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A Pareto optimization-based approach to Clustering and Routing in Wireless Sensor Networks

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Abstract

Clustering and routing in WSNs are two well-known optimization problems that are classified as Non-deterministic Polynomial (NP)-hard. In this paper, we propose a single multi-objective problem formulation tackling these two problems simultaneously with the aim of finding the optimal network configuration. The proposed formulation takes into consideration the number of Cluster Heads (CHs), the number of clustered nodes, the link quality between the Cluster Members (CMs) and CHs and the link quality of the constructed routing tree. To select the best multi-objective optimization method, the formulated problem is solved by two state-of-the-art Multi-Objective Evolutionary Algorithms (MOEAs), and their performance is compared using two well-known quality indicators: the hypervolume indicator and the Epsilon indicator. Based on the proposed problem formulation and the best multi-objective optimization method, we also propose an energy efficient, reliable and scalable routing protocol. The proposed protocol is developed and tested under a realistic communication model and a realistic energy consumption model that is based on the characteristics of the Chipcon CC2420 radio transceiver data sheet. Simulation results show that the proposed protocol outperforms the other competent protocols in terms of the average consumed energy per node, number of clustered nodes, the throughput at the BS and execution time.

Keywords: WSN, Clustering, Multi-hop routing, Pareto optimization, RSSI, CC2420

1. Introduction

Wireless Sensor Networks (WSNs) have emerged as a key technology in realizing many applications in a wide range of contexts including military operations, environmental monitoring, surveillance systems, healthcare, environmental monitoring and public safety. In order to realize the existing and potential applications for WSNs, sophisticated and extremely efficient routing protocols are needed. However, it is a challenging task to select or propose a new routing protocol for a specific WSN application due to the inherent properties of the individual sensor nodes such as the limited power supply and the limited transmission range [1].

Cluster-based routing (clustering) protocols can solve some of those challenges due to their scalability, energy-efficiency, and data delivery reliability [2, 3]. In a clustering protocol, the network operating time is divided into rounds and each round is usually divided into three phases: Cluster Head (CH) selection, cluster formation, and data transmission. The CH selection algorithm is responsible for selecting the optimal set of CHs according to some predefined objectives. After selecting the optimal set of CHs, the clusters are usually formed by associating each regular node to its nearest CH. The data transmission phase can either be intra-cluster or inter-cluster. Intra-cluster communication comprises the data transmission between the member nodes and their respective CH while Inter-cluster communication includes transmission of data between the CHs or between a CH and the Base Station (BS).

Data delivery reliability is considered a key requirement in WSNs [4]. In order to realize this requirement, clustering protocols should adopt a multi-hop inter-cluster communication model as it is considered a more realistic approach due to the limited transmission range of the sensor nodes. On the other hand, using a single-hop inter-cluster communication model, in which the CHs send the data directly to the BS, can adversely affect the network performance due to collisions and communication interference [5]. Therefore, clustering protocols should ensure high-quality links between the cluster members and their associated CHs.

Several link quality-based clustering protocols proposed so far use the distance between two nodes as a metric of their link's quality. However, several studies have shown that distance is not necessarily correlated with link quality as it ignores the link asymmetry characteristic of WSNs [6]. Two other prominent link-quality metrics are the received signal strength indicator (RSSI) and link quality indicator (LQI). These two metrics are provided by most of the wireless sensor chips [7]. The RSSI is a parameter that represents the signal strength observed at the receiver at the moment of reception of the packet. The LQI is described as the characterization of the strength and quality of the received packets. Several studies prove that RSSI can provide a quick and accurate estimate of whether a link is of very good quality [8].