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A decentralized energy efficient hierarchical cluster-based routing algorithm for wireless sensor networks

Maryam Sabet*, Hamid Reza Naji

Collage of Electrical and Computer Engineering, Graduate University of Advanced Technology, Kerman, Iran

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ABSTRACT

Load balancing using clustering method is one of the most practical solutions, regarding to energy limitation in wireless sensor networks. Clustering protocols have to ensure reliability and connectivity in WSNs even in large scale environments. In this paper, a new decentralized hierarchical cluster-based routing algorithm for WSNs is proposed. The most of energy consumption occurs due to transmission of messages, such as data and control packets. In our new approach clustering and multi hop routing algorithms are performing at the same stage to decrease control packets. According to non-uniform energy consumption among nodes, clusters are formed in such a way that cluster heads have the most competency in forwarding task of intra-cluster and inter-cluster transmission tree. Energy consumption, adjustment degree and the exact distance that each data traverses to reach the base station are three main adjustment parameters for cluster heads election. Simulation results show that the proposed protocol leads to reduction of sensor nodes' energy consumption and prolongs the network lifetime, significantly.

1. Introduction

Great advancement of science and miniaturization of battery-powered devices led to the development of tiny-size battery-operated sensors which are capable of monitoring physical phenomena like temperature, humidity, vibrations, seismic events, and so on [1–3].

Typically, a sensor node is composed of three principle components: a sensing subsystem for data acquisition from slightly ambience, a processing subsystem for local data processing and a wireless communication subsystem for transmitting necessary data [2]. A wireless sensor network consists of numerous sensor nodes with a limited transmission range developed in monitoring area and usually have unstructured infrastructure. These networks have huge usage in military or civil surveillance, target tracking, territory/premises protection, forecasting natural disasters and human health monitoring [4,5]. Particular examples in military include spatially correlated and coordinated troop, tank movements and collection of required information about geographical position of equipment. With natural disasters, sensor nodes can sense and detect the environment for disaster forecasting before they occur. For instance deployment of sensors along the volcanic area can detect the development of earthquakes and eruptions. In human health monitoring, some particular sensors can help control a patient's health [5].

In WSNs each sensor node reports occurred phenomena and performs local process including data fusion and quantum. These aggregated data are sent to the base station (BS) directly or via some other relay nodes. Finally, all gathered data which are associated with a parameter, would be processed and the ultimate result value is estimated fairly accurate. In these networks, failure of a node has almost no impact on the estimated value, however it causes loss of coverage area and delay increases in event diagnosing.

In WSNs, data aggregation involves combining data belonging to a specific event. The main aggregation objective is to prolong network lifetime by reducing consumption of resources (e.g. battery power or bandwidth) and number of transmission packets. Besides, data aggregation protocols effect on the quality of service parameters such as data accuracy, latency, fault tolerance and security [6].

Due to widespread use of WSNs and sensor's constraint issue, the necessity arises for new and energy efficient protocols around data aggregation subjective. Therefore, using energy-aware programs and algorithms is greatly significant [7,8].

One of the most common approaches to achieve data aggregation is that sensor nodes would be classified into several clusters and in each cluster, one node is selected as a cluster head for data aggregation tasks. Cluster head (CH) role turns around the nodes to ensure the load distribution between nodes. In recent years,

* Corresponding author.
E-mail addresses: maryam.sabet90@gmail.com (M. Sabet), hamidnaji@ieee.org (H.R. Naji).

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clustering algorithms, has attracted the attention of many researchers. They proved that clustering is an effective scheme in increasing the scalability, load balancing among nodes and prolonging the lifetime of WSNs [9,10]. A number of these approaches assume that a node can send its data to the BS directly, however it is not energy efficient due to long distance data transmission. To solve these problems, some approaches let nodes to relay their data within multiple hops to the BS [11]. Since, these methods need to retransmit some control packets for routing construction purposes some power wasting still exists in this stage.

In this paper we proposed an energy efficient hierarchical cluster-based routing algorithm for wireless sensor networks in a fully distributed manner. The key issue of our protocol scheme is that during construction of routing tree, CHs would be selected at the tree edges, based on effective local information. For CH decision-making procedure, we use multiple criteria, such as each node's residual energy and its distance to the base station along the created routing tree. Each node decides independently whether to become a CH. Usual nodes join to the appropriate CHs. Due to combination of routing and clustering essential scheme, the number of control packets would be reduced and consequently more power would be saved in each sensor node.

The remainder of this paper is organized as follows. Section 2 provides a brief survey of some closely related works. Section 3 describes the network model in our algorithm. Section 4 presents the cluster-based routing protocol in detail. Section 5 analyzes several properties of the protocol. Section 6 evaluates the performance of the algorithm via simulations and analyzes the results obtained in detail. Finally, Section 7 gives the concluding remarks.

