

Coverage Verification using Dimension Reduction in Wireless Sensor Network

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ABSTRACT

Wireless sensor network (WSN) have recently come forth as an eminent technology for monitoring and event detection application. In WSN a large number of sensor nodes perform sensing of a target field. The target field is said to be κ -covered, if its every point is within the sensing range of at least κ -sensors. The κ -coverage verification algorithm is proposed for verifying κ -coverage of a d-dimensional target field. The coverage verification problem in d-dimensional is reduced to (d-1) dimension by the use of dimension reduction technique based on divide and conquer approach. The algorithm proposed in this paper is distributed polynomial-time coverage verification algorithm which does not use location information. For keeping bandwidth and computational overhead as low as possible the efficient broadcasting is done between the nodes. The simulation result proven that it detects coverage hole if and if only the target field has a coverage hole in it.

General terms

Wireless Sensor Network (WSN), Coverage, distributed algorithm, wireless network.

1. INTRODUCTION

Wireless communications have enabled the development of low-cost sensor nodes [1]. Each sensor node is capable to sense particular events in its area to communicate with adjacent nodes. Thus, for event sensing applications, a large number of sensor nodes are deployed in a target field and they combine to form an ad-hoc network, referred to as a wireless sensor network (WSN), in which a sensor detects an event, it report it to a base station.

WSNs provide significant improvement over traditional sensing, since they collect monitoring information from many locations in the target field. Therefore, they have the potential to take on a major role in civil and military application. For such applications a WSN must guarantee a reliable detection. Coverage of the target field is considered as a measure of the quality of service (QoS) guaranteed by the WSN [2]. However, sensor nodes are prone for failures that may cause coverage holes in the target field. Coverage holes prevent the progress of the WSN ability to detect events and reduce the network reliability. Consequently, it is essential to equip the sensor nodes with simple and efficient coverage holes detection mechanism for ensuring the network reliability and providing the required QoS. Addressing this need, we present a simple and efficient κ -coverage verification algorithm. To the best of our knowledge, this algorithm provides guarantees on the detection without using the location information.

1.1 Related work

Coverage verification has gained center of attention in last few years and in surveys can be found in [3], [4]. The coverage studies can be classified into two types. The first one is probabilistic approach for calculating the required node density for ensuring appropriate coverage [5], [6]. The second one utilizes geometry approaches for detecting coverage holes.

There are various coverage holes detecting schemes based on voronoi diagrams and Delaunay triangulation in [2], [7], [8], and [9]. A different approach has been in [10], [11], [12], in these the authors stated that a sensor does not border a coverage hole if its sensing border is fully covered by the sensing range of its neighbors, refer to as local coverage verification approach as the sensing border concept. In [10] the author extends this result for κ -coverage, while in [11] the author utilizes this concept for maintaining sensing coverage and connectivity. The studies [11], [12] prove an interesting connectivity property that if the transmission radius of the nodes is at least twice of their sensing radius, then coverage implies connectivity of the sensor network. Several applications require deployment of sensor nodes in 2D and 3D environment. Most of the sensor networks deployed in 3D environment require exact location information. All the above methods need exact knowledge of the sensor location, which is not easy to predict. Other position calculating technique such as GPS (Global Positioning System), beacon-based solutions gives only coarse location estimation.

The coverage verification schemes that are not aware of nodes location is referred to as coordinate free solutions; this is relevant to this paper. In [18] the author stated hole detection scheme based on homology, but this scheme cannot be implemented easily in WSNs. In [20] the author presented a boundary recognition algorithms based on topological methods, but it does not guarantees hole detection. Finally in [22] the author present an interesting location-independent topology control heuristic that selects a set of sensor while preserving coverage. However, the selected set does not guarantee coverage in all situations. Thus there is a need for localized coordinate-free solution for coverage verification.

1.2 Our Contribution

This study addresses the challenge of κ -coverage verification without using the location information. A target field is termed κ -covered, for a predefined $\kappa \geq 1$, if every point in the target field included in the sensing range of at least κ nodes. We define a κ -coverage hole as a continuous area of the target field comprised of points that are covered by at most $\kappa - 1$ sensors. In particular, 1-coverage hole are simple a coverage hole is a continuous area that is not covered by any sensor.

