p-Percent Coverage in Wireless Sensor Networks

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Outline

Introduction

- Wireless Sensor Networks (WSNs) are now being used in many applications, such as environment and habitat monitoring, traffic control, and *etc*.
- Due to resource constraint of WSNs, it may be unnecessary or impossible to provide full coverage in many applications.
- By applying partial coverage, network lifetime can be prolonged remarkably.
  - Network lifetime can increase by 15% for 99%-coverage and over 20% for 95%-coverage.
- p-Percent Coverage Problem
  - requires that p percentage of the whole area should be covered.
- Connected p-Percent Coverage Problem
  - requires connectivity in addition.

Definitions

Definition

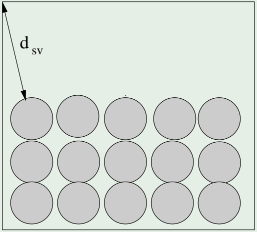
- Consider a point t located at (x_t, y_t). If the Euclid distance between t and sensor s_i is less than or equal to s_i's sensing radius, that is, $distance(t, s_i) \leq r_s$, point t is covered by sensor s_i.
- Consider an area A and a set of sensors $S = s_1, s_2, \cdots, s_n$. If every point in A is covered by at least one sensor in S, we say that area A is covered by S.
- If there is a subset $S' \subseteq S$ such that the area covered by S' is not less than p percentage of the area of A, we call S' is a p percent cover of A. That is, A is p percent covered by S'.
- If the subgraph induced by S' is connected, we call S' is a connected p percent cover of A.

An important metric

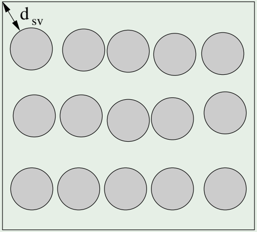
Definition

Sensing Void Distance d_{sv} is the distance between a point in a sensing void and the nearest point covered by an active sensor.

Example



(a) Poor Distribution



(b) Good Distribution

Network Model

- We are mainly interested in static symmetric multi-hop WSNs. The topology of a network is represented as a general undirected graph, denoted as $G(V, E)$, where V is the node set and E is the edge set. That means two nodes u and v are neighbors in the network if and only if u and v can communicate with each other.
- We also assume that the whole area can be at least fully covered by all nodes in the network. In other words, there does not exist sensing void area if all nodes are activated.

Outline

p-Percent Coverage Problem

Definition

p-Percent Coverage problem: Given a two-dimensional monitored region A whose area is $\| A \|$ and a sensor set S containing N sensors, the problem definition is as follows:

Objective: Minimize k

Subject to: W is a p percent cover of A

$k = | W |$

pPCA

Notions:

- C_i: Coverage Increment
- p_s: the percentage specified by application
- e_i: the remaining energy of node i
- ID_i: the ID of node i

Basic Idea

The node with the maximum (e_i, C_i) is added each time

pPCA

Algorithm

Algorithm 1 $pPCA(p_s, S)$

Sort nodes in non-increasing order in S based on their (e_i, ID_i)
$W \leftarrow \phi$ ▷ Constructing p-Percent Coverage Set W
while $p < p_s$ **do**
    if Find a node i with the highest (e_i, C_i) in $S \setminus W$ **then**
        $p \leftarrow p + C_i/A$
        $W \leftarrow W + i$
    else
        return false;
    end if
end while
▷ Optimizing p-Percent Cover W
Sort nodes in non-decreasing order in W based on their (e_i, ID_i)
Remove node i in W if $p > p_s$ after removing i
return W

pPCA

Theorem

The time complexity of pPCA is $O(N^2)$, where N is the number of all the deployed nodes.

Theorem

Denote the obtained set by pPCA as W and the optimal solution as opt. Then $|W| \leq (\ln(p\lambda) + 1)|opt|$, where λ is the number of the points in the whole area.

Proof.

Greedy-Set-Cover is a $(\ln|X| + 1)$-approximation algorithm. □

Outline

Connected p-Percent Coverage Problem

- Network connectivity needs to be guaranteed for routing and data querying.
- Almost all of the algorithms that considered connectivity were based on the assumption that the communication range is at least twice the sensing range.

We claim that communication range is not related to sensing range. This relaxation give our algorithms more flexibility to be used in general WSNs.

Problem Definition

Definition

Connected p-Percent Coverage problem: Given a area A, find a connected p percent cover W of A with minimum size.

Objective:	Minimize k
Subject to:	W is a connected p percent cover of A
	$k = \mid W \mid$

A naive method CpPCA-DFS

A naive method, called *CpPCA-DFS*, is based on the DFS search.

- nodes with maximum C_i will be explored firstly, till p percentage is satisfied.
- this scheme is very simple and efficient.
- the major defect of this scheme is that the distribution of covered area is very poor, in other words the Sensing Void Distance is very large.

We propose a distributed algorithm CpPCA-CDS to solve the *CPC* problem, and guarantee that the sensing void distance is bounded by a constant.

