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Dynamic adjustment of sensing range for event coverage in wireless sensor networks

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ABSTRACT

One primary goal of sensor networks is to guarantee robust and accurate event detection while reducing energy consumption for extended lifetime. To increase detection fidelity, recent literature introduces redundancy in the sensor field either by maintaining fixed *k*-coverage throughout lifetime or by providing dynamic *k*-coverage using mobile sensors after an event is detected. The former requires a large number of sensor nodes and the latter is costly and sometimes infeasible as mobile node deployment in inaccessible areas is difficult. Exploiting recent advances that allow adjustable sensing and transmission radius for sensors, we propose a scheme that ensures 1-coverage at deployment time, but on detection, extends to *k*-coverage to increase accuracy and robustness. Using an adjustable sensing model through power adjustment, we formulate an optimization problem that determines the optimal sensor set whose sensing and transmission radius are to be adjusted to provide expected coverage degree, through minimizing a cost function comprising energy consumption and achievable accuracy in detection. For a given sensing adjustability, a guideline for deterministic and random deployment is presented to ensure initial coverage. Detection performance and network lifetime are analyzed both theoretically and through simulation. Our approach avoids over-provisioning in sensor network, increases lifetime and scalability, and maintains detection performance in a cost effective way.

1. Introduction

Event detection using wireless sensor networks (WSNs) has growing applications that include environmental hazard and pollution detection (Ramesh, 2014; De et al., 2013; Bhattacharjeea et al., 2012), condition monitoring (Tung and et al., 2014; Huang et al., 2012), battlefield surveillance and border security (Sun et al., 2011), etc. One of the key issues in event-centric WSN is to ensure robust detection while conserving energy so as to prolong network's operational lifetime. For accurate and reliable event detection performance by WSNs, the most widely adopted technique is to introduce high degree of redundancy through *k*-coverage, where any point in the sensor field is within the sensing range of at least $k\ (>1)$ nodes. However, increased deployment cost and energy limitation make such approach unrealistic as the number of required sensor nodes grows very large to maintain the desired level of fault tolerance and accuracy (Wang, 2011; Alam et al., 2011).

The trade-off between detection performance and energy consumption is still a fundamental challenge in event centric WSNs. Though traditional cheap tiny sensors spend significant part of energy for communication purpose, new generation sensors are multimodal and equipped with camera, radar, sonars or infrared which consume a significant amount of energy for sensing as well. This new generation of sensors, being increasingly smarter and sophisticated, are also costly. The higher cost and energy consumption makes redundant coverage (i.e., static *k*-coverage) cost prohibiting because of high number of nodes required. This motivates the research community towards providing redundant coverage not by maintaining a permanent *k*-coverage all the time, but only to provide redundancy in an on-demand basis. On-demand coverage refers to the technique of providing instantaneous *k*-coverage only after an event is detected by at least one sensor. In almost all the existing literature (e.g., Ammari, 2012; Tan et al., 2010; Liu et al., 2013) on-demand event coverage is thought to be feasible only with the help of mobile nodes. Node mobility requires expensive locomotion units and also a significant amount of energy is consumed for physical movement of nodes.

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Besides, the nature of terrain in the sensor fields sometimes severely limits node mobility for effective coverage. The above limitations indicate that achieving on-demand k-coverage through node mobilization is not only unattractive but also infeasible in many real-world deployment scenarios.

Traditionally, event detection in WSN assumes a hard-limit sensing model of nodes, i.e., the sensing radius is fixed and within this radius the probability of detection by individual node remains the same. In practice sensing can be active or passive. Passive sensors detect radiation emitted or reflected by the object or surrounding areas. On the other hand, in active sensing technique, sensors emit energy often in the form of a beacon in order to scan the presence of certain signals or objects and can control sensing range through power adjustment. Many sensor devices in WSNs are based on active sensing technologies, such as those equipped with radars and sonars, thermocouple based temperature sensors (Gregory and You, 2005), underwater sensors (Melodia et al., 2013) or piezoelectric transducers (Lin and Giurgiutiu, 2012). A number of sensors with adjustable sensing radii are already commercially available (OSIRIS Photoelectric Sensors; Kompis and Aliwell, 2008; Photoelectric Sensors; Siciliano and Khatib, 2008). Exploiting such technology, in this paper, we propose the idea of on-demand k-coverage for event detection using static nodes with variable sensing range. The main idea is to guarantee redundant coverage for event detection dynamically while maintaining 1-coverage at the time of the deployment and returning to 1-coverage once the detection task is completed. Under normal condition, each sensor works in its lower end of sensing limit leaving the provision for increasing the sensing range later when necessary. During operation, as soon as a node detects an event, it requests neighbours to collaborate. A selected set of neighbour nodes then increase their sensing range temporarily to ensure redundant coverage of that event. Event detection is then accomplished via local decision fusion among these selected nodes. This adjustment in sensing radius also requires adjustment of transmission radius according to maintain connectivity among participatory nodes. Power adjustable communication is widely studied in the literature, while sensing power adaptation is relatively new. This capability of variable sensing range is exploited in this work to achieve desired robustness in detection through on-demand k-coverage using significantly fewer nodes, and thus making substantial cost saving. It should be noted that, though some works exist in the literature on variable range sensing and transmission (details in Section 2), they aim to provide redundant and persistent k-coverage by setting the sensing range (within sensing limit) at deployment time which remains unchanged during network lifetime. On the other hand, our work for the first time in the literature focuses on achieving on-demand k-coverage by varying sensing range *during operational time*. Moreover, the perspectives of existing works on variable sensing radii are not event-centric.

