Barrier Coverage Issues and Strategies in WSN: A Survey

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***Abstract*—The wireless sensor network (WSN) has emerged as an important technology in monitoring the environment and phenomena. Border surveillance using barrier coverage is one of several applications in WSN. Barrier coverage is a critical problem for security applications in WSN designed to detect intruders attempting to infiltrate protected areas. The topology of WSN typically depends on the target application and the geographical region where the sensor nodes are deployed. Deployment of a linear sensor applied to the border area where the sensor nodes are placed manually along a straight line across the region. However, it is not practical to implement it in hostile environments. There are several strategies can be used to optimize the barrier coverage and connectivity. Therefore, a good deployment of sensor nodes should be considered to perform a barrier coverage in the border region. The placement of sensor nodes affects the performance of border surveillance applications and operations.**

Keywords— wireless sensor network, barrier coverage, sensor node deployment, border surveillance

I. INTRODUCTION

In the last decade, the Wireless Sensor Network (WSN) has emerged as a powerful platform for integrating the physical and digital world. WSN is used for tracking and monitoring applications, including environmental monitoring, smart agriculture system, habitat monitoring, healthcare application, risky or disaster monitoring and military applications in security surveillance [1, 2]. In the environmental monitoring area, sensor nodes can be used to measure the amount of sunlight, humidity and temperature of the climate pressure. Sensor nodes are used by the military to monitor the intruder across the geographical area protected by the WSN application.

One of the most recent monitoring applications in WSN is border patrol and surveillance [3]. National border monitoring is one of the major concern of any country to protect and control their border from unauthorized cross border activities [4]. The border commonly separates the country physically using wall or fence. WSN has emerged as a promising technology that can assist the authorities in patrolling and monitoring the security area especially at the critical or inaccessible area.

According to [5], the coverage is commonly explained how well a sensor network sense and monitor the region of interest (ROI) and as the quality of service (QoS) measurement in WSN applications. The coverage types will be different based on the application. In border surveillance, barrier coverage aims to minimize the probability of undetected penetration through a sensor network. In barrier coverage, the deployment of the sensor nodes can be classified into two approaches; linear or static deployment and non-linear or dynamic deployment [6]. The placement of sensor nodes in WSN border surveillance is a key problem that is closely related to coverage and connectivity in the ROI or barrier coverage area. The position of sensor nodes affects the performance of the application and operation of WSN border surveillance. As a result, a good placement of sensor nodes for both coverage and connectivity should be considered for barrier coverage in the border region.

The rest of the paper is presented as follows: Section II presents several background of border surveillances. Section III describe the barrier coverage. The barrier coverage issues and challenges are presented in Section IV. The barrier coverage strategies presented in Section V and the whole paper summarized in Section VI.

II. BORDER SURVEILLANCE

Land and sea are the doors of the country. Border security is the main concern in all countries to protect against illegal activity and threats of terrorism. Continuous monitoring of border surveillance has become a requirement to every country due to terrorist threats, smuggling activities, increment crime, illegal immigrants and human trafficking [16]. Border surveillance application is required to monitor the country's boundaries for border security [7]. Patrolling also occurs along predetermine route during a specific interval time. There required an extensive human resource to patrol and control the border country.

The border surveillance required a real-time monitoring with the accurate results. One of the major challenges in border surveillance and monitoring of long stretches of borders area is the necessity for troop involvement in patrolling locations. The land barrier of the country is typically constructed by walls and fences. However, in some nations, the border area is surrounded by natural obstacle such as dense forest, rocky mountain, steep paths, swamps and rivers. Fig. 1 illustrate the Malaysia-Thailand border, covered by natural obstacles and hostile areas.

Fig 1. Boundaries of border covered by hostile area and natural obstacles

These areas are difficult for troops to enter and patrol the border in the region border at the aforementioned area. The problem with monitoring and protecting these borders is the troops to be deployed and the distance area to be covered. Therefore, it will limit the patrolling activities for border surveillance and monitoring. With limited troop involvement, WSN technology can provide precise monitoring and control of the border region.

III. BARRIER COVERAGE

Coverage is a fundamental requirement for WSN applications and reflects the performance of sensor nodes in monitoring a ROI. The rate of coverage is an important parameter that influences WSN's performance and QoS. The coverage can be classified into three types: area coverage, target coverage and barrier coverage. The coverage requirement is vary depending on the application. Some of the WSN monitoring applications required area coverage, which relies on the ROI's maximum coverage of the entire area. In some applications, such as environment application, full area coverage is not necessary where a certain degree of coverage is acceptable. Target coverage refers to observing or monitoring a specific number of targets. This type of coverage has been used in military applications for monitoring the enemy troop and capturing real-time video of target event.

