Linear and Non-Linear Barrier Coverage in Deterministic and Uncertain Environment in WSNs: A New Classification

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ABSTRACT

This paper Various studies cited in the literature deal with the classic problem of obstacle coverage, where the deployment environment, sensor nodes, and base stations have characteristics that are considered perfect but suffer from various flaws in the real world. This paper presents other barrier coverage types ranked in a new classification based on linear and nonlinear barrier coverage according to deterministic and insecure environments, and enumerates some of the different current and future challenges of these coverage types and connectivity in WSNs.

KEYWORDS

WSN, Barrier Coverage, Deterministic and Uncertain Linear Barrier Coverage, Deterministic and Uncertain non-linear Barrier coverage, Connectivity, Current and Future Challenges.

1. INTRODUCTION

The Wireless Sensor Network (WSN) technology was born with the recent advances in wireless communication and electronics that have enabled the development of inexpensive, low-power, and versatile sensors that are small enough to operate over short distances communicate within. The real mode is merged by the different types of uncertainties, such as imprecision in measurement components, atmospheric phenomena, intrusion, animals, and natural phenomena such as volcano, rivers, industrial phenomena and others [1]. The unreliability of communication radios and reception radios, etc., affects the quality of service and decisions regarding real-world information [2].

This survey addresses the problems of Linear-based barrier coverage models and Non-Linear-based barrier coverage models. This purpose is to expand the wireless sensor network as much as possible to overcome the previous uncertainties and guarantee the quality of service. Thus, the aim is to ensure barrier coverage with a minimal number of connected node subsets, and dominant nodes and minimal cost, regardless of the type of deployment (random or deterministic).

This paper is structured as follow; Section 2 reviews the problems that influence the Wireless Sensor Networks, and show the relationship between these problems. Section 3 summarizes the different types of coverage proposed in the literature.

Section 4 cites some related works in barrier coverage. It is subdivided into two main parts. The first part presents some deterministic and uncertain-based coverage strategies and show the drawbacks to open up avenues for research. The second part focused on the new barrier coverage classification (the linear and non-linear types barrier coverage in deterministic and uncertain environment in WSN, and quotes some linear and non-linear- bases coverage strategies and show the drawbacks to open up avenues for research. Section 5 describes the current challenges and future challenges of linear and non-linear coverage. Finally, Section 6 presents conclusions and future work.

2. PROBLEMS THAT IMPACT WIRELESS SENSOR NETWORKS

Implementing sensor networks poses many challenges for researchers to meet stringent constraints imposed by certain properties, including:

- Energy sources are very limited,
- An unattended and harsh deployment environment (the hostility of the environment),
- limited and unsecured radio links (unreliable communication),
- Changing network topologies (changing topologies of deployed sensor networks),
- Uncertain characteristics of either the deployment environment, or the components of the sensor nodes used,
- Heterogeneity of nodes and multi-hop communications, etc.

The most problems that affect the WSn are; Energy, Node Cost, Limited bandwidth, Deployment, Security, etc.

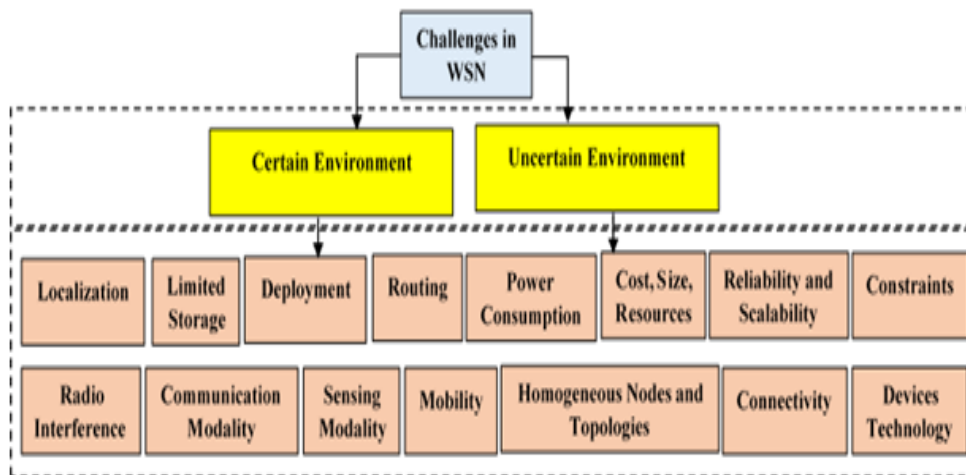The Fig 1 cites the majority of known problems in the literature.
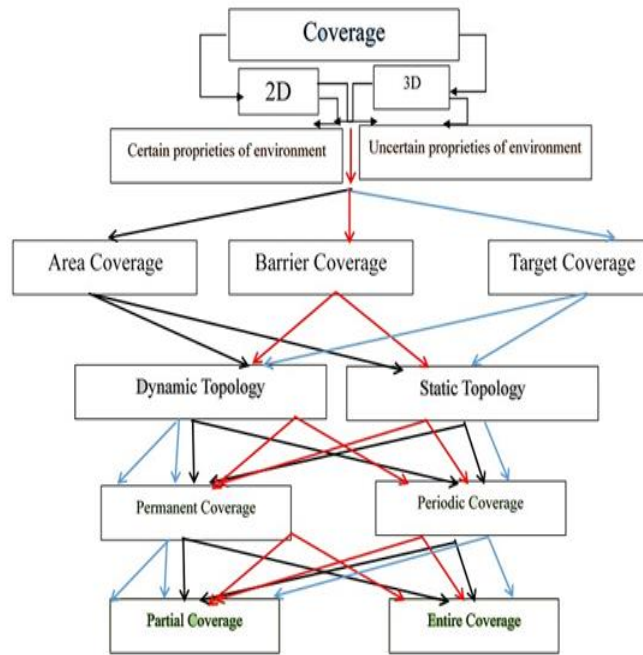

