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REGULAR PAPER

A new evolutionary based application specific routing protocol for clustered wireless sensor networks

Mohammad Shokouhifar*, Ali Jalali

Department of Electrical and Computer Engineering, Shahid Beheshti University, G. C., Tehran, Iran

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ABSTRACT

Energy consumption is a major issue in designing wireless sensor networks. To achieve the energy efficiency, many routing protocols have been proposed and LEACH is the representative one. LEACH utilizes randomize rotation of the cluster heads to evenly distribute energy load among all nodes. However, it depends only on a probability model and energy efficiency could not be maximized. In this paper, a new application specific low power routing protocol named ASLPR is introduced that takes into account some concepts from sensor nodes (e.g., distance from base station, residual energy, distance between cluster heads) to elect the optimal cluster heads. As the proposed routing protocol is complex and has some controllable parameters, tuning of its parameters is an important problem to achieve the best performance based on the application. In this work, a hybrid algorithm based on genetic algorithm and simulated annealing is applied to optimize ASLPR in order to prolong the network lifetime, based on the application specifications. Simulation results demonstrate the efficiency of the proposed methodology to balance the energy consumption of nodes and maximize network lifetime. The gain (on average) in stable region of ASLPR until first node dies is 78%, as compared with three LEACH-based protocols.

1. Introduction

The combination of a number of wireless sensors makes a wireless sensor network (WSN) which provides unprecedented opportunities in several domains ranging from military to agriculture, and has applications in civil as well as construction structural monitoring, industrial control, health monitoring, and home networks [1]. In the past few years, an intensive research was conducted that addresses the potential of collaboration among wireless sensors in data gathering and processing. However, wireless sensor nodes are constrained in the energy supply, processing power, bandwidth and memory. Since the network lifetime depends on energy consumption of the nodes within the network, the power supply component in the nodes is very important. Thus, innovative techniques that minimize the energy consumption and maximize the lifetime of the network are highly required. A routing protocol should takes into account the energy-awareness at all layers of the networking protocol stack (e.g., routing at the network layer), in such a way that the network lifetime is maximized [2].

In WSNs, a routing protocol is required when a node cannot send its data packet directly to its destination node, and has to rely on the assistance of intermediate nodes to forward its packet. Routing in WSNs is very challenging, due to several natural characteristics that distinguish them from typical communication networks such as wireless ad-hoc networks [3]. First, classical IP-based protocols cannot be used for WSNs, due to its inability to build a global addressing scheme for the deployment of wireless sensor nodes. Second, in contrast to the typical communication networks almost all applications of WSNs require that the sensed data from multiple sensor sources are flow to a particular base-station. Third, the generated data traffic has substantial redundancy, since the multiple wireless sensor nodes may sense the same data in the case of homogeneous WSNs. Such redundancy needs to be exploited via the routing protocol to improve the energy and bandwidth utilization. Fourth, wireless sensor nodes are tightly constrained in terms of transmission power, energy, and storage. Therefore, they require careful resource management [4]. In the last few years, many protocols have been proposed for the routing problem in WSNs [4]. In general, routing protocols for WSNs can be categorized into *flat*, *hierarchical*, and *location-based* [5]. In flat routing, all nodes have the same functionality and they work together to sense and route [6]. Hierarchical routing techniques divide the network into distinguished clusters. The most famous and attractive hierarchical protocol is Low Energy

* Corresponding author. Tel.: +98 9121944288; fax: +98 2122431804.
E-mail addresses: m_shokouhifar@sbu.ac.ir, shokoohi24@gmail.com (M. Shokouhifar), a_jalali@sbu.ac.ir (A. Jalali).

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Adaptive Clustering Hierarchy (LEACH), which has been widely accepted for its energy efficiency and simplicity [7]. In location-based routing approaches, the information about the location of sensor nodes is used to generate the routing path [8].

An intermittently connected mobile ad hoc network is a special type of wireless mobile network, in which, disconnection occurs frequently. Therefore, these networks cannot guarantee a completed path between the source and destination most of the time. To overcome such a drawback, Sun et al. [9] have proposed a routing scheme called primate-inspired adaptive routing protocol (PARP), which can utilize the features of the primate mobility to assist routing. For intermittently connected mobile networks, the number of message copies is another significant factor that affects the performance of the networks. Since the connection is hard to establish in these networks, the nodes need more strict mechanism on energy savings to guarantee future communications. The most efficient way for energy saving is to control the number of message copies. PARP determines the number of message copies and the routing strategy based on the walking length of the mobility model. Distinct from the conventional routing protocols for mobile ad hoc networks, PARP combines the mobility model and routing together [9]. Recently, cross-layer routing design for cognitive radio networks has been widely studied. A large queuing and back-off delay will reduce the transmission efficiency of a link and increase the cumulative end-to-end delay. In Ref. [10], a source routing protocol based on on-demand routing and dynamic channel assignment has been proposed to improve the transmission efficiency under multi-link interference situation. The channel assignment tries to maximize the transmission efficiency of links along the selected path, to reduce the average cumulative end-to-end delay of all flows and increase the packet delivery ratio [10].

