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Exposure in Wireless Sensor Networks: Theory and Practical Solutions

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Abstract. Wireless ad hoc sensor networks have the potential to provide the missing interface between the physical world and the Internet, thus impacting a large number of users. This connection will enable computational treatments of the physical world in ways never before possible. In this far reaching scenario, Quality of Service can be expressed in terms of accuracy and/or latency of observing events and the overall state of the physical world. Consequently, one of the fundamental problems in sensor networks is the calculation of coverage, which can be defined as a measure of the ability to detect objects within a sensor filed. Exposure is directly related to coverage in that it is an integral measure of how well the sensor network can observe an object, moving on an arbitrary path, over a period of time. After elucidating the importance of exposure, we formally define exposure and study its properties. We have developed an efficient and effective algorithm for exposure calculations in sensor networks, specifically for finding minimal exposure paths. The minimal exposure path provides valuable information about the worst case exposure-based coverage in sensor networks. The algorithm can be applied to any given distribution of sensors, sensor and sensitivity models, and characteristics of the network. Furthermore, it provides an unbounded level of accuracy as a function of run time and storage. Finally, we provide an extensive collection of experimental results and study the scaling behavior of exposure and the proposed algorithm for its calculation.

Keywords: wireless, sensor, network, exposure, coverage

1. Introduction

1.1. Motivation

Recent convergence of technological and application trends have resulted in exceptional levels of interest in wireless ad hoc networks and in particular wireless sensor networks. The push was provided by rapid progress in computation and communication technology as well as the emerging field of low cost, reliable, MEMS-based sensors. The pull was provided by numerous applications that can be summarized under the umbrella of computational worlds, where the physical world can be observed and influenced through the Internet and wireless sensor network infrastructures. Consequently, there have been a number of vigorous research and development efforts at all levels of development and usage of wireless sensor networks, including applications, operating systems, architectures, middleware, integrated circuit, and system. In many cases, the techniques and tools from general purpose and/or DSP computing can be adopted to the new scenarios with some modifications and generalizations. However, a number of technical challenges are unique in wireless sensor networks. Wireless sensor networks pose a number of fundamental problems related to their deployment, location discovery, and tracking, among which, exposure has a special place and role. Exposure can informally be described as the expected average ability of observing a target moving in a sensor field. More formally exposure can be defined as an integral of a sensing function that generally depends on distance from sensors on a path from a starting point p_S to destination point p_D. The specific sensing function parameters depend on the nature of the sensor device and the environment. A common model used in practice for omnidirectional sensors (such as seismic sensors) has the from αd^{-K}, with K typically ranging from 1 to 4.

The difficulty, complexity, and beauty of the exposure problem can be illustrated using a very simple, yet nontrivial problem illustrated in figure 1. The task is to find a path with minimal exposure for an object traveling from the point p_S to the point p_D. The field has a single sensor node s, located at the intersection of the diagonals of the square field F. The sensor s senses the object with sensitivity that is inversely proportional to the distance between the object and s.

Meguerdichian et al. [24] propose an algorithm for calculating the maximal breach path in a sensor network. The