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A heading adjustment method in wireless directional sensor networks

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ABSTRACT

The coverage of a region of interest in wireless directional sensor networks is determined by both the positions and the working headings of directional sensors. A considerable number of studies have focused on the maximization of covered area without concerning the differences between the different positions in the region. Actually, since the exposure possibilities between the different points are distinct, the coverage priorities of points are correspondingly different. In this paper, a coverage improvement method based on the Delaunay triangulation by adjusting the headings of sensors is proposed. The proposed method is not only to enlarge the coverage of the region of interest, but also to strengthen the coverage of vulnerable points. With the help of simulations, we show the effectiveness of the proposed method in coverage improvement with various parameters, such as amount of sensors and radius of sensors, compared with other related methods.

1. Introduction

Sensing coverage is one of critical standards in performance evaluation in a wireless sensor network (WSN), which shows how well the environment is monitored by the WSN [1]. There are an extensive number of studies concerning the coverage issue in the omni-directional effective sensor networks. The sensing range of an omni-directional sensor is commonly assumed to be a disk, with which the sensor collects the information on the surroundings, such as temperature, humidity, soundand levels of radiation [2]. The coverage capability of such kind of sensors depends on the positions and sensing ranges of the sensors. If the distance between a point and a sensor is not greater than the sensing range, the data on the point is assumed to be obtained. Actually, the effective sensing range of many kinds of sensors in the real applications are limited to some directions and specific angular dimension [3], such as video sensors, infrared sensors, and ultrasound sensors, which are usually called directional sensors. Unlike an omni-directional sensor, if a directional sensor intends to detect an event determinately, the event should be located in both the sensing distance range and the working direction range of the sensor simultaneously. In other words, the sensing coverage of directional sensors is not only determined by the positions and sensing ranges, but also determined by the headings and sensing angles of sensors [4].

In principle, all the technical difficulties concerning the coverage introduced by the traditional WSNs still exist in wireless directional sensor networks (WDSNs) [5]. Moreover, the directionality of the sensors has brought new challenges into the coverage issue in WDSNs. First, when emergencies occur, a sensor should rotate its heading, which is defined in Section 3, around a fixed axis autonomously or manually to locate or track them. Note that although directional sensors node could theoretically work in many different directions, the sensors can only work in a specified direction at a given time. Therefore, a sensor at the most of its working life should be in the optimal sensing heading for enhancing its coverage. It is difficult to accurately determine the headings of sensors for increasing the overall coverage area. Second, there are some studies concerning the problem of adjusting the working directions of the sensors to cover maximum region [3]. The main purpose of such studies is to find a direction, where overlapped sensing areas between sensors are minimized, in order to achieve the high coverage efficiency of directional sensors. In these methods, the ratio of the covered area to the overall region of interest (ROI) is used as a metric for the quality of the coverage of the sensor networks. Thus, the priority of each point, which should be covered by the sensors, in a ROI is considered same. Actually, there is different existing detection probability in different areas in ROI. The areas which are close to the sensors are more likely to be detected compared with the areas that are far away from the sensors in the region [6]. Therefore, the coverage priorities of points inside a ROI become different. For some events that need to be sensed, such as the fire spots, the values of parameters on the points close to the sensors can be derived from the nearby sensors due to the conti-

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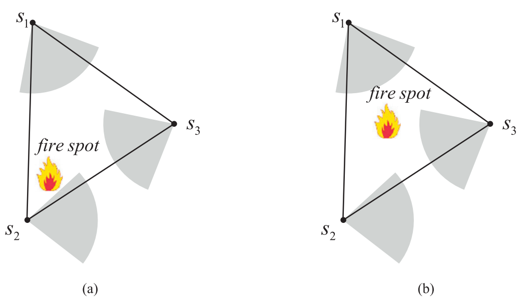

Fig. 1. (a) the fire spot close to the sensor; (b) the fire spot far away from the sensors.

nuity of the parameters, even though they are not directly sensed by any sensors. We use an example to illustrate the case, shown as in Fig. 1. In Fig. 1(a), the fire spot is not located in any sensors' ranges. Since the fire spot is close to the sensor s2, the property of thermal dissemination makes s2 have probability to sense the temperature of the spot. However, in Fig. 1(b), the fire spot is far away from the sensors, and the probability of being sensed becomes significantly lower.

Therefore, these points that are far away from the sensors in the region should have the higher priorities to be covered in the heading adjustment of the sensors. In this study, the points that have little detection probability are called vulnerable points. It will be difficult to improve the coverage by rotating headings of sensors whilst simultaneously minimizing the probability of missing vulnerable points.

