A Review of the Problems and Impacts Related to Network Voids in Wireless Sensor Networks

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Abstract

In this research paper, an exploratory study has been conducted to understand the various aspects of the network void problem. This paper provides insights into multiple research questions, which include how and why each void problem occurs. We have covered ten void problems (i.e., Coverage Voids or Holes, Routing Voids or Holes, Jamming Voids or Holes, Sink/Black Holes/Worm Holes, Trap Coverage, Energy Void or Hole, Joint Coverage Problem, Sleep wake-up Problem, Barrier Coverage Problem and Coverage Restoration Problem) and their definitions to understand how each problem affects the network performance, as well as the methods, approaches and algorithms used in preventing, defending and avoiding void problems. In the last section, future recommendations are presented for a complete solution to overcome the maximum number of issues out of the set of problems above. All information has been illustrated using a tabular summary format with analysis and insights.

Keywords: Coverage Voids, Network Coverage, Energy Void, Routing Void, Wireless Sensor Networks.

1. Introduction

Multiple glitches and issues may occur in ad-hoc networks. These issues may hamper their functionality in many ways. The working space that is fully covered with closely deployed nodes may have a coverage void, which is space not covered by a sensor node, because random deployment that creates network voids [1], unreachable areas due to the presence of hindrances [2], and, more likely, node failures [3] due to power exhaustion, or it may be simply due to the wrong location coordinates that occur because of the changing the topology of the network during a course of time. Similarly, a wireless sensor may not be able to send data packets correctly if routing voids or holes [4] or spaces devoid of any sensor nodes exist in the deployed network vector space. Thus, a wireless sensor network (WSN) fails to obtain its objectives of full strength coverage and reliable communication, which is measured in terms of packet delivery ratios because some of the nodes do not fulfil their functional obligation in terms of sensing data, such as temperature and humidity. Adversaries deliberately create several anomalies that try to avoid the sensor network. These malicious nodes may jam the communication to form jamming holes, or they can overcome regions that are in a wireless network by a distributed denial of service attacks such as a sink [5] /black [6] /worm holes [7] to hinder their operation, which is normally based on trust. Thus, in this paper, one shall address the following questions in this context for the quest to understand this area.

A. How should one define these issues in terms of understanding and addressing them?

B. Why there is a need to solve these problems /issues related to network voids and how do these network void and connectivity issues occur? What new level of problems are arising from new applications?

C. What happens when the problems mentioned above occur in wireless sensor networks?

D. Why do these voids occur in the network?

E. How have researchers approached [prevention, detection, repairing, avoidance] this problem? What algorithms are they using to solve these issues in the network?

F. What are the future recommendations and directions for this area?

2. Section A

How should one define these issues in terms of understanding and addressing them?

For a proper understanding of the types of issues that might occur in this area of study, there is a need to first understand whether these issues are deterministic in nature or if they have some criteria for the proper and appropriate solution or not. This analysis is not possible without building a terminology for these problems on this subject. Hence, the following Table I defines the areas that are required to understand the issues mentioned in the introduction.

TABLE I

PROBLEM AREAS IN WIRELESS NETWORK COVERAGE

S No.	Problem Area	Issues, Problems and Definitions
1	Coverage Voids or Holes [8]	It is essential to note that the network coverage void problem depends on the application requirements. It is a technical fact that the coverage voids may require a higher coverage for a given target space for fault tolerance/redundancy or accurate target localisation using the triangulation-based positioning protocols or trilateration-based localisation.
2	Routing Voids or Holes[9]	A routing hole consists of an area that is in the wireless sensor network (WSN) where either the wireless nodes are not accessible, or the available nodes do not participate in the routing operation of path finding.
3	Jamming Voids or Holes [10]	Jamming may be thoughtful or accidental. Un-intentional jamming occurs when one or greater amount of the wireless nodes breakdowns or constantly transmits and along these lines possesses the wireless channel by denying the facility to other close vicinity nodes. In deliberate jamming, an adversary is trying to hamper the functionality of the wireless network by meddling with the communication ability [11] of the sensor nodes.
4	Sink/Black Holes/Worm Holes [12]	A malicious node may cause nodes that are located in different areas of the wireless sensor networks (WSNs) to believe that they are close neighbouring nodes thus resulting in the wrong routing convergence and leading to sink [5] /black [6] /worm holes [7], where sensor coverage leads to the selection of the wrong path.
5	Trap Coverage [13]	This concept takes the definition of the full coverage of nodes by assuming that moving objects that remain within the definitive speed limit can be fully covered by considering the holes of a maximum diameter computation at a given trajectory.
6	Energy Void /Hole [14]	Typically in sensor networks, the traffic is induced by the sink centric traffic or by the non-uniform distribution of the sensing activities that manifest as energy holes throughout the WSN, when an uneven consumption of power resources takes place.
7	Joint Coverage Problem [15]	This problem defines the issues when more than one node is in proximity, and their sensing coverage overlaps with different levels of strength.
8	Sleep Wake-up Problem [16]	This problem arrives, when to save power, the sensors undergo sleep–wake cycles leading to asynchronous sensor sensing coverage, and routing paths are distributed when some nodes are asleep and when some nodes are awake.
9	Barrier Coverage Problem [17]	The problem of building a fortification using the wireless sensor network that is stealth against another network to safeguard one's own communication network from intrusion.
10	Coverage Restoration Problem	The initial placement of sensors may not achieve the goal of full coverage for multiple reasons. The number for a sensor's density may have been low, or the original placement may have been arbitrary (for instance, sensors deployed from the air) leaving parts of the area revealed. A percentage of the sensors may have broke down, leaving coverage holes that need to be restored dynamically in real time when the network is communicating data.