2. Literature survey

In order to distribute load among nodes and to cope with energy constraint problem, a number of clustering algorithms have been proposed. LEACH [12] is one of the famous classical distributed algorithm in this field. This algorithm consists of two separate phases. In setup phase each node elect itself as a cluster head with a certain probability and in steady state phase each cluster's member node transmit sensed data to correspond cluster head. After data aggregation, each cluster head sends data to the base station directly. Since each node's chance of becoming a cluster head is independently based on a probability value, low battery nodes also have the opportunity to play cluster head role, hence appropriate distribution of cluster heads would not be ensured.

LEACH widely has been served as a benchmark so that a lot of improvement schemes on this algorithm have been proposed such as LEACH-C [13], centralized clustering algorithms and LEACH-E [14] and LEACH-B [15], distributed clustering algorithms which concentrate on energy consumption reduction using node's residual energy and more relevant criterion.

The authors in [16] organized the network in cluster of even sizes. Each cluster consists of a CH, next head and a set of sensor nodes. Base station splits network into clusters and selects a CH based on received information from sensor nodes. Afterwards, the set of eligible next heads that have residual energy above the threshold is created to take CH task in the next round. This method could lead to more power maintenance in sensor nodes.

Authors [17] proposed an energy efficient clustered schema for heterogeneous WSNs (EEHC) based on weighted election probability of each node for becoming CH. Its goal is to elect suitable CHs in distributed manner in presence of heterogeneity hierarchical WSNs. Eventually, it can obtain acceptable results [18].

All above protocols assure that CH nodes send data to the base station through a single hop. Since data transfers to the base station dissipate much more energy, it would accelerate nodes' death. Therefore, for power saving purposes some multi hop clustering approaches have been proposed. Well known protocol PEGASIS [19] is one of the extension of LEACH, which utilizes a collection set of nodes to form a chain. It starts from the farthest node and each node sends data only to the nearest neighbor. In each round, Chain leader task is shifted around nodes to help energy balancing between sensors. But data delay increases and is not suitable for large scale networks.

In article [20] a distributed randomized clustering algorithm for generating a hierarchy of CHs is proposed. It is observed that with increasing number of levels, nodes' energy saving also increases. However, it causes a long delay of the algorithm.

HEED [9], a distributed clustering approach for long-lived ad hoc networks, is suggested. It selects CHs based on energy and secondary parameter like adjustment degree. HEED could terminate in O(1) iteration, incurs low message overhead and guarantees connectivity of clustered networks, with effective increase in network lifetime.

DEECIC [21] aims at selecting the smallest set of nodes, undertaking CH task, which can cover the whole network. It develops a unique ID assignment method based on each node's local information. With 2-hop intra-cluster communication and well load distribution among nodes, it can keep network coverage while causing extension of network lifetime.

In article [22] to keep the expected no of CHs stable and adjust the electing probability, a sliding window has been established. This protocol utilizes initial energy information of nodes as the first effective parameter and average energy of nodes that have not already been CHs in the network, as secondary parameter. It would guarantee the uniformity of energy consumption in the network cycle.

The main idea of author [23] is to reduce data transmission distance for sensor nodes by using the uniform cluster concepts. Average distance between sensor nodes and residual energy are used to choose nodes for playing the CHs role in the network. Each CH sends data to base station through CH relay nodes.

In article [24] a different approach is proposed with dividing the monitoring region into hexagon cells. For this purpose, node's geographical location information is considered. Each cluster can be formed with at least seven hexagon cells. Clusters include nodes with the same cluster identity and a CH located in the central cell of each cluster. It uses the transmission power management method for decreasing the rate of packets collision and makes enhancement in channel reuse and energy efficiency.

To ascertain sensor nodes' energy optimization issue in article [25] introduced energy-harvesting (EH) nodes, exploited in a clustered WSNs to serve as relay for CH nodes. This algorithm tends to find an optimal location for a CH in a cluster where minimizing the overall maximum energy consumption of CHs and non-CH nodes and the best location of correspond EH nodes as well. This can validate the near optimality performance with the help of EH nodes.

In paper [26] an optimal duty-cycle based energy-neutral communication protocol is proposed for MFC-powered WSNs. Mathematical models have been employed to minimize the probe packet reception time. In addition an energy-neutral joint scheduling and routing protocol in multi-hop MFC networks is introduced. This method guarantees the lifetime of sustainable nodes with throughput-optimal node-to-node transmission strategy and assures sustainable sensing of a multi-hop WSNs. Result shows that communication protocol is able to provide sustainable and reliable data transmission under low and dynamic power inputs.

Paper [27] proposed a new routing scheme called primate-inspired adaptive routing protocol (PARP). This protocol aims at utilizing the features of the primate mobility for routing assistance. It can determine the number of message copies and the routing