In this paper, we mainly focus on the coverage issue of WDSNs which are composed of rotatable directional sensors like cameras. The objective of this paper is to address the aforementioned problems and presents a heading adjustment method for WDSN not only to enlarge the area covered by the directional sensors as much as possible, but also to improve the coverage for the vulnerable points that are with low observability from sensors. The main contributions of this paper are as follows:

- The vulnerable points in a ROI from the perspective of coverage are recognized by our proposed Delaunay Triangulation based method. The sensors rotate their headings towards the nearby vulnerable points with higher priorities.
- In order to maximize the coverage area, we design a collaborated mechanism to reduce the overlaps between the sensing ranges of directional sensors.

The remainder of the paper is organized as follows: in Section 2, we briefly summarize the related work on the coverage improvement of directional sensor networks. Section 3 provides the preliminaries used in the study. In Section 4, we present in detail the heading adjustment method of directional sensors for improving the coverage of WDSN based on the properties of Delaunay Triangulations. Section 5 includes the simulations conducted to assess the performance of the proposed method. Finally, conclusions are given in Section 6.

2. Related work

The most well-known problem of full coverage in directional sensors is the Art Gallery problem [7], which strives to solve the problem of guarding an art gallery with the minimum number of guards who together can observe the whole gallery. Several previous studies have considered adaption of this problem to WDSN. Khanjary et al. use continuum percolation to find the minimum number of sensors required to achieve a certain degree of sensing coverage and network connectivity in fixed-orientation directional sensor networks [5]. Yildiz et al. develop a bi-level algorithm to find the minimum-cost camera placement to achieve angular coverage continuously over a given region [8]. Nene et al. utilize the mobility of sensors to find the optimal displacement for maximizing coverage of randomly deployed wireless camera sensor networks [9]. The general idea in these studies is to select directional sensors to reduce the field of view overlap or improve coverage.

There are also some studies focusing on the coverage enhancing issue of WDSNs after the initial deployment. The most of studies in coverage enhancing are mainly concentrated on deployment of mobile directional sensor nodes, and adjustment of working direction, sensing radius, and angle of view of the sensors [10]. By virtual of the mobility of sensors, Zhang et al. [11] propose a sensor-to-point coverage distance to address the redeployment problem of mobile directional sensors. The coverage distance is used to generate a directional Voronoi partition which is designed to fulfill the coverage optimization. Liang et al. have designed circumcenter-based and incenter-based schemes to guide the mobile sensor to move the optimal position for achieving maximal coverage [12]. Li et al. propose deployment to control the node movements and orientations using local information, which is based on the characterizations of the optimal solutions to coverage maximizing mobile sensor deployment problem [13]. In [14], Tao et al. have introduced a notion of sensing centroid to substitute the position of a sensor. Then, they map the area coverage optimization problem in directional sensor networks into the uniform distribution problem of sensing centroids, and they also propose a constrained artificial fish-swarm algorithm to solve the optimization problem. However, the expensive cost and the high energy consumption of locomotion make the availability of the mobile directional sensors limited. Especially, it is unpractical to involve a large number of mobile sensors in a WDSN. Therefore, the motility feature of directional sensors has been utilized to maximize the coverage.

Motility has a significant improvement on coverage, since the headings of sensors can be adjusted. Cheng et al. have proved that the maximum direction area coverage problem is NP-complete, and it is difficult to obtain the solution in polynomial time [15]. In order to enhance the area coverage, they also present a grid-based algorithm to choose the least overlapped direction as the working direction of a sensor. However, this method is impossible to be applied in the real applications, due to the fact that there is no grid in the region. Liang et al. propose a greedy algorithm for improving the area coverage by scheduling working directions of sensors to achieve the least overlapped region [16]. In their algorithm, the points of tangency or the points of intersections of sensing range are used as the candidate rotating directions. Kandoth et al. [17] provide a face away method by using the known directions of neighboring sensors to find the direction with least density of neighbors for each sensor. However, the face away method becomes ineffective when a large number of directional sensors exist in the ROI. Heading adjustment is also adjusted to address the problem of barrier coverage [18]. Chen et al. [19] propose two algorithms to mend the barrier coverage gaps: one is to only rotate two critical sensors and the other is to rotate sensors in a chain-reaction manner to mend the gap. Since the problem of barrier coverage is dramatically different from the problem of region coverage, the methods cannot be applied in our problem.

Besides, computational geometrical methods are also used in the coverage issue of WDSNs. Li et al. propose a greedy approximation algorithm by using an assistant sensor to detect whether every edge of the Voronoi diagram has been covered by the directional sensors [20]. Although the results of detection can be used to activate the sensors and to adjust the headings, the assistant sensor does not exist in practice. Moreover, they assume that the assistant sensor could move in ROIs. Sharmin et al. [21] propose a Voronoi-based area coverage mechanism for a clustered direc-