Barrier coverage refers to the detection of movement across a barrier of sensor nodes [8]. In several applications, sensor nodes are used in barrier area to detect the intruders that attempt to enter the entire area. The applications used to monitor the movement detection along the international border to detect illegal intrusion. Unlike area coverage, barrier coverage does not care of event happens in the ROI unless there are intruders penetrating the ROI. Barrier coverage does not required full area coverage of the ROI to be covered by sensor nodes, which significantly reduces the cost of sensor deployment [9]. According to [1, 10], there are two categories of barrier coverage namely as weak barrier coverage and strong barrier coverage that reflect the quality of the detection of the events on the boundary of the ROI. Weak barrier coverage requires only the detection of intruders moving along congruent crossing path. However, there are some paths which may be complex and cannot be detected by any sensor. A strong barrier coverage requires intruder to be monitored and detected with arbitrary moving path. Therefore, barrier coverage in WSNs is an ideal solution for the purpose of intruder detection of security applications.

IV. BARRIER COVERAGE ISSUES IN BORDER SURVEILLANCE

Border surveillance using WSN are deployed at perimeter or border locations for monitoring and to detect unauthorized intrusions. The application becomes critical due to the risk of intrusion on border and some border locations are located in hostile area. There are several solutions using WSN for border surveillance applications. The authors [9, 11] found the solutions using WSN in border surveillance application by organizing the network nodes as line-sensor. Every movement passed through the barrier area will be detected by the sensor node. In other hand, the sensor nodes are deployed in a deterministic position in a single line through the border. Therefore, the deployment should guarantee the barrier coverage. Fewer sensor nodes need to be deployed in a perfect linear sensor deployment in order to maintain the barrier coverage [12]. This topology of deployment will impact the performance of monitoring when a failure occurs between nodes where there is no alternative route to forward the data to the base station. Any gaps or interruption in monitoring area will cause a severe damage to the security of the border country.

The important aspect of the success of the surveillance mission is to provide full coverage of the surveillance field [13]. The coverage degree in the ROI is the first concern in deploying the sensor nodes. In [14], the authors studied on the barrier coverage of a line-based or linear sensor deployment strategy and how sensor mobility can be exploited to improve barrier coverage. The authors consider a line-based sensor deployment strategy with a distributed random offset (LNRO) where the sensor nodes are dropped along a straight line of barrier area. The algorithm proposed by [14] also present an algorithm to find barrier gaps and relocates the sensor nodes to overcome the coverage hole while minimizing the energy consumption between sensor nodes. The proposed algorithm organized all sensor nodes in a linear line to achieve barrier coverage. However, as the number of mobile sensor nodes increases, the range of movement required to cover the barriers coverage will be decreases. Therefore, the alternative is not practical where a lot of sensor nodes are needed to be deployed to obtain barrier coverage after the initial random deployment.
The sensor nodes can be used in deterministic or random deployment based on the nature of the monitoring area and the WSN applications [15]. However, in the harsh environments and inaccessible area such as battlefield, disaster area or border surveillance, linear deployment is infeasible and very risky. The sensing coverage of the sensor nodes may have gaps where it depends on the sensing range, number of sensors, and deployment scheme. Typically, border surveillance requires the monitoring of a large geographical area. Therefore, a linear sensor is not practical to be implemented in a hostile or inaccessible area. To overcome the aforementioned problems, a random deployment of sensor nodes is required to be deployed in a non-linear or dynamic deployment. The sensor nodes are deployed from the aircraft. There are studies on barrier coverage summarized in TABLE 1 with the implementation of barrier coverage in random deployment of sensor nodes.

TABLE I. Summary of barrier coverage studies in random deployment

Author	Description
[16]	presented some concepts the strong barrier coverage, weak barrier coverage, and probabilistic barrier coverage
[17]	implement distributed algorithm to build several separate barriers in order to ensure optimal coverage in a random deployment of sensor nodes
[18]	energy-efficient barrier coverage for directional sensor networks with mobile sensors.
[19]	used concept of mobility to improve the barrier coverage solve the problem of energy efficient for barrier coverage using mobile sensors.
[20]	proposed mobile barrier deployment algorithm on sensors to move cooperatively and form maximal K strong barrier.
[21]	optimal strategy of movement based on the optimization problem to provide a strong barrier coverage.
[22]	proposed new distributed algorithm depend on the virtual forces to present the movements of sensors.
[9]	construct a strong barrier coverage by using mobile sensors to close the gaps located inside the deployed stationary sensors.