There are some popular criteria for definition of network lifetime in WSNs, including First Node Dies (FND), Half Node Die (HND), Last Node Dies (LND), etc. [3]. It is remarkable that the network lifetime is defined based on the application, and there is no an specific definition that covers all of the applications. For example, in a hospital health monitoring network, lifetime should be defined as FND, due to the information of sensor nodes is distinguished, and it is different from a node to another. In these networks perishing of a sensor node may generate irreparable damages. Therefore, lifetime in these kind of applications with distinguished nodes should be define as FND. On the other hand, there are a large number of applications with homogeneous nodes, such as construction structural monitoring in Buildings, Tunnels, Bridges, etc. Perishing of some of sensor nodes is not critical in these applications, and network is trustable as long as at least the determined number of nodes will be remained alive. Therefore, lifetime may be defined in different criteria based on node density, application specifications, and distribution of nodes in the network.

In the clustering-based routing protocols, data gathered by the sensor nodes is transmitted to the sink through the cluster heads (CHs). As the nodes communicate data over shorter distances in these protocols, the energy spent in the network is likely to be substantially lower compared to when each node communicates directly to the Base Station (BS). It is notable that as distance increased, energy consumption grows exponentially for the transmitter node. To this end, various clustering-based protocols have been proposed aim at generating the minimum number of clusters and minimum transmission distances. These algorithms are distinguished by how the CHs would be elected. Recently, Swarm Intelligence (SI) algorithms have begun to attract attention from researchers to develop clustering-based routing protocols in WSNs [3,11–16]. The main goal of these SI-based protocols is to dynamically cluster sensor nodes such that the energy consumption of the network is minimized. They have proved that their protocols outperform other attractive routing protocols such as LEACH in prolonging the network lifetime. However, making a precise inspection of their results, one can see that one common drawback emerges. While these SI-based routing protocols prolong the network lifetime (e.g., HND or LND), they decrease the stability period of the system (e.g., FND) which is crucial for many applications like health monitoring networks.

In this paper, a hybrid clustering-based Application-Specific Low Power Routing (ASLPR) protocol is introduced, that takes into account some concepts from the current situation of sensor nodes in the network (e.g., the distances from sensors to the base station, the remained energy of sensors, distance of nodes from other cluster heads etc.), and can optimally balance the energy consumption among the sensors. As the proposed routing protocol is complex with some controllable parameters, a hybrid algorithm based on genetic algorithm and simulated annealing is used to optimize the proposed protocol. The main advantage of the proposed protocol is that ASLPR can adaptively tune its parameters in order to generate the maximum lifetime in each specific application. Therefore, we are motivated by the fact that there are many applications that would benefit highly from maintaining the stability as well as the network lifetime, thus maintaining better tradeoff between reliability and lifetime of the system. On the other hand, the proposed ASLPR protocol can maximize the defined lifetime scheme (e.g., FND, HND, etc.), based on the application.

The rest of the paper is organized as follows: Section 2 briefly reviews some hierarchical clustering-based routing protocols in WSNs. In Section 3, the drawbacks of the current hierarchical clustering-based routing protocols are addressed and the ASLPR algorithm is proposed as an effective solution to their problems. The optimization procedure of ASLPR protocol using hybrid genetic algorithm and simulated annealing is described in Section 4. Also, Section 5 presents simulation results and comparison with other LEACH-based routing protocols. Finally, Section 6 concludes this paper with possible future directions.

2. Related works

In this section, three clustering-based routing protocols, including LEACH [7], energy-aware LEACH-EP [17], and distance-aware LEACH-DT [18] are discussed in details. Generally, clustering-based protocols segment a network into non-overlapping clusters, each of them contains a CH. Non-CH nodes transmit their data packet to CH nodes, where the sensed data can be aggregated as these signals can be sufficiently correlated, and transmitted to sink. The LEACH protocol [7] uses stochastic self-election, where each node has a probability P of becoming a CH in each round. On the other hand, LEACH forms clusters via a distributed algorithm, where nodes make autonomous decisions to be CHs without any centralized control. It guarantees that each node would be a CH only once in consecutive $1/P$ rounds. Initially, each node decides to be a CH with a probability P. The role of being a CH is rotated periodically among the nodes of the cluster aims to balance the load and distribute the energy consumption. The operation of LEACH in the every round can be separated into two phases: the setup phase and the steady phase. During the setup phase, each sensor node n chooses a random number between 0 and 1. The node n becomes a CH for the current round, if its random number is less than the threshold $T(n)$. The threshold $T(n)$ is calculated according to Eq. (1), where P is the desired percentage of nodes to become CHs, r is the current round number, and G is the set of all nodes that have not being selected as CH in the last $1/P$ rounds.

$$T(n) = \begin{cases} \dfrac{P}{1 - P \times \left[r \bmod (1/P) \right]} & \text{if} \quad n \in G \\ 0 & \text{otherwise} \end{cases} \tag{1}$$