Enhancing the Routing Performance of Wireless Sensor Networks using Connected Dominating Sets

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Abstract

Many prominent applications in wireless sensor networks require collected information has to be routed to end nodes in an efficient manner. In general, Connected Dominating Set (CDS) based routing is a promising approach for enhancing the routing efficiency in sensor networks. Our idea is to generate a quality based CDS algorithm, which can resolve the standing issues like cardinality, risk factor, node failures, redundant links and network dynamics. We report a systematic approach, which has three phases. Initial phase considers the issues of revoking a partial CDS tree from a complete CDS tree. Secondary and final phases make the design of the complete algorithm by considering the elimination of dominant-act nodes using an iteration process. Our findings reveal better performance than the existing algorithms in terms of hop count, CDS size and density.

Keywords

Cardinality, dominant-act, dominating set, routing, wireless sensor networks

1. Introduction

Researchers and practicing scientists are finding new avenues for using sensor network in varieties of application areas that include emergency response, disaster relief, monitoring, surveillance, data collection and community wireless networking. Sensor networks consist of one or more base stations and a large number of inexpensive nodes, which combine sensors and low power wireless radios. Due to limited radio range and battery power, most nodes cannot communicate directly with a base station, but rather rely on their peers to forward messages to and from base stations. The task of constructing stable and efficient routing algorithms for wireless sensor networks (WSN) represents greater challenge compared to routing in networks based on a fixed and wired infrastructure. Since there is no fixed infrastructure or centralized management in WSN, virtual backbone has been proposed as the routing infrastructure[1,2]. Here a Connected Dominating Set (CDS) has been proposed to serve as a virtual backbone. CDS based routing is a promising approach for enhancing the routing efficiency in WSN[3]. The virtual backbone should be designed in such a way that the nodes not present in the skeleton are within the transmission range of some nodes in the skeleton.

Routing based on a CDS is a frequently used approach, where the searching space for a route is reduced to nodes in the set. Using only a subset of all nodes for the routing tasks could lead to a more efficient use of resources. The nodes in the subset act as gateways used for routing by the rest of the nodes not in this subset. Therefore we want to distinguish between gateway and non-gateway nodes. For routing, it is beneficial to construct a small size backbone network tend to reduce overhead for access time and update time. Construction of the Minimum Connected Dominating Set (MCDS) is a well-known problem in graph theory. Unfortunately, the dominating set problem has been proved to be NP-hard[4].

In this paper, to keep the virtual backbone as small as possible, our idea is to generate a quality based CDS algorithm, which can resolve the issue of minimizing the cardinality factor. Our findings reveals better performance than the existing algorithms in terms of CDS size, risk factor and density. This paper is organized as follows: section2 overviews the literature review of related works. section3 presents the proposed algorithm on generating small size quality dominating set. Performance evaluation is done in section4 where our algorithm is compared with existing algorithms. We summarize our major results in section5. Finally in section6 we conclude this paper and discuss future work.

2. Literature Review

We can use an unweighted graph G=(V,E) to represent a WSN, where V represents a set of wireless sensor nodes and E represents a set of edges. An edge between host pairs {u,v} indicates that both hosts v and u are within their wireless transmitter ranges. Thus the corresponding graph will be an undirected graph. If two hosts that want to communicate are outside their wireless transmission ranges they could communicate only if other hosts between them are willing to forward packets for them. A subset of nodes $R \subseteq V$ is called dominating set if any vertex in V is either in R or is adjacent to a node in R. A connected dominating set is a dominating set whose induced graph is connected. All known algorithms for constructing CDS, consider the number of nodes (cardinality) as the sole criteria. The smaller the size of a dominating set better is the quality. Minimizing the cardinality of the computed CDS can help to decrease the control overhead and topology update is restricted to a small subset of nodes.

Many works seek a minimum connected dominating set in Unit-Disk Graph (UDG) as their major design goal. The communication range of a node in a wireless sensor network is typically modeled as a disk centered at the node with radius equal to the transmission range of the radio. When transmission range is fixed for all nodes, the network has the property of a unit-disk graph, where an edge exists if and only if two nodes have inter-nodal distance less than or equal to 1 unit[5].Figure.1 shows a UDG.