We consider a large WSN with many nodes. The sensing radius of each node is upper-bounded by r_u and its transmission radius is lower-bounded by R_u . The nodes are not aware of location however, a node can estimate its distance from its neighbors, and it shares these estimations with them. Thus, each node has only localized distance information of the distance between adjacent node in its area and their sensing radius. In spite of this limited information, we provide an efficient solution with proven guarantees of its coverage verification quality. Moreover, we prove that coordinate-free, distributed and accurate κ -coverage verification solution exists if and only if $R_u \geq 2 \cdot r_u$.

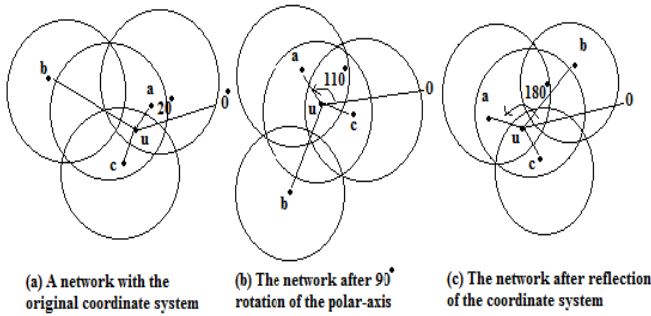


Fig.1. Motivation for the r-map coordinate system

This scheme utilizes the sensing border concept and every internal node verifies a local coverage in its area by checking that its sensing border is completely κ -covered by its neighbors. But, unlike the other proposals, we show that such verification can be achieved without using location information. A key observation for our solution is that the local coverage of a node is preserved in any coordinate system. For instance, consider a node u and three other nodes that completely cover its sensing border, as illustrated in figure 1(a). This local coverage is preserved also if the coordinate system is rotated or flipped over, as depicted in figures 1(b) and 1(c). Consequently, a node u can verify local coverage if it can determine the relative location of its neighbors' in any arbitrary coordinate system. In the study, we define a flexible variant of the polar coordinate system, termed an r-map coordinate system. Then, we present simple algorithms for calculating the neighbors' location of a given node at this coordinate system and verifying κ -coverage's.

First, we prove a necessary condition that accurate coordinate-free detection solutions exist only if $R_u \geq 2 \cdot r_u$. Then, we extend the connectivity property, presented in [11], [12], and prove that coverage implies connectivity if and only if $R_u \geq 2 \cdot r_u$.

Second, we introduce the concept of cyclic segment sequence and use it to construct a localized, simple and efficient algorithm for detecting 1-coverage holes.

Third, we present a distributed and localized κ -coverage verification scheme. The scheme extends the cyclic segment sequence concept and detects the presence of κ -coverage holes. Initially it calculates the r-map coordinates of the neighbors' of a reference node u . Then, we use the sensing border concept to detect the κ -coverage holes. The scheme running time is $O(n^3)$. Where n is the number of sensors in the area of u .

Fourth, our simultaneous demonstrate that the proposed scheme works very well and detect every coverage hole, also in case of inaccurate distance estimations.

We believe that the result of the study are fundamental for WSN management and will impact future protocols. In

particular, the proposed solutions are essential for the design of localized, coordinate-free topology control scheme for maximizing the network lifetime, while ensuring its coverage.

2. THE NETWORK MODEL

We consider a WSN comprise of a large number of sensors, also called nodes, denoted by V . The sensors are distributed over a large target field and they are designed to detect specified events. Each node u can sense specified events in its sensing range and communicate with adjacent nodes in its transmission range, referred as the node cell. We denote by D_u the sensing range of a given node $u \in V$ and by C_u the sensing border of u around its sensing range. We assume that sensing and transmission range of a node u are disks with radii r_u and R_u , accordingly, where $R_u > r_u$. Moreover, we assume an upper bound of $S R$ on the sensing radius of each node and a lower bound of $T R$ on its transmission radius, i.e., for every node $u \in V$, $r_u \leq S R$ and $R_u \geq T R$. We define the d -area of node $u \in V$ as the disk of radius $d \leq T R$ centered at the location of u and we denote by $N_u(d)$ the set of neighbors' of u that are located in its d -area. For the sake of simplicity, we assume that there are two sensors at the same location and each sensor has a unique identification number.