Figure 1. WSN Problems [3]

Figure 2. WSN Coverage Types [3]

3. COVERAGE TYPES

There is a range of types proposed in the literature, as illustrated in Figure. 2. The main types are:

- **Target coverage:** Target Coverage, also known as Point Coverage, is used to monitor specified targets in an AoI.

Fig. 3.(1) illustrates a target coverage scenario where six sensor nodes are deployed to monitor the five targets in the Area of interest (AoI). Where, target t_5 is covered by only one sensor node. The other targets; t_1, t_2, t_3 and t_4 are simultaneously covered by two sensor nodes. Target coverage reduces energy consumption because it monitors

Only specifies the position of the target within the AoI.

- **Area Coverage:** The area coverage, is to monitor the AoI by a minimal set of deployed sensor nodes in the area of interest (Figure.3.(3)).
- **Barrier Coverage:** The Barrier Coverage is to deploy a limited number of sensing nodes in area borders, for monitoring, and building a Barrier against intrusion (Figure 3.(2)).

A comparison between the different strategies used for k-barrier Coverage according to different classifications in Table 1 and Table 2.

4. NEW CLASSIFICATION OF BARRIER COVERAGE

The barrier coverage of a geographical area by a network of sensors focuses on the answers to the questions:

- How to cover a geographical area against all intrusion types with a minimal set of sensor nodes?
- How can coverage and connectivity be guaranteed for a maximum period for applicable objectives?

- How can coverage be guaranteed for a maximum period of time in uncertain environment?
- In which deterministic and uncertain positions should sensor nodes be placed or deployed to ensure maximum coverage of the area of interest?

In practice, barrier coverage is usually embodied in the answer to two basic questions [16] :

- How to evaluate barrier coverage performances rate, when sensor nodes are deployed in form of monitoring barriers?
- How to improve coverage performance when the active barriers is minimal?.

Many researchers are currently interested in developing solutions that address various needs [17], and have proposed divers classification such the classification illustrated in Figure. 4.

The Barrier Coverage aims to detect and to minimize the intrusion through the network (WSNs). Boulis [18] pointed out that the monitoring of WSN is based on the management of three factors: the energy level of each sensor node, the coverage area and the connection characteristics between nodes. [11]

Intrusion detection is one of the most important issues in WSNs, whose goal is to detect any intruder trying to enter the network. In fact, many security applications need to detect intruders, such as border protection, critical infrastructure protection and hazardous substance

monitoring. In WSNs, area coverage and barrier coverage [17] are proposed to achieve the objective of intruder detection. In this case, we proposed a new   classification of barrier coverage types; (a) Linear barrier coverage, and (b) non- linear barrier coverage. In this case. Each type characterized by strong or weak barrier, in static or dynamic topology, depending
on the need for permanent or periodic coverage of the application.
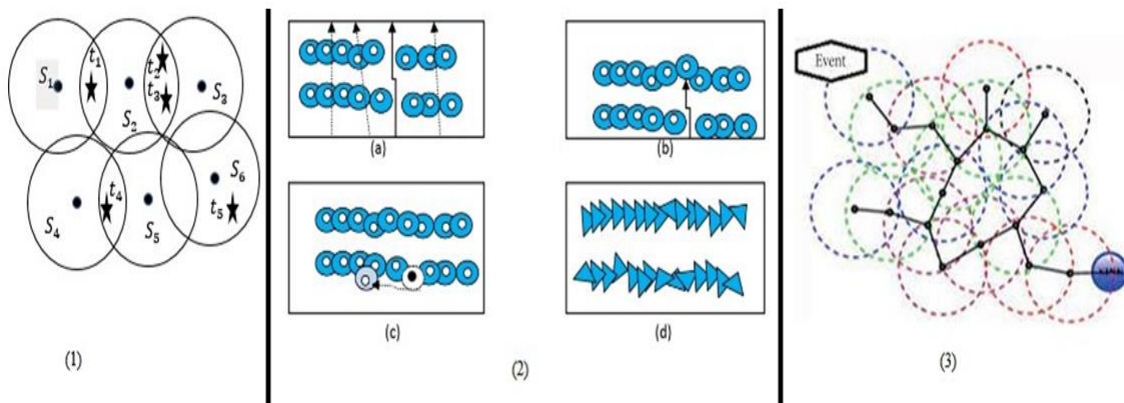