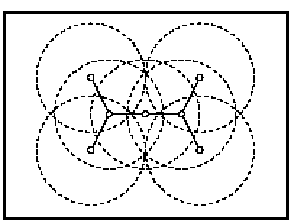

Figure 1. Illustrating UDG

Guha and Khuller (GK) have proposed two centralized approximation algorithms for computing CDS[6]. These algorithms are based on the construction of a spanning tree of the given graph. The first algorithm, referred to as the basic algorithm, begins by construction of the spanning tree by selecting the largest degree node as the root of the partial tree. The tree is grown a few nodes at a time, by selecting the leaf node that maximizes the number of adjacent nodes outside the partial tree. The final connected dominating set is given by removing the leaf nodes from the constructed spanning tree. The basic algorithm can be improved by slightly modifying the scanning rule. A new operation called "scanning a pair of adjacent vertices" is introduced. At each step the algorithm performs and 'ordinary scan' and a 'look-ahead scan'. The scan that has a larger yield is used to grow the tree.

A few distributed algorithms for constructing CDS have been reported [7]. Most distributed algorithms for CDS are theoretically interesting but are difficult for real world implementation. Some distributed algorithms for CDS are, in fact, distributed implementations of the variations of centralized algorithms and have high message complexity overhead [8]. In recent years, a few interesting localized algorithms for CDS have been proposed[9]. One of the first localized algorithms for generating CDS was reported by Wu and Li[9]. This algorithm marks nodes purely on the basis of 1-neighbor and 2-neighbor information. Each node examines the connectivity of its neighbors locally and marks itself as a dominating node if the connectivity information satisfies certain properties. Specifically, a node x marks itself dominating if it has two neighbors u and v which are not directly connected. The dominating set produced by using only the local marking process can have many redundant nodes. Clearly our algorithm named Reduced Size Connected Dominating Set (RS-CDS) is fewer complexes than existing algorithms in particular the size of the dominating set generated.

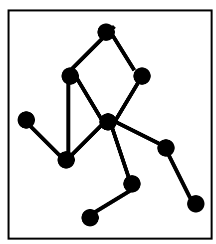

Figure 2. (a)

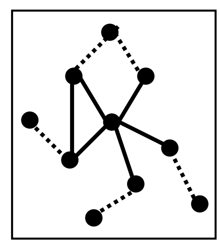

Figure 2. (b)

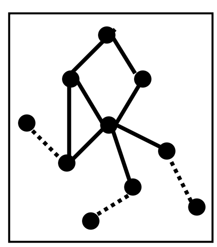

Figure 2. (c)

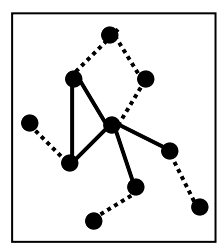

Figure 2. (d)

Figure 2(a) shows a graph representing a WSN. Figure 2(b) shows a dominating set produced by the GK Algorithm[6]. Figure 2(c) shows a dominating set produced by WL Algorithm[9] for the same network. But this network admits a size reduced CDS as shown in Figure 2(d).

3. Algorithm Development

The topology of sensor network can be modeled as a unit disk graph, a geometric graph in which there is an edge between two nodes if and only if their distance is at most one.

Input : Input is Unit Disc Graph G(V,E) representing the sensor network.

Output: A set of nodes $R \subseteq V$ connected as a tree ie cardinality reduced connected dominating set.

Step 1: CDS-Tree construction

- Let $v \in V$ be the largest degree node. Include v to empty tree T.
- For all nodes w adjacent to v, choose largest degree node. Add edge (v ,w) to T.
- If two or more nodes like $w_1, w_2 \ldots, w_n$ has largest degree add edge $(v, w_1), (v, w_2), \ldots (v, w_n)$ to T.
- Repeat the above steps until all the nodes in the graph were present in the tree T.
- After constructing the partial CDS tree remove all leaf nodes present in the tree. Now the tree is called *CDS tree*.

Step 2: CDS-Queue construction

- Queue Q=Null
- Based on the CDS tree construction, classify the nodes in the tree according to the level of the tree.
- From lower level to upper level of tree l_n, $l_{n-1}, \ldots l_0$. Add elements in l_n to Q, until all elements in various levels to Q.

Step 3: Elimination of dominant-act node in CDS tree

After constructing the CDS tree[10], some node is not truly dominant ie they are regular node. To remove those nodes, we give some criteria.

- While there is at least one element in Q {
  - Let w be the element with one unconnected dominant node and one regular node that has maximum degree.
  - Remove the element w from the queue and delete that node from the tree, since the node is considered as regular node.}

Step 4: R is set to non-leaf nodes of T.

To further reduce the size of CDS, we observe that what is more related to the size of CDS is the node degree. According to our proposed algorithm the Step 3 still removes some nodes in CDS. Because they act as dominant node but originally they are the regular nodes.

Lemma 3.1: *The spanning tree T generated from our algorithm represents a connected graph R.*

Proof: Let G be a conneted graph. Let T be a minimal conneted-spanning subgraph of G. Then for any line X of T, T-X is disconnected and hence X is a bridge of T. Hence T is acyclic. Further T is connected and hence is a tree.

