Automatic Barrier Coverage in Smart City

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Contributor: Ying Shao , Qiwen Wang , Xingjian Lu , Zhanquan Wang , E Zhao , Shuang Fang , Jianxiong Chen , Linghe Kong , Kayhan Zrar Ghafoor

Barrier coverage is a fundamental application in wireless sensor networks, which are widely used for smart cities. In applications, the sensors form a barrier for the intruders and protect an area through intrusion detection.

barrier coverage mobile sensor networks boundary detection

1. Introduction

Barrier coverage [1] is one vital application in wireless sensor networks (WSNs) for smart cities [2][3], which forms sensor nodes surrounding barriers to protect a region by detecting all intruders. A wide range of safety scenarios of smart city demand barrier coverage exist, for example, the country border surveillance for stowaway detection. Researchers extend the classic concept of barrier coverage to a new branch, which moves the sensor nodes surrounding a dangerous region and protects any unexpected visitors by warning them away from the dangers, so-called *warning barrier coverage* (WBC). The WBC is promising in many danger keep out application for smart cities. For example, a WBC can surround debris areas in floods and alarm rescue workers to avoid unnecessary harms. Moreover, WBC can warn people to avoid entering dangerous areas such as hazardous gas leaks and even nuclear radiations in cities.

Researchers compare the classic barrier coverage and WBC in **Table 1**. Different from the classic barrier coverage, WBC focuses on the danger keep out applications whose boundary of target region is previously unknown. To avoid danger, people cannot become close to the region or deploy sensor nodes manually. Hence, besides the visitor detection, sensor nodes in WBC should have the capability to detect the boundary as well. Based on the sensing results, mobile sensor nodes form the barrier collaboratively.

Table 1. Comparison between classic barrier coverage and warning barrier coverage.

Barrier Coverage	Classic	Warning
Target Region	Known	Unknown boundary
Sensing Capability	Intruder detection	Visitor detection and boundary detection
Moving Capability	Mobile/static node	Mobile node
Typical Application	Border surveillance	Danger, keep out!

Regardless of the classic barrier coverage used in WBC, the formation process [4] is crucial because newly deployed sensor nodes lack a dependable infrastructure for communication and detection. The formation process in WBC is defined to form sensor nodes into *k* barriers enclosing the region, thus detecting or warning unexpected visitors.

Researchers have put forward various solutions in the literature for classic barrier coverage formation for smart cities. For instance, Kumar [1] proposed a centralized algorithm to determine weak *k*-barrier coverage in a region using randomly deployed sensor networks. Later, ref. [5] devised efficient algorithms to construct strong sensor barriers. And ref. [6] studied the barrier coverage of line-based deployment. In addition, ref. [7] funded a cluster-based barrier construction algorithm in mobile wireless sensor networks.

Different from the known region in classic barrier coverage, the boundary of a dangerous region in WBC is usually unknown. Hence, the classic formation approaches are not appropriate for WBC in smart cities. In addition, most existing works [1][6] fall into the category that forms the barrier coverage by stationary sensor nodes. Nevertheless, if the stationary sensor nodes are stochastically deployed, many redundant nodes will be needed to ensure a strong barrier [5]. On the other hand, if the stationary nodes are manually deployed, a significant amount of manpower and time are consumed. Especially in some cases for smart cities, the region is rather large in scale or hides dangers. Therefore, using stationary nodes is more of a hindrance than a help in WBC. A few state-of-the-art works also considered using mobile sensor nodes [8][9][10] to facilitate the barrier coverage.

2. Automatic Barrier Coverage in Smart City

In the construction of smart cities, information and communication technologies are used to improve the living standards and management of citizens and governments [11][12]. The Internet of Things (IoT) using sensors is widely used in smart cities [13]. In particular, the coverage-related problem [14][15] is a fundamental topic in WSNs to measure the monitoring quality of a sensor network deployed in a given region. Barrier coverage guarantees the detection of any intruder attempting to cross the barrier of sensor networks or penetrating the protected region. There are numerous studies on classical intrusion detection and avoidance [16][17][18]. Ref. [19] presents methods for intrusion detection and tracking with pan–tilt cameras. And ref. [20] proposes a probabilistic sensor tasking algorithm in which cameras sense the environment independently of one another, thus reducing the communication overhead. In addition, diverse directions are excellently studied for coverage problems, such as barrier coverage [1], sweep coverage [21], surface coverage [22], and trap coverage [23].

In these directions, barrier coverage is one valuable and practical application for smart cities, which is advocated in [1] for the purpose of intrusion detection in country borders, critical infrastructure protection, and battlefield perimeter surveillance. The barrier coverage formed by stationary nodes has been widely studied. For instance, the minimum cost for achieving *k*-barrier coverage is calculated in [24]. In [5], strong sensor barriers were devised. Line-based and curve-based barrier coverage were studied by [6][25], respectively. Multi-round sensor deployment for guaranteed barrier coverage is proposed in [26]. Nevertheless, a significant amount of resources such as redundant

nodes in stochastic deployment and manpower cost in manual deployment will be needed due to the reliance on stationary nodes only.

Mobile nodes for barrier coverage was firstly introduced in [4], in which the nodes with limited mobility (e.g., one-step move with one chance) are utilized to improve the quality of barrier coverage. With the rapid development of autonomous robot technology, sensor nodes with strong mobility [27] become practical. In addition, a movement barrier formation algorithm MobiBar designed in [28] presented distributed algorithms for barrier coverage using sensor relocation. Ref. [29] proposed a heuristic target-barrier construction algorithm to solve the target-barrier coverage problem while satisfying the boundary constraint conditions. These works mainly focus on centralized analysis, which is not suitable for large-scale barrier coverage for smart cities.

Distributed algorithms for mobile barrier coverage were also investigated in the literature. The chain reaction algorithm [30] was firstly developed for mobile barrier formation. But it totally ignores the situation of node failure, which may lead to certain loopholes in the barrier. Based on mobility and intruder prior information, PMS [31] is able to improve the quality of barrier coverage. However, PMS assumes that the region knowledge is pre-known, which is not practical in most real WBC applications for smart cities. Moreover, ref. [32] presented a distributed cellular automaton based algorithm for the autonomous deployment of mobile sensors. The limitation is that the number of sensors needs to be deployed in a fixed manner.

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