Table 1 General Notation

Symbol	Semantics
V	The set of sensors in the given WSN.
U	The node that executes our scheme.
$d_{u,v}$	The Euclidian distance between nodes u and v .
N_u	The set of neighbours of node u .
D	The dimension of the target field
K	The coverage requirement
R_u	The transmission radius of node u .
r_u	The sensing radius of node u .
$T R$	A lower bound on a node transmission radius, ($R_u \geq T R$).
$S R$	A upper bound on a node sensing radius, ($r_u \leq S R$).
r	$= 2 \cdot S R$
N_u^S	The set of nodes whose sensing range subsumes u 's sensing border.
κ_u	$\kappa - N_u^S $
$C_{u,v}$	The set of intersection points of the sensing borders of nodes u and v .

We distinguish between periphery nodes that are located at the boundary band and other nodes, refer to internal nodes. In this study we assume that only internal nodes need to verify their coverage. The sensors are not aware of their locations. However, every sensor knows if it's a periphery or an internal node. This may be achieved in several ways; one option is configuring the nodes before placing them. Another option is walking along the target field boundary with a hand-held device that updates all the periphery nodes. Finally, assuming

that the target field does not contain the coverage holes upon its activation time, the nodes may execute a boundary detection algorithm like the algorithm proposed in this study or the one proposed in [20]. Our only requirement is that each node can estimate its distance from its neighbors' without the need to detect their orientation. This is the realistic assumption as reasons studies [23], [24] have introduced accurate distance estimation techniques that are applicable for wireless sensor.

3. THE COVERAGE DETECTION PROBLEM

We considered a WSN comprised of numerous sensors spread over a large target field, as described in section II. We say that a point in the target field is κ -covered if it is included in the sensing ranges of at least κ nodes; otherwise it is termed κ -uncovered. Similarly, the target field is considered κ -covered if every point is κ -covered. We define a κ -coverage hole as a continuous area of the target field comprised of κ -uncovered points. For instance, if $\kappa = 1$ then every point of the coverage hole is not monitored by any sensor. Our objective is to verify that the target field does not contain κ -coverage holes of any size for a given $\kappa \geq 1$. We distinguish between the detecting the presence of coverage holes and finding their exact locations. Since, the sensors are not aware of their locations, they cannot report about the exact location of a coverage hole when they detect one. Thus, we assume that once a coverage hole has been detected, other means are applied for inferring the hole location, e.g. by backtracking the paths of the coverage hole report messages.

This study addresses the challenge of detecting the presence of coverage holes without pointing their exact locations. We assume that every internal node performs the proposal coverage verification scheme and informs a centralized base station when it detects a coverage hole. To this end, every node periodically estimates its distance from each one of its neighbors and shares this information with them. Continuously each node has only localized distance information comprised of the distance between adjacent nodes in its cell and their sensing radii. Recall that localized distance information does not imply that the distance between every pair of sensors in a node's cell is known, since nodes in a given cell are not necessarily adjacent to each other. Thus, our objective can be defined as designing a simple, accurate and efficient coordinate-free scheme that enables every internal node to detect the presence of κ -coverage holes in its area by using only localized distance information.

4. COVERAGE VERIFICATION SCHEME

In this section, we present a framework for solving the d -dimensional κ -coverage verification problem in a distributed manner. Where $\kappa \geq 1$ is arbitrary and $d \in \{1, 2, \text{ and } 3\}$. using a divide and conquer approach. Each sensor verifies that its sensing border is κ -covered by dividing the problem into simpler instances. In which the coverage requirement κ is reduced or the problem dimension is reduced to $d-1$. Whenever a node determines that its sensing border is not κ -covered its report that there is a presence of a hole. If the sensing border of all nodes are κ -covered. And therefore the presence of a hole is not reported. Clearly there is no hole. In the following, we elaborate on the algorithm executed by each individual sensor u .

4.1 Verify _ Coverage

Begin

/*initially it checks the sensing border of node u is κ -covered by sensors in the set N_u^* */

if $d=1$ **then**

Checks κ -coverage of u 's sensing border

else

Determine N_u^s

if $|N_u^s| \geq \kappa$ **then**

Return u 's sensing border is κ -covered

else

set $\kappa_u = \kappa - |N_u^s|$

for every node $v \in N_u \setminus N_u^s$ **do**

check whether the sensing border of u and v intersect

end for

if the sensing border of no sensor $v \in N_u \setminus N_u^s$ intersects u 's sensing border **then**

Return that u 's sensing border is not κ -covered

For Every node v such that u 's and v 's sensing borders intersect **do**

project all sensors in the set $N_u \setminus (N_u^s \cup v)$ onto the dimensional space containing $C_{u,v}$

verify_coverage($(uv)^*$, $N_{(uv)}^*$, κ_u , $d-1$)

end for

if for all nodes v such that u 's and v 's sensing border intersect $C_{u,v}$ is κ_u -covered by sensors in the set $N_u \setminus (N_u^s \cup v)$

then Return that u 's sensing border is κ -covered

else Return that u 's sensing border is not κ -covered

end if

end if

end if

end if

end

4.2 Subsumption and Intersection

We now present two properties that can be easily used to confirm or rule out κ -coverage of the sensing border of a sensor in some cases. It is easy to check the correctness of these properties.