3. Section B

Why is there a need to solve these problems /issues related to voids? What is the significance of studying this set of *problems? What new level of problems are arising from new applications?*

It is apparent from Section A, TABLE I, that this area of study is vast. Each set of problems needs special treatment in terms of building preventive, detection, avoidance, repair, self-healing or maintenance solutions to solve the network coverage problems because it is a mixed bag of multiple issues that are interrelated to each other.

TABLE II
FACTOR AFFECTING NETWORK COVERAGE

1	Geometry	Geometric dimensions of the area under wireless sensor deployment.
2	Quality of Service (QoS)	Quality of Service: In fact, coverage is the metric that determines the quality of communication in terms of how much geographic area is covered. Reliable communication with no loss and no connectivity can occur when coverage is under the process of developing various types of voids and barriers.
3	Energy	The energy-conserving factor determines how successfully these issues can be overcome by building green with ultra-low-powered devices.
4	Adversity	Adversity is defined as the exploitation of the vulnerability of wireless sensor networks or the deliberate jamming or building of sink, black, and worm holes to create network and coverage voids.

The significance of the study can also be assessed from the mission critical applications for which the wireless sensor network might be deployed. The following tables illustrate and explain why this topic needs high-level attention for successfully maintaining the network for high availability with full scalability when using wireless sensor networks.

TABLE III
FINE GRAIN ISSUES IN NETWORK COVERAGE

S No.	**Issue**	**Example where these issues play a significant role**
1	Geometry	A wireless sensor network tracks any movement of objects to safeguard several assets by using a strong room of banks. If the dimensions of the strong room of banks are large and its perimeter shape is irregular, it needs special care to fix up the location of each motion sensor to cover up the perimeter. Thus, the guard for this sensor network should not have voids and gaps where someone may sneak in.
2	Quality of Service(QoS)	Quality of Service is critical in networks that are real time in nature for providing a proper decision in real time, for example, a sensor deployed for tracking where a change in temperature may lead to fire. If this network has voids and the fire spreads, the sole purpose of this lead delay in action is to save the situation.
3	Energy	Today, ultra-low power consuming devices that maximise the life of sensors is needed. The inherent nature of wireless sensors is that the battery power is replenished in this sensor, for example, if the wireless sensor is under water or is deployed for some high-altitude application, such as snowfall monitoring. If there are energy voids in between, a proper routing path may receive work.
4	Adversity	Until and unless there are plausibility checks on the deployment of a wireless sensor network in today's context, no network can remain free from attacks because there is a growing underground economy that benefits from them. Per recent studies, many folds increase in the reported incidence-related attacks that are designed to bring down the mission critical applications and lead to a denial of service [DoS], for example, a wormhole attack.

It is clear from the above Table III that there is urgency to study this area because billions of wireless sensors are deployed for innumerable applications in all spheres of life and technology. One new area which needs attention in this context is 'Body Sensor Network'. If body sensor network suffers from any of these problems, the health monitoring using such technology would remain dream and as in emerging area of VANET (Vehicular ad hoc network).

4. Section C

What happens when the problems mentioned above occur in wireless sensor networks?

A simple answer to this question is that these problems lead to various types of network void problems including coverage, energy, and routing. However, for this survey, papers are solicited from multiple journals that help to address this question and assess the impact on the network and further analysis which would keep us understand the impact on network vectors including availability, integrity, and confidentiality.