Concept of Connected Dominating Sets

- A CDS is the earliest structure proposed as a candidate for virtual backbones in WSNs.

Definition

For a graph $G(V, E)$, a Dominating Set S of G is defined as a subset of V such that each node in $V \setminus S$ is adjacent to at least one node in S.

Definition

A Connected Dominating Set (CDS) C of G is a dominating set of G which induces a connected subgraph of G.

An example of CDS

Example

- All black nodes form a CDS.
- Messages delived along the CDS.

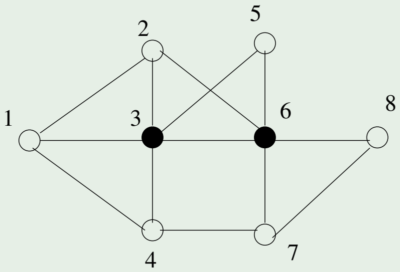


Figure: A 1-CDS example

An example of CDS

Example

- All black nodes form a CDS.
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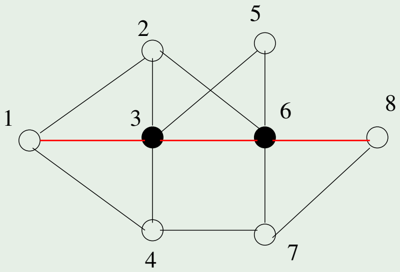


Figure: A 1-CDS example

Connected p-Percent Coverage Algorithm (CpPCA-CDS)

CpPCA-CDS has three phases:

1. Construct a CDS using CDS-BD-D
2. Build a DFS search tree in CDS
3. Add nodes to meet p percent coverage

CpPCA-CDS

Theorem

The set W obtained from CpPCA-CDS is connected and can p-percent cover the whole area.

Proof.

According to the property of a *CDS*, one node which is not in W must have a neighbor in W and W is connected. Therefore, whenever a node is added to W, W keeps connected. □

Theorem

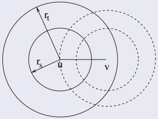
The time complexity of algorithm CpPCA-CDS is $O(|V| + |E|)$ and the message complexity is $O(|V|)$, where $|V|$ is the number of the nodes in the whole network, $|E|$ is the total number of edges.

CpPCA-CDS

Theorem

The Sensing Void Distance after using CpPCA-CDS can be bounded by $|r_{t_{max}} - r_{s_{min}} + r_{s_{max}}|$*, where* $r_{t_{max}}$ *is the maximum transmission range,* $r_{s_{min}}$ *and* $r_{s_{max}}$ *are minimum and maximum sensing range respectively. For a homogeneous network in which every node has the same transmission range and the same sensing range, the sensing void distance can be bounded by* r_t*.*

Proof.



- Assume that point q is in a sensing void area.
- A inactive node v that can cover point q
- Exists a dominator node u which dominates node v

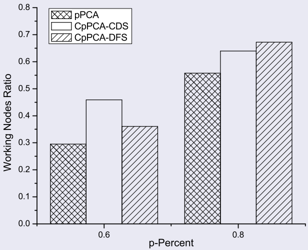
□

Outline

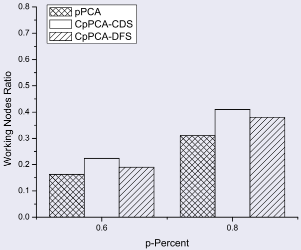
Simulation Results

400 by 400 area. Transmission Range is 100. Sensing Range 50.

Comparison of pPCA, CpPCA-CDS and CpPCA-DFS.



(a) Working Nodes Ratio when $D_{\varphi} = 3$

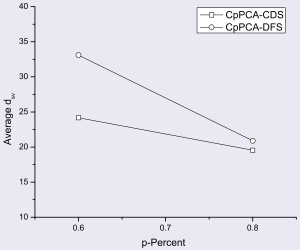


(b) Working Nodes Ratio when $D_{\varphi} = 5$

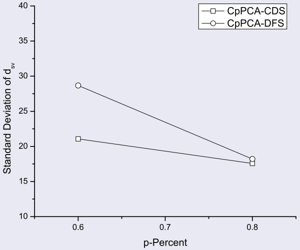
Simulation Results

400 by 400 area. Transmission Range is 100. Sensing Range 50.

Comparison of Sensing Void Distance when $D_\varphi = 5$



(c) Average Sensing Void Distance



(d) Standard Deviation of Sensing Void Distance

Outline

Conclusion

- We investigate p-Percent Coverage Problem (PC) and Connected p-Percent Coverage problem (CPC)
- We propose two distributed algorithms pPCA and CpPCA-CDS to address the PC and CPC problems respectively.
- We introduce the concept of CDS to address CPC problem for the first time.
- The Sensing Void Distance after using CpPCA-CDS can be bounded by a constant.
- Although location is required in most of the work about the partial coverage, it is better to investigate this problem using location-free algorithms.

Q & A

Thank You