There are several challenges to overcome before the above idea can be made workable. These are (i) For a specific event location, determination of the set of sensors that need to adjust sensing range and the extent of their adjustment to yield expected detection performance with minimum energy consumption. (ii) Since the capability to adjust the sensing range is limited, the network topology and sensor density should be maintained in a way so as to make the on-demand coverage feasible. (iii) Increasing sensing radius involves increased energy consumption as described in Section 3.2. Hence, the sensor selection process needs to ensure balanced energy consumption among sensors to yield a better network life. (iv) To make such system scalable, the on-demand k-coverage scheme needs to be distributed. This involves a local collaboration and decision making among those sensors that participate in the detection process.

In this work, we exploit the benefits of variable sensing range technology to provide on-demand k-coverage in event-centric WSNs with only static sensors. Our contributions are

- On-demand k-coverage scheme for event detection by adjusting the sensing range of static nodes during operational time. This is the first time such a dynamic event detection scheme for WSN is proposed.
- Distributed sensor selection algorithm to ensure joint optimization of energy consumption and detection performance. Event detection probability and lifetime of the scheme is also analyzed.
- Analytical model to guide the sensor deployment strategy to facilitate implementation of the scheme in real applications.
- Apart from cost saving from fewer sensor requirement, higher event detection probability and longer network lifetime are achieved.

The rest of the paper is organised as follows. Section 2 discusses related works while Section 3 outlines the system model. In Section 4 we formulate the variable range on-demand event coverage scheme, its deployment guideline to aid implementation and analysis of network lifetime. Section 5 presents performance evaluation and Section 6 concludes the paper.

2. Related works

Energy and accuracy aware detection has been the primary focus of the research on event centric WSN systems for the last decade. Most works (e.g. Li et al., 2010; Zhu and Ni, 2008; Ammari and Das, 2012; Lei et al., 2013; Johnson et al., 2012) propose k-coverage using redundant static nodes. This could be an appealing solution when sensors are very inexpensive so that a large area can be covered with redundant nodes. However, that is not the case in general and specially for sensors with active sensing technology, self-localization capability (equipped with GPS) and multi-modal sensing capability (Melodia et al., 2013; Lin and Giurgiutiu, 2012). In such cases, full k-coverage all over the target sensor field turns out to be an impractical solution due to prohibiting cost. To address this issue, some works proposed a hybrid (an intermix of static and mobile nodes) or mobile sensor networks to reduce redundancy while providing reasonable degree of robustness dynamically. Bisnik et al. (2007) explored the Quality of Coverage (QoC) in mobile sensor network considering the event dynamics, node velocity and number of mobile sensors. Wimalajeewa and Jayaweera (2010) proposed a mobility protocol for mobile nodes so as to maximize the coverage-time of the area that is left uncovered by static nodes. Tan et al. (2010) proposed a reactive mobility technique where sensors remain stationary until any event is detected and move towards the possible event location to increase the accuracy of the final detection. Such scheme results in a significant increase in delay because of the limited physical movement speed. A similar idea was studied by Ammari (2012) which, to ensure k-coverage, proposes a distributed movement strategy that considers a node's closeness to the target region to minimise mobility energy. Liu et al. (2013) proposed a mobility strategy using a game theoretic approach to provide coverage at specific time instant and during time intervals. Mobility is an energy-draining operation and replenishing energy is difficult, sometimes impossible. Node mobility can be fully or partially limited by obstacles. Evidently, this approach of moving nodes for on-demand event coverage is not suitable.

The idea of adjustable range is known in communication domain for long. However, the technique is employed primarily