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Sensor management policies to provide application QoS

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Abstract

Wireless sensor networks are uniquely characterized by tight energy and bandwidth constraints. These networks should be designed to provide enough data to their application so that a reliable description of the environment can be derived, while operating as energy-efficiently as possible and at the same time meeting bandwidth constraints. These goals are typically contradicting and must be balanced at the point where the application is best satisfied. In this paper, we address the problem of maximizing lifetime for a wireless sensor network while meeting a minimum level of application quality of service. This maximization is achieved by jointly scheduling active sensor sets and finding paths for data routing. significantly increased through optimized several heuristic methods. Simulation results show that several heuristic policies can achieve near optimal network lifetime.

Keywords: Sensor management; Energy-efficiency; Application QoS

1. Introduction

Interest in the use of wireless sensor networks has blossomed over the last several years due to technological advances enabling smaller devices and the realization of the potential benefit of such networks in many applications. In some situations, sensor networks may consist of sensors with overlapping coverage areas that provide redundant information, giving an application a quality level that is more than necessary. Rather than provide this unnecessary redundant data, it may be desirable to reduce power consumption and conserve energy in these sensors to lengthen the lifetime of the network or minimize the rate at which the sensors must be replenished with energy. This energy conservation can be accomplished through a number of methods. For example, sensors' reporting rate or data resolution can be adjusted, or the sensors can be turned off completely for an extended period of time. Balancing the application quality with this goal of energy-efficiency essentially provides a type of application quality of service (QoS). To efficiently provide this QoS to the application, interaction with lower levels of the sensor network's protocol stack is required. Recently, efforts have been made to develop middleware providing this interaction while simplifying software development efforts [1,2]. Here, we discuss the advantages of efficient sensor management when used in such a middleware system.

In this work, we show how the use of two strategies—turning off redundant sensors and using energy-efficient routing—can be used to extend network lifetime while meeting a required level of

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application quality. Recent research has focused on methods of in-network data aggregation to reduce the amount of communication in dense wireless sensor networks. In this case, low-level fusion is typically performed on data from neighboring sensors before being sent to a data sink. As an alternative to this approach, redundant sensors can be turned completely off for periods of time to save energy. Of course, there is a tradeoff between power consumption and overall quality of the data delivered by the network when choosing which approach to use. We consider the latter approach in this work but realize the benefits of the former. In our work, we also take careful consideration at the routing layer, calculating routes in conjunction with the sensor scheduling. We show in this paper how to jointly optimize sensor scheduling and data routing to extend the lifetime of sensor networks and we analyze the performance of some simple heuristic sensor management and routing policies.

The rest of this paper is organized as follows. Section 2 gives the problem formalization. Section 3 describes the simple policies that we use for scheduling and routing in our simulations. Section 4 provides simulation results. Section 5 provides context for where intelligent scheduling/routing can be used. Section 6 addresses related work. Section 7 concludes the paper.

2. Multihop sensor network management problem

If an application is able to perform at an acceptable level using data from a number of different sensor sets, we would like to schedule the sets so as to maximize the sum of the time that all sensor sets are used. Acknowledging the impact that route selection will have on network lifetime, we would like to determine route selection in conjunction with the sensor schedule. In general, the routes should be chosen so that nodes that are more critical for use as sensors are routed around as often as possible. Also, when determining the length of time for which a sensor set should be used, it is important to consider that the affected sensors are not only those that are active in the set, but also those being used in the chosen path(s) to the data sink. Obviously, it is wise to tightly couple the scheduling of sensor sets with the selection of routes. In this section, we formalize this problem and model it as a generalized maximum flow problem with additional constraints. For a description of the generalized maximum flow problem, the reader is referred to [3].

We assume that for the majority of the network lifetime, the sensors act in a vigilant state, observing a potential phenomenon in the environment being monitored. In this case, the state of the application remains constant over time. In applications such as object tracking where higher data quality/confidence is required in the current vicinity of the object and nearby sensors become more critical, the application state changes frequently and the problem becomes much more difficult to model. In this work, we assume the simpler model of a constant state application but discuss the implications that multi-state applications would have on our model in Section 3.

2.1. Problem formalization

In previous work, we have shown how to maximize network lifetime via optimal scheduling in single hop wireless sensor networks [4]. Here, we extend the model to account for multihop networks. We consider a multihop network consisting of N_S multi-mode sensors and refer to the complete set of sensors as $S = \{S_j, j \in \{1, \dots, N_S\}\}$. In general, we will assume that all sensors in the network are capable of operating in $N_{m,j}$ active modes and additionally in sleep mode, where the sensor's power consumption is negligible. An example of a sensor that is capable of operating in multiple active modes is a video camera that can send data at variable resolution or an ECG system that can work with different numbers of leads.

In order to achieve the application's required QoS, it may be possible to use a number of the sensors by themselves or in combination. A sensor set is determined to be *feasible* if (i) the total bandwidth necessary to support the traffic of the set in any region is below the capacity of the network and the data is guaranteed to be schedulable and (ii) the set provides the necessary reliability to the application. We will refer to the set of feasible sensor sets as $F = \{F_i, i \in \{1, \dots, N_F\}\}$. In order to