Figure 3. (1) Target Coverage: a network with 6 sensor nodes and 5 targets, (2) (a) Weak barrier coverage. (b) Strong barrier coverage. (c) Hybrid barrier coverage. (d) Barrier coverage in directional sensor networks, (3) WSN Area Coverage

Table 1. Comparative study between the different k-Barriers Coverage works according the Connectivity and k-barrier Type.

Ref/ No, Pub Year	Paper Highlight	Deployment Type	Sensor type	Connectivity	K-Barrier Type	Space
Hong Y, et al [4], 2022	Monitor intruders in high resolution and maximize network longevity	Deterministic deployment	Cameras	Connected barriers	Strong Barrier	3D
Zhanwei Yu [5], 2019	Minimizes hybrid access point (H-AP) power supply by jointly optimizing power/information transfer timing and H-AP transfer performance while meeting node throughput requirements.	Random deployment	Static	Connected nodes	Weak Barrier	2D
Ernest Bonnah et, al [6], 2020	Coverage maximization scheme, by using the exposure profile from the sensor node to the sink node to calculate the minimum exposure path	Random deployment	Static	Connected nodes	Strong Barrier	2D
Ernest B, et al [7], 2017	Linear Programming (LP) techniques and on-linear optimization problems in WSN	Random deployment	Static	Connected nodes	Non-Linear Barriers	2D
Kaiye G, et al [8], 2021	Minimizing the cost of the entire system while meeting pre-specified requirements on the expected signal coverage and system reliability.	Random deployment	Mobile	Connected nodes	Linear Barrier	2D
Hong Y, et al [4], 2022	monitoring the intruder with high resolution and maximizing the network lifetime	Deterministic deployment	Cameras	Connected barriers	Strong Barrier	3D
Zhan wei Yu [5],2019	Minimize hybrid access point (H-AP) energy provision via jointly optimizing the time allocation of energy/ information transmissions and H-AP's transmission power while satisfying node throughput requirement.	Random deployment	Static	Connected nodes	Weak Barrier	2D

Table 2. Comparative study between the different k-Barriers Coverage works according k-barrier
Type and strategy objective

Ref/No, Pub Year	Paper Highlight	K-Barrier Type	Strategy/ Objectives
A. Boualem, et al [9], 2017	Probabilistic interference and Truth-Table model for Strong K-Barrier Coverage	Strong Barrier	Sensing model
Xing-Gang Fan, et al [10], 2020	An Efficient Scheme for Mobile Nodes to Join Barriers One by One to Form Strong Barrier Coverage	Strong barrier	Sensor mobility
Ernest Bonnah, et al [11], 2020	The coverage maximization scheme uses the exposure profile of the sensor nodes from the sink node to calculate the minimum exposure path	Strong Barrier	Coverage intensity
Xiaoyang L, et al [12], 2018	Genetic algorithm of route planning of WSN	Weak Barrier	Node localization method
A. Boualem, et al [9], 2017	Probabilistic interference and Truth-Table model for Strong K-Barrier Coverage	Strong Barrier	Sensing model

5. CURRENT AND FUTURE CHALLENGES BARRIER COVERAGE PROBLEM

In many cases, inconsistent detection requirements must be considered when using WSNs, depending on the size or sensitivity of the surveillance area. For example, high detection accuracy is required for sensitive areas, and low detection accuracy is required for smaller areas. Atmospheric event influences shaping the physical environment Location, communication strength and monitoring of sensor nodes in the network. This reality makes it necessary to consider the nature of uncertainty. Many proposed works in literature consists of introducing fuzziness in the process of scheduling sensor nodes in WSNs for several purposes. The following types of uncertainty are present in WSNs:

