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WSNs deployment framework based on the theory of belief functions

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ABSTRACT

Deployment is a fundamental issue in Wireless Sensor Networks (WSNs). Indeed, the number and locations of sensors determine the topology of the WSN, which will further influence its performance. Usually, the sensor locations are precomputed based on a "perfect" sensor coverage model. However, in reality, there is an inherent uncertainty and imprecision associated with sensor readings. This issue impinges upon the success of any WSN deployment, and it is therefore important to consider it at the design stage. In contrast to existing work, this paper investigates the belief functions theory to design a unified approach for robust uncertainty-aware WSNs deployment. Specifically, we address the issue of handling uncertainty and information fusion for an efficient WSNs deployment by exploiting the belief functions reasoning framework. We present a flexible framework for target/event detection within the transferable belief model. Using this framework, we propose uncertainty-aware deployment algorithms that are able to determine the minimum number of sensors as well as their locations in such a way that full area coverage is provided. Related issues, such as connectivity, preferential coverage, challenging environments and sensor reliability, are also discussed. Simulation results, based on both synthetic data set and data traces collected in a real deployment for vehicle detection, are provided to demonstrate the ability of our approach to achieve an efficient WSNs deployment by exploiting a collaborative target/event detection scheme. Using the devised approach, we successfully deploy an experimental testbed for motion detection. The obtained results are reported, supported by comparison with other works.

1. Introduction

Wireless Sensor Networks (WSNs) are composed of small sensor nodes with limited computational and communication capabilities. One of the fundamental services provided by WSNs is the monitoring of a specific Region of Interest (RoI), where the main duty is sensing the environment and communicating the information to the base stations. Such a network can be used to monitor the environment, detect, classify and locate specific events/targets.

As a fundamental issue in WSNs, deployment is a research topic that has attracted much attention in recent years [1–3]. Indeed, the number and locations of sensors, deployed in a RoI, determine the topology of the network, which will further influence many of its intrinsic properties, such as its coverage, connectivity, cost, and lifetime. Consequently, the performance of a WSN depends to a large extent on its deployment.

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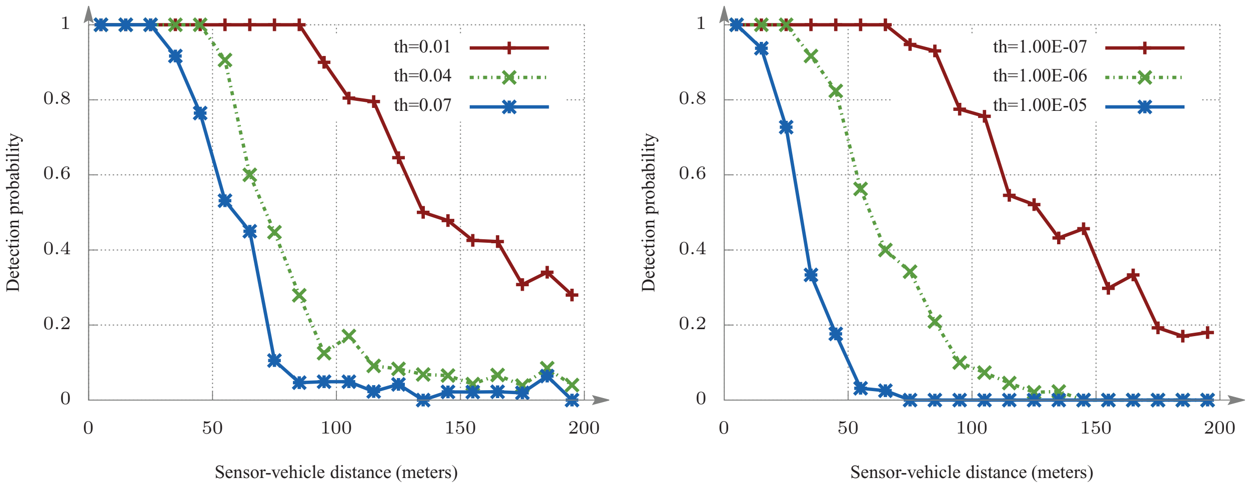

(a) Acoustic sensors. (b) Seismic sensors.

Fig. 1. Detection probability *vs.* the sensor–vehicle distance.

WSNs deployment is usually application-driven, and the sensor locations are precomputed based on a “perfect” sensor coverage model. The most widely used sensor coverage model in the literature is the *binary coverage model* (often called the disk model), which assumes that an event happening within the sensing radius of a node is always detected, while any event outside this disk is assumed not to be detected. However, sensors may not always provide reliable information, either due to operational tolerance levels or environmental factors. In reality, it is well known that there is an inherent uncertainty and imprecision associated with sensor readings. To illustrate the inaccuracy of the binary coverage model, we plot in Fig. 1 the average sensing performance of two types of sensors, namely: acoustic (Fig. 1a) and seismic (Fig. 1b) sensors using the data traces collected from a real vehicle detection experiment [4]. In the experiment, the sensor detects moving vehicles by comparing its signal energy measurement against a threshold (denoted by *th*). As shown in Fig. 1a and b, there is no clear cut-off boundary between successful and unsuccessful detection for the two modalities (acoustic and seismic).

These results confirm that, for many types of sensors, a longer distance between the sensor and the target/event generally implies a greater loss in the signal strength or a lower signal-to-noise ratio [3,5]. This issue impinges upon the success of any WSN deployment, as the sensor locations are computed while ignoring this issue and it is imperative to have practical considerations at the design stage to anticipate this sensing behavior. Thus, a key challenge in the deployment of WSNs is to consider the imperfections associated with sensor readings.

Recent research works [6–11] have adopted a probabilistic coverage model that takes into account the probabilistic sensing behavior of sensors. Although this model captures the behavior of sensors more realistically, it does not exploit the collaboration among sensors. In addition, it is difficult to extend the probabilistic coverage model to include deployment-related issues such as the reliability of sensors [3]. Thus, a generic and flexible coverage model is important, and it is one of our motivations in this work.

The representation and management of the imperfections associated with sensor readings can be done using mathematical formalisms such as fuzzy sets theory [12] for imprecise data or Probability theory [13], Possibility theory [14], and Belief Functions theory [15] in the case of uncertain data. Probability theory has been widely used in the context of WSNs. However, this latter has limitations to represent uncertainty. The most significant one is that it cannot express total ignorance except by an equidistribution of probabilities for the different hypotheses. The total ignorance means that there is absolutely no information about the system or subject under study. Based on the principle of maximum entropy, equidistributions are usually assumed when the probability theory is applied in this case. A problem arises because introducing any form of distribution is equivalent to assuming extra knowledge. The advantage of the belief functions theory [15] is its ability to separate the two sources of imperfection, imprecision and uncertainty, and its fairly simple modeling of doubt and lack of information. These advantages seem valuable in the context of sensor network deployment, where data are often uncertain. In contrast to existing work, we investigate the belief functions theory to design a unified approach for robust uncertainty-aware WSNs deployment.

Because the deployment should be application-driven, we focus on a particular application of WSNs, target/event detection. To detect a target moving through the RoI, sensors have to make local observations of their surrounding environment and collaborate to produce a global decision that reflects the status of the RoI. This collaboration requires the local processing of observations, communication among nodes, and information fusion [16]. Indeed, each sensor provides information on the presence of a target/event, and the local decisions are combined to make a final decision regarding the presence of a target/event.