TABLE 1 shows that mobile sensor nodes are used in barrier coverage with a random deployment of sensor nodes. In some barrier coverage applications, the sensor nodes cannot be implemented precisely at the desired location due to deployment constraints such as hostile area. Therefore, the random deployment is the only choice where the sensor nodes are randomly deployed around the target area. Such applications can benefit from mobile WSNs if the deployed sensors can autonomously move after deployment to achieve the desired barrier coverage. The autonomous mobile sensor node can be used to relocate the position of the sensor node after the initial deployment in order to achieve the barrier coverage and to maintain the connectivity between connected nodes [6, 23].

V. Barrier Coverage Strategy in WSN

The node placement in sensor node deployment will affect the various network performances metrics such as coverage, connectivity, throughput, energy consumption and delay in WSN applications [24]. The best way of the sensor nodes deployment needs to consider maximize possible of coverage and connectivity in the ROI. It is not realistic and impossible to place the sensor nodes in a large area with predetermined or deterministic positions. Instead, it requires random deployment. However, the coverage and connectivity requirements cannot be guaranteed in random deployment, as the exact location of each sensor cannot be formed. Even in the high node density, complete coverage and connectivity of the monitoring area cannot be 100% guaranteed. Thus, random deployment can lead to a coverage hole, sensing overlapping and disconnected nodes [25]. As an alternative to overcome this problems, mobile sensor nodes can be used in WSN deployment [26].

Crucially, WSN requires the node placement of sensors network to be designed in order to determine the physical location of the sensor nodes [27]. Sensor node placement influence the coverage monitoring area and connectivity between nodes. Therefore, the optimal node placement approach needs to be implemented to maintain the coverage area and connectivity. In order to solve both problems, the solution reflected on the positioning of sensor node rely on the WSN application [28, 29]. The solution can be reached through the first phase of WSN, which is how the planning position of sensor nodes is implemented. This is important to ensure the maximum coverage, and minimize the overlapping and coverage hole in the target area. The maximum coverage and fully connected area also can be achieved with optimal placement of minimum number of sensor nodes.

Different strategies can be implemented to optimize coverage in WSN. Classification of the strategy can be divided into 3 groups: force based, grid based or computational geometry [30]. Fig 2 summarized the approach used in each coverage strategy.

Fig 2. Coverage strategy in WSN

The grid-based strategy is a type of deterministic deployment where the sensor nodes positions are fixed based on regular grid pattern such as triangular lattice, hexagonal grid and square grid. A comparison between the aforementioned different grid-based techniques is summarized in TABLE 2.

TABLE II. Comparison between Grid-based Techniques

Techniques	Advantage	Disadvantage
Triangular, square and hexagonal[30]	Provide multiple coverages and maintain the connectivity	Coverage rate is depending to the ratio of sensing range, Rs and communication range, Rc that give an impact to the network performance
Triangular[30]	Achieve a full area coverage with a minimum number of sensor nodes	Did not consider network connectivity
Square[30]	Achieve a coverage and connectivity with a minimum number of sensor nodes.	Did not consider obstacle and sensor mobility

The computational geometry strategy is based on geometrical objects such as points, polygons and line segments. The most popular computational geometry strategy used in WSNs are Voronoi diagram and Delaunay triangulation. TABLE 3 show the comparison between computational geometry strategy used in WSN.

TABLE III. Comparison between Computational Geometry Strategy

Techniques	Advantages	Disadvantage
Voronoi diagram and distributed greedy algorithm [31]	Improved the coverage for rotatable directional sensors	Valid for heterogenous sensors that have different sensing range and different sensing angles
VEC, VOC and Minimax[32]	Ability to extend to large deployment and to reduce coverage hole	Complexity of coverage hole detection. Poor performance on initial cluster deployment lower communication range

The force-based strategy is a simple node placement strategy. It based on the virtual force approach where the sensor nodes are subjected to attractive, repulsive and null virtual force. The comparison between force-based strategy is shown in TABLE 4.