TABLE IV
PROBLEMS ADDRESSING THE CONSEQUENCES

S No.	Problem Area	Packet Delivery Ratio	Bandwidth	Coverage Ratio	Energy
1	Coverage Voids or Holes	Packet delivery is [18] lowered.	Bandwidth may be underutilised [19] or over-utilised in a non-uniform manner.	Coverage is reduced [20] and voids propagate where the distance and movement of sensors is high.	Energy consumption in certain parts of the network increase leading to battery drainage [21] and the rapid creation of voids.
2	Routing Voids or Holes	Packet delivery is unreliable and erratic in nature.	Bandwidth may be choked in one part of the network due to limited routing path availability.	Network Coverage becomes partial.	Energy consumption in live nodes increases for many of the nodes, which have established paths.
3	Jamming Voids or Holes	Packets sent to keep the channels blocked.	Collusion occurs leading to bandwidth congestion	Coverage is restricted to a few nodes.	Energy consumption in certain parts of the network may increase leading to battery drainage and the creation of voids.
4	Sink/Black Holes/Worm Holes	Packets received but not forwarded in sections of the wireless sensor network.	Bandwidth may be underutilised or over-utilised in a non-uniform manner.	Coverage is reduced and voids propagate where the distance and movement of sensors is high.	Energy consumption in certain parts of the network may increase leading to battery drainage and the creation of voids.
5	Trap Coverage	Deployment of the nodes does not cover the moving objects or diameters, and no packets can be delivered.	Computational cost increases are due to geographic searching for appropriated node locations.	Full Coverage is not possible for moving objects.	Many nodes will be idle and will not communicate with phantom energy consumption.
6	Energy Void /Hole	Packet delivery is lowered.	Optimal utilisation is not occurring either over/ underutilisation.	Coverage is reduced and voids propagate where the distance and movement of sensors is high.	Energy optimisation is one of the important issues in the research of wireless sensor networks.
7	Joint Coverage Problem	Packet delivery is lowered.	Bandwidth may be underutilised or over-utilised in a non-uniform manner.	Coverage is reduced and voids propagate where the distance and movement of sensors is high.	Energy consumption in certain parts of the network may increase leading to battery drainage and the creation of voids.
8	Sleep Wake-up Problem	The packet delivery does not follow monotonically increasing values. Instead, it is erratic because this problem with energy is still being saved with some more lifetime of the network. However, most of the nodes in the waiting or sleeping state with network coverage are not per the QoS requirements.			
9	Barrier Coverage Problem	Because of this defensive mechanism for safeguarding the IT assets, failure to address this defence mechanism will compromise network communication and lead to a privacy breach.	A strong transmission and a sensing range are a requirement for which protection is not possible.		
10	Coverage Restoration Problem	Because of both the energy and geometric reasons, voids may occur, but the self-healing process with a proper fault tolerance can ensure better bandwidth management and an excellent packet delivery ratio for the networks.	Link quality is lowered, and hence bandwidth is lowered.		

Analysis of above findings:

From the above Table IV even outline of these problems, we can infer that these problems will impact all network vectors, which include availability, confidentiality, integrity, scalability. Consequently, result need to be assemble to prevail over these results may be by using bio inspired algorithm that can help to fill vector space model, to bring these sort of problems down.

5. Section D

Why do these voids occur in the network?

The main reasons for these network coverage problems are as illustrated in Table V.

TABLE V
NETWORK PROBLEMS

S No.	Problem Type	Why these problems occur?
1	Coverage /Routing	1) Node failure. 2) Node malfunction. 3) Wrong deployment of nodes. 4) No-fault tolerance scheme. 5) No network monitoring system. 6) No intrusion detection system. 7) Utilisation of high-computational resources. 8) Limited energy. 9) The duty cycle of the sensors for sleep and wake is not in sync. 10) No preventive practices.
2	Sink hole /Worm hole /Black hole /Jamming	1) No network monitoring. 2) Intrusion detection system not utilised.
3	Sleep–Wake problem	1) The duty cycle of the sensors for sleep and wake is not in sync. 2) Target sink pre-emptively is not known.
4	Energy Hole	1) Duty cycle of the sensors for sleep and wake is not in sync. 2) Skewed energy residual distribution. 3) Nodes broadcast unnecessarily. 4) Non-geographically aware routing. 5) Non-energy/power aware routing.
5	Barrier Problem	1) Topology model does not calculate the coordinates of the nodes properly. 2) Surveillance and exposure are not proper.
6	Coverage Restoration	1) No-fault tolerance mechanism. 2) No self-healing mechanism.

6. Section E

How have researchers approached [prevention, detection, repairing, avoidance] this problem? What algorithms are they using to solve these issues in the network?

