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Swarm intelligence based fuzzy routing protocol for clustered wireless sensor networks

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ABSTRACT

Wireless sensor networks are rapidly evolving technological platforms with tremendous applications in several domains. Since sensor nodes are battery powered and may be used in dangerous or inaccessible environments, it is difficult to replace or recharge their power supplies. Clustering is an effective approach to achieve energy efficiency in wireless sensor networks. In clustering-based routing protocols, cluster heads are selected among all sensor nodes within the network, and then clusters are formed by simply assigning each node to the nearest cluster head. The main drawback is that there is no control on the distribution of cluster heads over the network. In addition to the problem of generating unbalanced clusters, almost all routing protocols are designed for a certain application scope, and could not cover all applications. In this paper, we propose a swarm intelligence based fuzzy routing protocol (named SIF), in order to overcome the mentioned drawbacks. In SIF, fuzzy c-means clustering algorithm is utilized to cluster all sensor nodes into balanced clusters, and then appropriate cluster heads are selected via Mamdani fuzzy inference system. This strategy not only guarantees to generate balanced clusters over the network, but also has the ability to determine the precise number of clusters. In fuzzy-based routing protocols in literature, the fuzzy rule base table is defined manually, which is not optimal for all applications. Since tuning the fuzzy rules very affects on the performance of the fuzzy system, we utilize a hybrid swarm intelligence algorithm based on firefly algorithm and simulated annealing to optimize the fuzzy rule base table of SIF. The fitness function can be defined according to the application specifications. Unlike other routing protocols which have been designed for a certain application scope, the main objective of our methodology is to prolong the network lifetime based on the application specifications. In other words, SIF not only prolongs the network lifetime, but also is applicable to any kind of application. Obtained simulation results over 10 heterogeneous networks show that SIF outperforms the existing clustering-based protocols in terms of generating balanced clusters and prolonging the network lifetime.

1. Introduction

A Wireless Sensor Network (WSN) is a collection of compact-size low power computational nodes capable of detecting local environmental conditions, and forward such information to a central base station (sink) for appropriate processing (Yick, Mukherjee, & Ghosal, 2008). WSNs can be applied in several applications such as military, agriculture, nuclear systems, volcanic eruption, earthquake detection, healthcare monitoring, industrial and manufacturing automation, weather sensing, structural monitoring in buildings, tunnels, and bridges (Sohrabi, Gao, Ailawadhi, & Pottie, 2000). Unlike the traditional wired systems, deployment cost in WSNs is set to minimum. In addition, a WSN has the ability to adapt dynamically with changing environment (Chong & Kumar, 2003). The environment can be the physical world, a biological system, or an information technology framework. A wireless sensor node consists of four major parts: sensor unit, processing unit, energy supply unit, and transceiver. The sensing circuitry transforms the sensed data into an electric signal. Each node sends the sensed data via radio transmitter to the sink, either directly or through the other intermediate nodes (Zungeru, Ang, & Seng, 2012).

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Since sensor nodes are battery powered and may be applied in dangerous or inaccessible environments, it is difficult and even impossible to replace or recharge the power supplies (Akyildiz, Su, Sankarasubramaniam, & Cayirci, 2002). Therefore, efficient routing techniques are highly required to prolong the network lifetime. The lifetime can be defined as First Node Dies (FND), Half Node Die (HND), Last Node Dies (LND), etc. However, the precise definition of lifetime is determined based on the application specifications. For example, it should be defined as FND, for those applications with heterogeneous nodes (e.g., patient healthcare monitoring), that perishing of a sensor node may generate irreparable damages. On the other hand, in homogeneous networks, perishing of some nodes is not critical as long as at least the determined number of nodes have been remained alive (Shokouhifar & Jalali, 2015a).

In WSNs, routing is very challenging due to several natural characteristics of WSNs that distinguish them from typical communication networks, e.g., ad hoc networks. First, it is impossible to generate a global addressing scheme for the deployment of pure number of nodes. Therefore, classical IP-based protocols cannot be used in WSNs. Second, in contrast to the typical communication networks, almost all applications of WSNs require flow of the sensed data from multiple nodes (sources) to a particular sink. Third, since multiple nodes may sense same data within the vicinity of a phenomenon, the data traffic has significant redundancy in it. Such redundancy needs to be utilized by the routing protocol to improve bandwidth and energy efficiency. Fourth, sensor nodes in WSNs are highly constrained in terms of transmission power, energy supply, processing capacity, and bandwidth. Therefore, they require careful routing and resource management to reduce the total energy consumption (Attea & Khalil, 2012).