TABLE IV. Comparison between Force-based Strategy

Techniques	Advantages	Disadvantage
VFA [33, 34]	Provide acceptable coverage and connectivity Ability to deal with obstacles	High computational capability for the base station to new position calculation
Van der Walls force-based [35]	Higher coverage rate and can deal with obstacles	Did not consider connectivity and power consumption
DVFA [36, 37]	Achieve full coverage and connectivity	Additional cost in traveled distance
EVFA [38]	Provide ideal deployment of sensors nodes that ensure simple coverage and connectivity	Did not deal with obstacles

Based on the coverage strategy summary stated in TABLE 2 to TABLE 4, the force-based approach is an applicable strategy suitable to implemented in a barrier coverage area. The Virtual Force Algorithm (VFA) is force-based strategy provides acceptable coverage and connectivity.

The VFA is used to redeploy the sensor network after an initial random deployment [39]. Each sensor node in the VFA acts as a source of force for all other sensor nodes within its communication range. The VFA approach uses attractive or repulsive methods to exert force between nodes. When the distance between two sensor nodes is close enough, the force is repulsive. The force method intends to separate them, but when two nodes are far from each other, the force becomes attractive and attracts them closer [40, 41]. The attractive method can avoid the coverage holes while the repulsive method can prevent the redundant coverage or sensing overlapping.

Metaheuristic algorithm also has been proposed by most researchers as a solution of the problems in deployment, coverage and connectivity in WSN environment. The metaheuristic algorithms are intended to search for the best solutions and select the solutions or best candidates. It also ensures that the algorithm can effectively explore the search space. There are some popular metaheuristic optimization algorithms such as Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Tabu Search, Bee Algorithm, Firefly Algorithm and Cuckoo Search (CS) Algorithm [42, 43]. A number of optimization techniques have been implemented in placement of WSN node such as Particle Swam Optimization [44], Genetic Algorithms [45, 46] and Ant Colony Optimization [47]. The summary of the researcher's metaheuristic approach is listed in TABLE 5.

TABLE V. Summary of the advantages and disadvantage of metaheuristic approach in WSN problems

Techniques	Advantages	Disadvantage
Territorial Predator Scent Marking Algorithm (TPSMA) [48]	ensure maximum WSN coverage area for effective monitoring	didn't ensure overlapping area
Biogeography-based optimization (BBO)[49]	optimize the coverage in WSN	leads to slow convergence and can decrease the lifetime of the WSN network or even deplete the sensor node energy due to limited energy resources
Gradient method and simulated annealing algorithm[50]	improve area coverage and barrier coverage with minimum number of sensor nodes	only consider 1-k connectivity to the base station
Genetic algorithm [24]	requires a smaller number of relay nodes to provide K-connectivity	consume more power consumption
Glowworm Swarm Optimization (GSO)[51]	where the sensor nodes move and attract rely on the distance between the sensor nodes and their neighboring sensors	slow convergence
Firefly Optimization Algorithm[42]	increase area coverage and Minimize power consumption	increase network cost
Cuckoo Search Algorithm[43]	maximizing the target coverage with a minimum number of sensors. It can find the optimal locations of the sensors, fast convergence and fast local search	implement in deterministic and random deployment strategy

Overall, these studies show that Cuckoo Search (CS) algorithm outperform the various metaheuristic algorithms in solving the optimization problems in WSN as shown in TABLE 5. Some researchers implement optimal strategy in mobile barrier deployment to optimize the barrier coverage in order to form a strong barrier coverage. The coverage goal and position of sensor nodes and deployment strategies must be considered in barrier coverage. Thus, to perform a barrier coverage in the border region, a good positioning of sensor nodes for both coverage and connectivity should be considered.

VI. CONCLUSION

In conclusion, this paper has presented a broad overview about the deployment issues of barrier coverage in border surveillance. Barrier coverage in wireless sensor network can be thought of as how well the wireless sensor network is able to monitor a particular region of interest. This paper reviewed the issues and technique of barrier coverage.

Various strategies can be used to optimize the coverage in WSN, which are classified into three groups: force-based, grid-based or computational geometry. Instead of these strategies, the placement of sensor nodes in the WSN environment will also affect coverage and connectivity in barrier coverage. The force-based strategy is a suitable be implemented to overcome the problem in random deployment. This strategy used a method of virtual repulsive and attractive forces. There are some metaheuristic algorithms used to optimize the coverage and connectivity in WSN. The coverage goal and position of sensor nodes and deployment strategies must be considered in barrier coverage. Therefore, a good deployment of sensor nodes should be considered to perform a barrier coverage in the border region. The placement of sensor nodes affects the performance of border surveillance applications and operations.

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