- Uncertainty in radio communication links. Communication performance increases with spatial distance. Mobility, power, performance, and connectivity are constraints that prevent network sensor nodes from communicating when deployed in a three-dimensional (3D) environment.
- Uncertainty in the testing process. Environmental disturbances, angles, nonlinear distances, noise, sensor types, and other factors will bring uncertainty to the detection process of sensor networks.
- Detection uncertainty in data collection. When sensors are deployed in harsh environments, various factors can affect the quality of the collected or captured data, such as degradation (wind, terrain, animals, etc.).
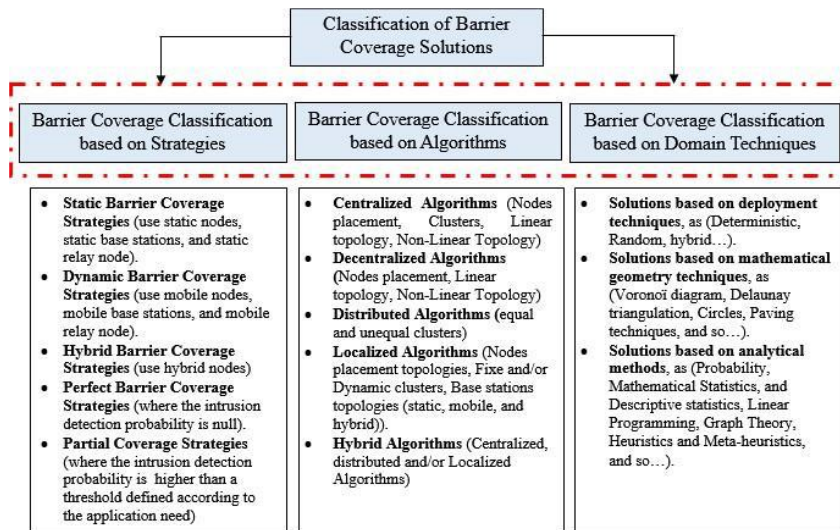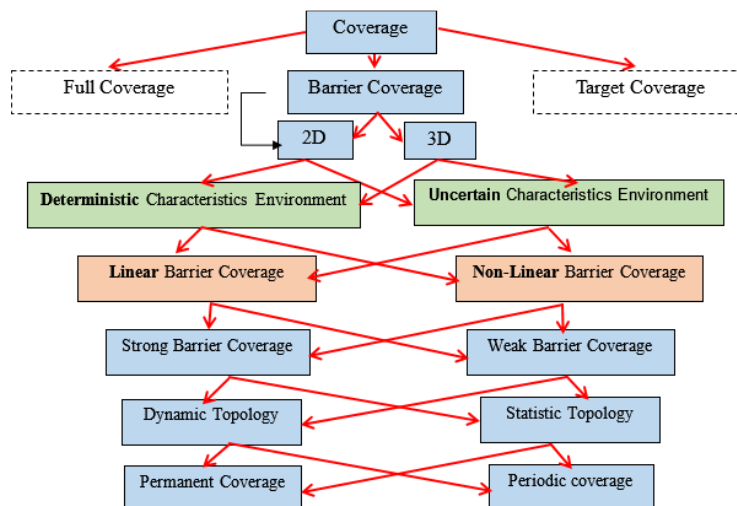
Figure 4. Our WSN Barrier Coverage
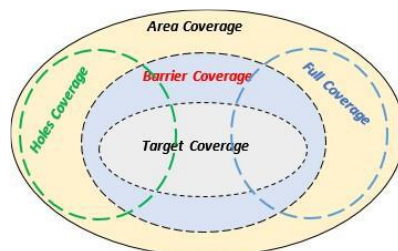

Figure 5. The New WSN Barrier Coverage

Figure 6. The New WSN Coverage Types

6. CONCLUSION

Several classifications focus on proposed solutions to ensure 1-barrier coverage and/or K-barrier in WSNs. In this paper, we divide barrier coverage into two axes; (a) deterministic-based barrier

coverage model, (b) uncertain- based barrier coverage model. In each model, we classify barrier coverage according to deterministic and uncertain 2D and 3D environments. Depending on the application's need for continuous or intermittent coverage, we classify (1) linear and (2) nonlinear barrier coverage into strong and weak barriers in static or dynamic topologies. The gap between existing work and practical application needs to be considered in future research to address current and future needs, such as: Boolean barrier coverage, probabilistic barrier coverage, and fuzzy barrier coverage. Based on the requirements for monitoring the occurrence, importance and hazards of phenomena. In this paper, we mainly answer the following questions: "what new types of barrier coverage have emerged, how to deal with the problem of coverage of hazardous area boundaries and borders, what is the proposed solution for this, what are Current and future of this sacred task What were the challenges and, what deployment topologies were used...".

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