Generally, routing protocols for WSNs can be categorized into flat, location-based, and hierarchical techniques (Ming & Wong, 2007). In flat approaches, all nodes have the same functionality and they work together to sense and route (Intanagonwiwat, Govindan, & Estrin, 2000). In location-based routing protocols, the information about the location of sensor nodes is used to generate the routing path (Xu, Govindan, & Estrin, 2001). Hierarchical protocols segment a network into non-overlapping clusters, each of them contains a Cluster Head (CH), acts as a gateway between its members and sink (Heinzelman, Chandrakasan, & Balakrishnan, 2000). Clustering-based hierarchical techniques are effective to balance the energy consumption in the network. As nodes communicate data over shorter distances, the overall energy consumption is likely to be substantially lower compared to when each node communicates directly to the sink. Unlike sensor nodes, sink has unlimited energy and can communicate with the end user via satellite, internet, or any other communication media. In general, clustering in WSNs consists of two phases: setup phase and steady state phase. Setup phase includes selection of CHs and forming clusters. In steady state phase, the member nodes transmit their data to their corresponding CH and, the CH sends the collected data to the sink. In the steady state phase, CHs are firstly selected among all nodes within the network, and then, clusters are formed by simply assigning each node to the closest CH (Vlajic & Xia, 2006).

1.1. Our contribution

In this paper, we present an application specific Swarm Intelligence based Fuzzy routing protocol (named SIF), which considers the residual energy, the distance to the sink, and the distance from the cluster centroid to select appropriate CHs. Since in the previous clustering-based protocols, CHs are selected among all sensor nodes, there is no control on the distribution of CHs over the network. In SIF, an overall clustering is firstly performed on all sensor nodes via Fuzzy C-Means (FCM) algorithm. Then, the proper CHs are selected via Mamdani fuzzy inference system. The main objective is to form balanced clusters over the network. Since tuning the fuzzy rule base table very affects on the performance of the fuzzy systems, we utilize a hybrid swarm intelligence algorithm based on Firefly Algorithm (FA) and Simulated Annealing (SA) to tune the fuzzy rules of SIF according to the application specifications. We present an efficient encoding scheme to represent feasible solutions, and design a weighted average multi-objective fitness function to optimize the fuzzy rule base table of SIF.

Our contributions in this paper can be summarized as follows:

- We propose a new clustering scheme for WSNs, in which, CH-selection phase is done after cluster forming phase.
- FCM clustering algorithm is utilized to form balanced clusters over the network.
- We use Mamdani fuzzy inference system for the selection of appropriate CHs.
- A hybrid swarm intelligence based algorithm (named FA-SA algorithm) is utilized to optimize the fuzzy rule base table of the fuzzy system. FA is a population-based algorithm with good global exploration ability. Also, SA is a very good local search algorithm. Our motivation is to simultaneously gain with the advantages of the both algorithms.
- The fitness function of the FA-SA algorithm is defined to prolong the lifetime based on the application specifications.
- The proposed SIF routing protocol is simulated over 10 heterogeneous networks to demonstrate that SIF is superior to the existing clustering-based protocols in terms of generating balanced clusters and prolonging the network lifetime.

The rest of the paper is organized as follows: In Section 2, hierarchical clustering-based routing protocols are discussed. In Section 3, the communication model used in WSNs is formulated. The proposed SIF routing protocol is introduced in Section 4, and the optimization procedure of SIF using the hybrid FA-SA algorithm is presented in Section 5. Simulation results and comparison with the previous clustering-based protocols are illustrated in Section 6. Finally, Section 7 provides the conclusion remarks and some suggestions for the future works.

2. Related works

In recent years, various clustering-based routing techniques have been proposed which are distinguished by how the CHs would be selected. Generally, clustering-based protocols segment a network into non-overlapping clusters, each of them contains a CH. Non-CH nodes transmit their data to the corresponding CHs, where the collected data packets can be aggregated (as they are sufficiently correlated) and then transmitted to the sink. Selection of the appropriate CHs can significantly minimize the overall energy consumption of nodes, and enhance the network lifetime. In this Section, hierarchical clustering-based routing protocols, including classical approaches (Heinzelman et al., 2000; Heinzelman, Chandrakasan, & Balakrishnan, 2002; Jia, He, Kuang, & Mu, 2010; Kang & Nguyen, 2012), evolutionary and swarm intelligence approaches (Attea & Khalil, 2012; Hussain & Matin, 2006; Hussain, Islam, & Matin, 2007; Hussain, Matin, & Islam, 2007; Jin, Zhou, & Wu, 2003; Mudundi & Ali, 2007; Shokouhifar & Hassanzadeh, 2014; Shokouhifar & Jalali, 2015a), and fuzzy approaches (Bagci & Yazici, 2013; Gupta, Riordan, & Sampalli, 2005; Jain & Reddy, 2015; Kim, Park, Han, & Chung, 2008; Lee & Cheng, 2012; Ran, Zhang, & Gong, 2010; Sert, Bagci, & Yazici, 2015; Zhang, Sun, & Zhang, 2014) are discussed in details.