Property 1(Subsumption): The sensing border of sensor u is entirely subsumed in the sensing range of sensor w if and only if $d_{u,w} + r_u \leq r_w$.

By using property 1, a sensor u can easily verify if its sensing border is entirely subsumed in the sensing range of another sensor w . Suppose u 's sensing border is subsumed in w 's sensing range. Then, since every point on u 's sensing border is covered by sensor w , we can check $(\kappa-1)$ -coverage of u 's sensing border by sensors other than sensor w . Let $N_u^s \subseteq N_u$ be the set of sensors such that u 's sensing border is entirely subsumed in the sensing range of each sensor in set N_u^s . N_u^s is found by using property 1. If $|N_u^s| \geq \kappa$, then u 's sensing border is κ -covered. Now, let $|N_u^s| < \kappa$, and $\kappa_u = \kappa - |N_u^s|$. Clearly in this case, u 's sensing border is κ -covered if and only if it is κ_u -covered by sensors in the set $N_u \setminus N_u^s$. To check whether the above condition holds, u needs to detect intersecting sensing borders.

Property 2(Intersection): The sensing border of sensor $v \in N_u \setminus N_u^s$ intersects u 's sensing border. If and only if $d_{u,v} < r_u + r_v$ and $d_{u,v} + r_v > r_u$.

The first condition in property 2 states that there is overlap between the sensing ranges of u and v and the second condition states that v 's sensing border is not subsumed in u 's sensing range. Now, if the sensing border of no sensor in

$N_u \setminus N_u^s$ intersects u 's sensing border, then u 's sensing border is not κ_u – covered by sensors in the set $N_u \setminus N_u^s$, this condition cannot be verified using property2. We assume that $|N_u^s| \leq \kappa$ and that the sensing border of at least one sensor in $N_u \setminus N_u^s$ intersects u 's sensing border, and focus on checking κ_u coverage of u 's sensing border by sensors in the set $N_u \setminus N_u^s$

5. SIMULATION RESULT

In this section, the coverage degree achieved by the coverage verification algorithm is shown. The coverage degree κ is varied between 1 & 8 and observe the achieved coverage at every single point in the area. The simulation results shows that the algorithm achieves 100% of the points are sufficiently covered.

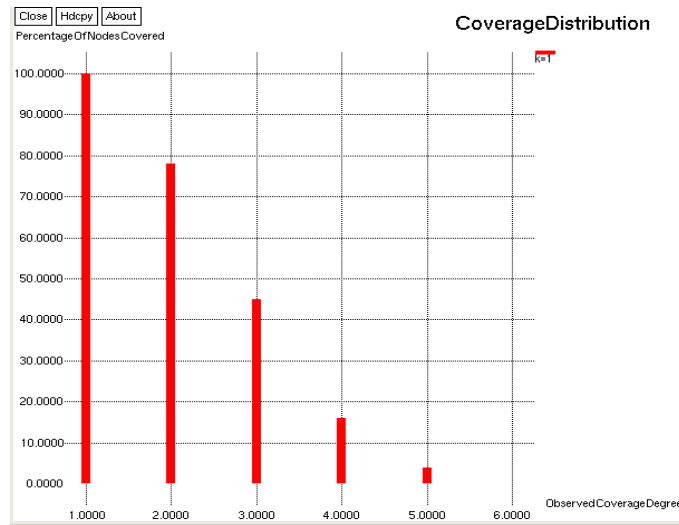


Fig.5 (a) Observed coverage degree VS Percentage of nodes covered graph for Coverage Distribution $\kappa=1$

