Worst and Best Information Exposure Paths in Wireless Sensor Networks

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Abstract. This paper proposes the concept of information exposure for a point and for a path based on estimation theory. The information exposure of a point is defined as the probability that the absolute value of estimation error is less than some threshold; and the information exposure for a path is the average information exposure of all points along the path. The higher the information exposure, the higher the confidence level that some information of a target is exposed and the better the target is monitored. An approximation algorithm is proposed to solve the problem of finding the worst (best) information exposure path in wireless sensor networks, and its performance is evaluated via simulations. Furthermore, a heuristic for adaptive sensor deployment is proposed to increase the information exposure of the worst information exposure path.

1 Introduction

Recently, *wireless sensor networks* (WSNs) that consist of a large number of sensors each capable of sensing, processing and transmitting environmental information have attracted a lot of research attention [1]. WSNs can be used for example in environmental monitoring, military surveillance, space exploration, etc. A fundamental issue in a WSN is the *coverage problem* [2][3]. In general, coverage is used to determine how well an area (points, lines or regions) is monitored or tracked by sensors. Many algorithms and solutions have been proposed to determine the points, lines and region coverage based on a unit disk sensing model such as in [4][5].

In target tracking, when a target passes through a sensor field, the target may choose a path on which it is least likely to be detected [6][7][8]. In [6], a *maximal breach path* (*maximal support path*) is defined as the path on which the distance from any point to the closest sensor is maximized (minimized). If the target moves along the maximal breach path, it is least likely to be detected by the closest sensor. In [7], a minimum exposed path is defined as the path on which each point is monitored by a number of sensors and the total sensing intensity is minimized. This model considers that each point of the path may be monitored by more than one sensor. The target experiences the least sensing intensity along the minimal exposed path, and hence it is least likely to be detected.

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In [8], the *exposure* of a path is defined to be the net probability of detecting the target when the target moves along the path. It not only considers using one or more sensors to monitor a point, but also applies *value fusion* to determine the detection probability of the point. However, the model considers only the detectability. In some cases, one may need not only to detect the existence of the target, but also to estimate some parameter values of the target. For example, when a tank traverses a field, obtaining the emitted energy amplitude of the tank (or the seismic energy amplitude) may not only help to determine the existence of the tank but also the model of the tank.

The above motivates us to propose an *information exposure* model based on parameter estimation. In particular, when a number of sensors are used to monitor a point and to estimate the value of a parameter at this point, the information exposure of this point can be defined as the probability that the absolute estimation error is less than some threshold. If the information exposure is high, information about the target at this point can be estimated (exposed) with a high confidence level. Hence, the higher the information exposure, the better the point is monitored. The information exposure for a path is then defined to be the average of the information exposure of all points on the path, and the worst (best) information exposure path problem is defined as finding the path with the minimal (maximal) information exposure. We propose an algorithm to approximately solve this problem by converting it to a problem of finding a minimal mean weighted path in a weighted graph. Numerical examples are provided to illustrate the proposed concepts and the algorithm, and a heuristic is proposed for adaptive sensor deployment.

The rest of the paper is organized as follows. Section 2 introduces the concepts of point and path information exposure based on estimation theory. The approximation algorithm to solve the worst (best) information exposure path problem is proposed in Section 3 and evaluated in Section 4. Section 5 concludes the paper with some remarks.

2 Information Exposure Path

2.1 Target Parameter Estimation

Consider a field with a number of sensors deployed to detect a target passing through the sensor field. The target emits a signal with amplitude θ which is measured by the sensors. Consider a snapshot of the sensor field and the target, and let $d_k, k = 1, 2, ...,$ denote the distance between a sensor k and the target at the snapshot. The parameter θ is assumed to decay with distance, and at distance d it is θ/d^α, where $\alpha > 0$ is the decay exponent. The above sensing model has been used in [7] for determining path exposure. The measurement of the target signal amplitude, x_k, at a sensor k may also be corrupted by an additive noise, n_k. Thus,

$$x_k = \frac{\theta}{d_k^\alpha} + n_k, k = 1, 2, ..., \tag{1}$$