most part of the energy consumption is related to wave transmission, improving the energy consumption of routing protocols is one of the main methods to increase the network lifetime [6].

A new category of WSN, which harvests environmental renewable energy (solar, wind, vibrations, etc.) are now emerging [7]. In these networks, as long as the energy consumption is less than the harvested energy, nodes don't breakdown because of energy shortage. So the aim of routing optimization in Energy Harvesting Wireless Sensor Network (EH-WSN) must be to

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maximize the performance according to the amount of harvested energy, keeping the network stable [8]. The fact that in wireless networks data transmission consumes more energy than data processing motivated various studies of WSN routing [8].

An important feature of WSN is its self-organizing feature and also the ability to communicate with each other in a short-range and multi-hop routing [7]. The energetic properties of an EH-WSN node are different from the properties of the battery-powered sensor nodes [8]. In a battery-powered sensor node, the total energy decreases over time and sensor nodes can work until the energy level falls down an unusable level [7]. At energy harvesting sensor nodes, if the harvested energy is not sufficient the nodes get in to the sleep mode, waiting the battery to be recharged. Thus these kinds of nodes can be recharged and reused [8].

As the charging rate is usually much smaller than the energy consumption of sensor nodes, these nodes need to be turned off for a period of time in order to recharge, but this leads to changes in the network's topology [8]. Compared to battery-powered WSNs, EH-WSNs have their unique characteristics, therefore the WSN routing protocols are not suitable for EH-WSN [9].

In this paper, the chance of each node to be selected as a Cluster Head (CH) is determined according to its energy status and to the amount of harvested energy. Nodes with higher chances have less delay times. The node with the smallest time delay comparing to its neighbors is selected as CH. After choosing a CH and forming a cluster, all nodes of each cluster start to send packets to the CH based on energy-aware multi-hop routing. Then CH sends these packets to the Base Station (BS) through multi-hop routing.

The continuation of the paper is organized as follows: Section 2 provides a review of the recent literature related to the subject, the proposed algorithm is described in Section 3, simulations and the assessment of the proposed algorithm are shown in Section 4 and eventually, Section 5 presents the conclusions of the paper.

2. Related work

Several research works were done to improve the energy consumption by using clustering-based protocols. Heinzelman et al. [1] proposed the Low-Energy Adaptive Clustering Hierarchy (LEACH), which distributes clusters randomly. Each node can play the CH role, based on a predefined probability.CH position rotates among different nodes to prevent battery draining in any of them. Other nodes are connected to CH with minimal energy needed to reach it. Then the current CH coordinates its nodes through time slots allocation in order to send the data.

Hybrid Energy-Efficient Distributed Clustering (HEED) is another widely used algorithm, introduced in 2004 [10]. This algorithm uses the combination of remaining energy and communication cast as a criterion to select CHs.

Stable Election Protocol (SEP) is an extension of LEACH, which aims to utilize heterogeneous nodes in WSN [11]. This protocol has the same function as LEACH, but the difference is that SEP nodes have two different levels of energy and the chances of higher energy nodes to be selected as CH exceed the chances of the other nodes.

Other solutions named Energy Efficient Heterogeneous Clustered (EEHC), Energy Efficient Clustering and Data Aggregation (EECDA) were proposed by Kumar et al. [12,13]. In these methods, networks were assumed heterogeneous and nodes were divided into three categories: ordinary, advanced and superior nodes, and the probability of each node to be selected as CH was determined according to the instantaneous energy of nodes and is used to calculate the number of optimized network CHs.

Energy and Coverage-Aware Distributed Clustering (ECDC) is another protocol which was introduced in 2014 [14]. ECDC is an energy-efficient and coverage-aware algorithm. A node with higher energy and suitable coverage is selected as CH. In comparison with other protocols, this protocol has less control overhead and also performs in a fully distributed manner.

Centralized Balance Clustering (CBC) [15] is centralized and performed in three steps. At first it calculates the number of clusters according to network conditions and makes a hexagonal clustering according to the balance of cluster numbers. Then a CH is selected for each cluster, based on energy and nodes distribution. In the third step, a scheduling is made to send data and avoid collision. This method reduces the network energy consumption.

Energy Aware Routing Algorithm (ERA) [16] forms clusters by taking into account the energy level of CH. CHs are organized in different levels in order to build a virtual backbone for routing data.

Hybrid Unequal Clustering with Layering Protocol (HUCL) [17] uses a hybrid unequal clustering method to increase the network lifetime. This method uses a combination of static and dynamic clustering in which clustering overhead is considerably reduced compared to other dynamic clustering techniques.

Energy Aware Distributed Unequal Clustering Protocol (EADUC) [18] is an improvement of HUCL. This method forms clusters with unequal sizes. Clusters near the BS have smaller size. Some parameters such as energy of nodes are considered in determining competition radius for nodes within clusters. The improved version of this method for inter-clustering considers the energy of nodes to choose the next step.

Recently, several studies have been done on WSN equipped with energy harvesting sensor nodes. One of these methods is s-LEACH [19] in which all nodes used solar energy but they are still equipped with a battery as a backup energy source. In this algorithm a CH is initially selected by the BS. In the next step a new CH is selected by the current CH.

Adaptive Energy Harvesting Aware Clustering Routing Protocol (AEHAC) [7] assumes that each node can harvest energy from an environment without chemical battery backup and assess the speed of short-term energy harvesting. Nodes with higher harvesting speed are more likely to be selected as CHs.

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