TABLE VI
RESOLVING ISSUES

S No	Problem Area	How researchers are solving the problem
1	Coverage Voids or Holes	1) Using search surface optimisation [22] 2) Trust-based algorithms [23] 3) Minimum cost-based functions[24] 4) Low-energy adaptive clustering [25] 5) Probabilistic routing [26] 6) Energy conserving topology maintained [27] 7) Machine learning algorithms [28]
2	Routing Voids or Holes	1) Routing along perimeters [29] 2) Virtual modelling of holes [30] 3) Disjoint multiple path routing [31] 4) Reducing packet retransmission 5) Contention-based geographic routing [32] 6) Load balancing with latency factor-based routing 7) Observer packet information algorithms 8) Multi-level virtual positioning algorithms (MVP) [33]
3	Jamming Voids or Holes	1) Clustering head positioning with detection 2) Greedy forwarding with virtual positioning [34] 3) Avoiding local minimum algorithms 4) Fault tolerance schemes

		5) Hole masking algorithms [35] 6) Cost metric based on transmission power
4	Sink/Black Holes/Worm Holes	1) Bidirectional verification [36] 2) Authenticated broadcast [37] 3) Identity verification 4) Trust, credit and reputation-based systems 5) Machine learning algorithms [28]
5	Trap Coverage	1) Diameter of moving objects [38]
6	Energy Void /Hole	1) Energy-aware geographic routing (EGR)[39]
7	Joint Coverage Problem	1) Graph search algorithms [40] 2) Worst case scenario [41] 3) Voronoi diagram approach 4) Integer linear programming model 5) Tabu search [42] 6) Joint scheduling method [43] 7) Energy and bandwidth with minimum coverage breach algorithms 8) Random selection algorithms [44] 9) Self-organising networks [45]
8	Sleep Wake-up Problem	1) Any cast-based algorithms [46] 2) Access point selection algorithms [47] 3) Cluster-based energy conservation [48] 4) Randomised independent sleeping
9	Barrier Coverage Problem	1) Randomised independent sleeping [49] 2) Linear programming (LP)-based solution 3) Maximum utility algorithm (MUA), [50]
10	Coverage Restoration Problem	1) Interference-free link scheduling with the minimum number of time slots. 2) Fuzzy control 3) Markov decision process (MDP) [51] 4) Partially observable Markov decision process (POMDP)

Analysis of the above findings:

It seems lot of work have been done in this area, as shown in the above Table VI, however new techniques like SEM Structure Equation Modelling and use of bio inspired algorithm is much less, therefore future research may explore these method to develop better generation of solvers to resolve such problems. There is a need for discovering optimal solution in this direction, which may help the new community.

7. Section F

What are the future recommendations and directions for this area?

The best optimal solution to this problem area lies in the fact that there is not an absolute, highly accurate solution to all of these problems. However, now there is a combination of many counter actions that are available for achieving a solution. After conducting this exhaustive study on these ten problem areas, we recommend the following items for future recommendations because the wireless sensor network may suffer from all of these problems at the same time or may just suffer from one of the ten problems discussed so far. Therefore, there is an urgent need to build a holistic solution for these problems and thereby incorporating a combination of counter actions with the current state-of-the-art routing algorithms. Thus, here are the suggestions:

1) Transmission power and bandwidth are an essential metric for measuring and making a decision that finds the proper routing path. Therefore, this factor must be considered for any solution to counter these ten problems especially in the case where a fortification solution is built to safeguard the wireless sensor network from adversity.

2) Graph search methods must be used to determine the optimal positions of the control devices that take routing decisions because it is essential for determining the local minimum in the wireless sensor network, for example, the trust-region method for constrained optimisation can be used to find a local minimum with many constraints or restrictions for these steps.

3) The solution must incorporate or use a machine learning algorithm along with non-linear searching algorithms to build on the fly learning solutions because these voids may occur

dynamically for multiple reasons, such as a change in topology.

4) The solution to counter this problem must consist of the routing protocol, which verifies bi-directionally all of the controls as good data packets, to counter of worm/ black/sink and jamming attacks.

5) The solution must consider the wake–sleep modes and cycles for identification of possible network voids that may occur.

Energy saving coverage is essential due to the inherent nature of the wireless sensor networks.

8. Conclusions

In this research work, a systematic approach has been developed to understand the problems related to network voids by addressing five basic research questions and further tabulating these findings for a better view of the problems in this area. These five questions are based on an inquisitive urge to understand the ten main problem areas of network voids. These questions help to define the problems for seeking the cause and effect of these ten network void problems that hamper the networks. In this process, it has been found that the use of machine algorithms that help in finding the optimal solutions by search methods are also being used. However, several additional levels of experimentation to improve the effectiveness of these techniques will be conducted, even though there is a need to develop a complete solution that can address a mixed bag of these problems. Hence, in the last section, future recommendations have been given for building a proper next level of solutions that can handle these multiple occurring problems. The main contribution of this research work is that it demonstrates a systematic approach for understanding these problems in depth with a minimum amount of time and with maximum resources as tabulated in this paper based on which next generation of solutions that are made.

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