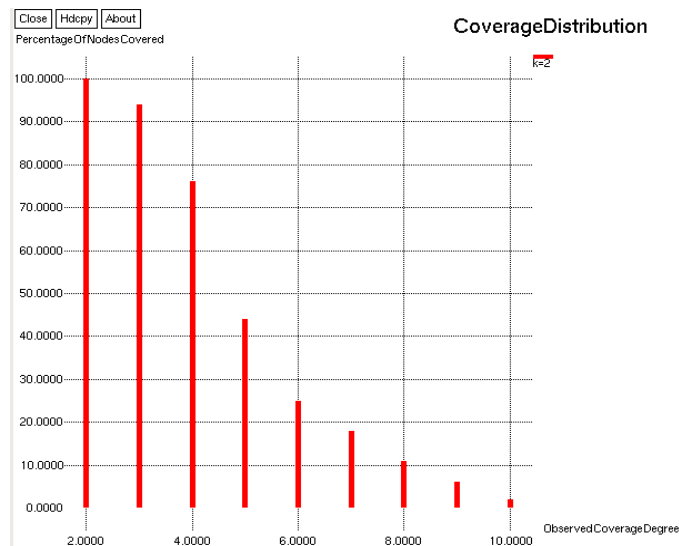


Fig. 5 (b) Observed coverage degree VS Percentage of nodes covered graph for Coverage Distribution $\kappa=2$

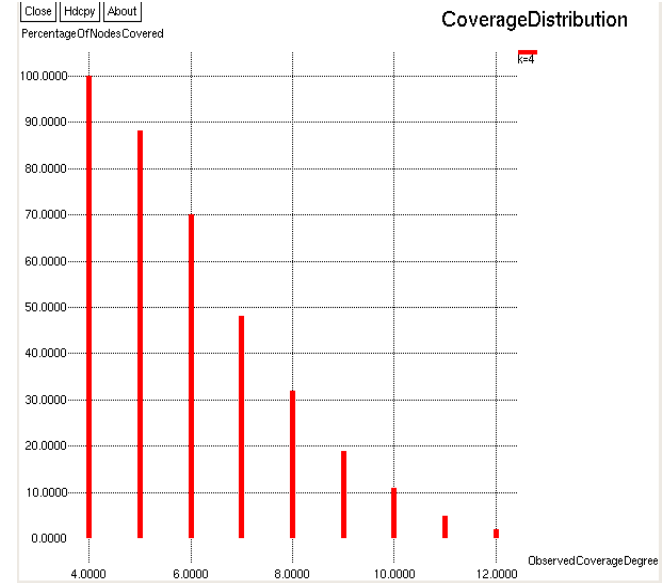


Fig.5 (c) Observed coverage degree VS Percentage of nodes covered graph for Coverage Distribution $\kappa=4$

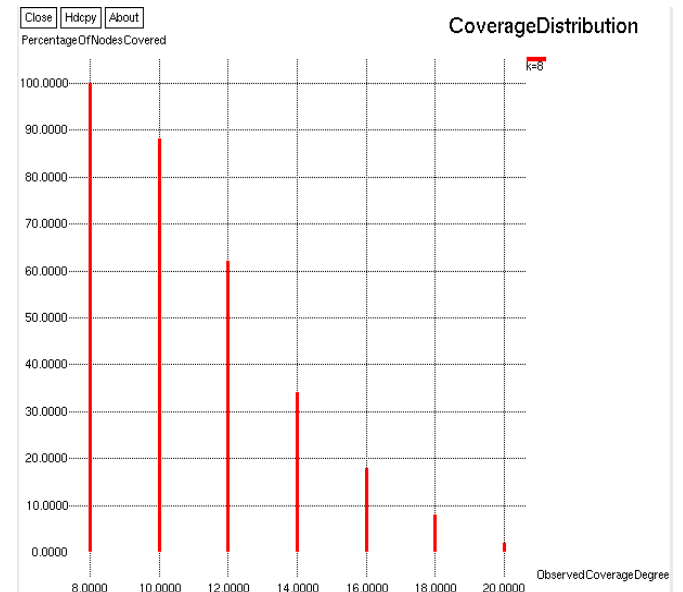


Fig.5 (d) Observed coverage degree VS Percentage of nodes covered graph for Coverage Distribution $\kappa=8$

6. CONCLUSION AND FUTURE WORK

The efficient, distributed, coordinate-free algorithm for verifying κ -coverage of a d -dimensional target field is presented. The simulation results show that the algorithm achieves 100% coverage of the points in the target field. Note that the algorithm implemented in this paper can be used to detect coverage hole if and only if the target field has the coverage hole. In future, the dimension reduction concept can be implemented with the algorithm for reducing the coverage redundancy and interference.

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