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Modeling and optimization of energy efficient routing in wireless sensor networks

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ABSTRACT

Wireless sensor networks (WSNs) have important applications in remote environmental monitoring and target tracking. The development of WSNs in recent years has been facilitated by the availability of sensors that are smaller, less expensive, and more intelligent. The design of a WSN depends significantly on its desired applications and must take into account factors such as the environment, the design objectives of the application, the associated costs, the necessary hardware, and any applicable system constraints. In this study, we propose mathematical models for a routing protocol (network design) under particular resource restrictions within a wireless sensor network. We consider two types of constraints: the distance between the linking sensors and the energy used by the sensors. The proposed models aim to identify energy-efficient paths that minimize the energy consumption of the network from the source sensor to the base station. The computational results show that the presented models can be used efficiently and applied to other network design contexts with resource restrictions (e.g., to multi-level supply chain networks).

1. Introduction

Wireless sensor networks (WSNs) have gained worldwide attention in recent years, particularly with the proliferation of Micro-Electro-Mechanical Systems (MEMS) technology, which has facilitated the development of smart sensors. These sensors are small, and require limited processing and computing resources, and are inexpensive compared to traditional sensors. These sensor nodes can sense, measure, and gather information from their environment and transmit the sensed data to the user based on local decision processes. Thousands of mini-computers equipped with sensors are deployed in a particular environment. After activation, the sensors form a self-organized network and provide data. The trend towards wireless communication is increasingly changing electronic devices in almost every sphere of life [1]. Networks of small sensor nodes, called sensor networks, facilitate the monitoring and analysis of complex phenomena over large regions and for long periods of time. Recent advances in sensor network research have made it possible to develop small and inexpensive sensor nodes that can obtain significant amounts of data about physical values. A WSN is a special type of ad hoc network composed of a large number of nodes that are equipped with different sensor devices. This network type has been supported by technological advances in low-power wireless communications and by the silicon integration of various functionalities, including sensing, communication, and processing [2]. A WSN consists of spatially distributed autonomous sensors that cooperatively monitor physical or environmental conditions. In addition to one or more sensors, each node in a sensor network is typically

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equipped with a radio transceiver or other wireless communications device, a small microcontroller, and an energy source, usually a battery. The cost of sensor nodes is similarly variable, ranging from hundreds of dollars to a few pennies, depending on the size of the sensor network and the level of complexity that is required of individual sensor nodes. The size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed, and bandwidth [3]. A sensor network is normally a wireless ad hoc network, which means that each sensor supports a multi-hop (multi-level) routing algorithm (such that several nodes may forward data packets to the base station).

In general, a WSN is composed of hundreds or even thousands of small, low cost, low power sensor nodes. These nodes are deployed in an ad hoc fashion to register physical phenomena and usually communicate with each other through wireless communication channels. The design of most wireless sensor networks is based on an ad hoc (multi-hop) network technology that organizes and maintains a group of moving objects equipped with a communication device in an area in which there are no fixed base stations or access points [4]. Although ad hoc network technologies are capable of constructing sensor networks, the design and use of sensor networks to monitor stationary nodes such as construction sites, historic buildings, and bridges can be further simplified to reduce power consumption and overhead. The simplest approach to routing in wireless sensor networks is direct transmission, in which each node transmits its own data directly to the sink. If the base station is far away, the cost of sending data directly to that station will become too large, and the nodes will die quickly.

The development of WSNs was motivated by military applications such as battlefield surveillance. WSNs are now used in many industrial and civilian application areas, including industrial process monitoring and control, machine health monitoring, environment and habitat monitoring, healthcare applications, home automation, traffic control, and scientific exploration in dangerous environments [5]. Domingo [6] examined how to extend hop length while maintaining good energy efficiency and packet size optimization in body sensor networks (BSNs). They show that the optimal packet length for improving the energy efficiency depends on the type of BSN (in-body or on-body). In logistics, WSNs can use a range of sensors to detect the presence of vehicles ranging from motorcycles to train cars.

A routing protocol specifies how routers communicate with each other, disseminating information that enables them to select the appropriate route between any two nodes in a computer network. The choice of route is executed via routing algorithms. Each router has a priori knowledge of only the networks that are directly attached to it. A routing protocol shares this information first with its immediate neighbors and then throughout the network. In this way, routers gain knowledge of the topology of the network. Routing protocols designed for data transfer in traditional ad hoc networks cannot be used with sensor networks. This is because sensor nodes have limited battery power and because data transmission or reception consumes more power consumption than sensor nodes do sensing and computation operations. Therefore, it is desirable to conserve the energy of the nodes in the network while routing query responses back to the sink node.

2. Literature review

There has been considerable research conducted in the area of routing in wired networks [7,8]. Wired networks, unlike wireless sensor networks, are not limited by energy, node failure due to physical issues, or lack of a centralized controller. Therefore, it is easier to design and model wired network systems. Conversely, due to the inherent problems with multi-hop wireless sensor networks, the design of routing protocols poses many new challenges, and much work has been done in this area.

In recent years, several studies have proposed more efficient algorithms for routing protocols [9–16]. Hur et al. [9] proposed an adaptive routing algorithm for location-aware applications, using their addressing scheme in large-scale WSNs. Mizanian et al. [10] proposed a new analytical model for calculating the RRT (reliable real-time) degree in multi-hop WSNs, where the RRT degree is the percentage of real-time data that the network can reliably deliver on time from any source to its destination. Al-Karaki et al. [11] presented a cluster-based algorithm that can be used to address the routing problem under in-network aggregation without sacrificing data quality in WSNs. They focused on the joint problem of data routing with data aggregation and routes, maximizing the network lifetime via data aggregation and in-network processing techniques. Eom et al. [12] proposed an efficient and refined approximation method for quality of service (QoS) metrics of isolated cell of wireless networks. The proposed method is based on state space merging of two-dimensional Markov chains. Ahn and Park [13] proposed an improved optimal algorithm using a virtual infrastructure for the minimum connected dominating set problem in WSNs. Samadian and Noorhosseini [16] proposed a probabilistic support vector machine (SVM)-based method in WSNs. Their method provided even more improvement on the accuracy of the sensor node locations against a post processing step for PSVM.

The development of a reliable and energy-efficient protocol is important to various WSN applications. Depending on the application, a network may consist of hundreds or thousands of nodes. Each sensor node uses the protocol stack to communicate with other nodes and the sink. Hence, the protocol stack must be capable of energy efficient communication and must be able to work efficiently across multiple sensor nodes. Sohrabi et al. [17] presented a suite of algorithms used to self-organize wireless sensor networks in which there exist a large, scalable number of mostly static nodes with highly limited energy resources. Iqbal et al. [18] proposed a novel dynamic clustering algorithm for load-balanced routing based on route efficiency. The algorithm exploits the pattern and load of the traffic and the energy dissipation rate for each node on the route to calculate the node and route efficiency levels. Chang et al. [19] proposed an efficient color-theory-based energy efficient routing (CEER) algorithm for prolonging the life time of each sensor node. Their approach is unique in that it can efficiently