4. Performance Evaluation

In this section, we compare our approaches, with GK and WL[9] algorithm. Our comparison was conducted through analytical study and simulation. Simulation for recalculation of connected dominating set in a dynamic network will be part of our future work.

The generated CDS in GK algorithm[6] has high approximation ratio and high implementation complexities (in message and time). In addition it is not clear in their algorithm description how each individual node is informed on when to start the second stage. The CDS maintenance is expensive too, as their approaches need to maintain a spanning tree. There is no performance analysis in the Wu and Li's original paper[9], which incorrectly analyzes the algorithm's time complexity. This algorithm needs at least two-hop neighborhood information. Clearly our approach is less complex than existing algorithm in all measurements, in particular, the number of rounds needed. Note that the numbers of rounds is an important metrics measuring the performance of the algorithm. Our proposed algorithm takes $O(n^2)$ time where n is the number of nodes in the network.

The CDS generated from our approach also reduce the risk factor[11,13].Consider a connected dominating set such that a tree rooted at a given node r, such a tree is used as a backbone network to broadcast messages from the root node r to all other nodes. If one of the nodes (say x) in the CDS tree becomes inactive then all nodes which are reachable only through the node x gets disconnected. Thus a good measure of the risk factor should reflect the extent of the vulnerability of the CDS when some members of the dominating set become inactive. We can illustrate this with an example CDS tree shown in Figure.3 where the CDS tree is drawn with thick black edges. The root node a has 2 children b and c. An inspection of this network shows that the number of nodes, which are reachable only through c is 2 and b is 5.In terms of reachability node b is significant. We can measure the risk factor in terms of the maximum risk or in terms of the average risk associated with the children of the root node. Let cov(x) denote the number of nodes that can be reached only through node x when the CDS tree is used to broadcast message.

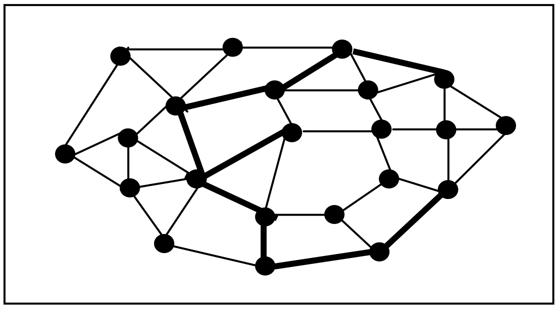

Figure 3. Illustrating Reachability**.**

The maximum risk factor of a CDS tree T, denoted by max-risk(T), is the maximum value of cov(x) when x is any child of root node r.ie.

max-risk(T)=max {cov(x)/x is a child of r}

The average risk factor of a CDS tree T, denoted by avg-risk(T) is the average value of cov(x) where x is a child of root node r ie

avg-risk(T)=(1/m)Σcov(x)

Where m denotes the number of children of root node r. In the example CDS tree shown in Fig.3, the value of max-risk(T) is 5 and the value of avg-risk(T) is 3.5.

5. Experimental Results

In order to test the performance of the proposed algorithm we implemented them for experimental investigation. The algorithms considered for the experimental investigation are (i) GK algorithm (ii) WL algorithm (iii) Sprinkler (iv) Reduced Size Connected Dominating Set (RS-CDS). All implementation have been done in the JAVA programming language.

Table 1. CDS Size obtained by various algorithms

Node Density	GK	WL	Sprinkler	RSCDS
2	1.2	6.6	6	1
3	2.6	9.8	8.8	1.5
5	5.2	15.6	15.2	3.2
10	5	27.2	23.6	4
15	4.4	36.2	32.6	3.5
20	4.4	41.4	37.6	3.5
25	4.4	53.4	46.4	3.6
30	3.8	55	48.6	3
35	4.8	69.6	63	4.1
40	4.4	69.4	60.6	4
45	4	86.4	77	3.8
50	3.6	79.8	68.4	3.2

Several connected dominating sets were constructed by executing these algorithms on various randomly generated connected networks. The Unit disc graphs induced by randomly generated nodes were taken as the input connected sensor network. The nodes were generated by randomly picking x and y coordinates in the range 20-650. These randomly generated coordinates were used to place nodes in the canvas of pixel size approximately 700 by 600. Ten UDGs were randomly generated for a given values of node density (number of nodes per unit area). For each randomly generated UDG, CDSs were constructed by using the proposed algorithms. For comparison and reference, CDS were also generated by using the well-known Sprinkler algorithm[12]. Values for size of the CDS, average risk factor were measured.

Table 2. Average risk factor obtained by various algorithms

Node Density	GK	WL	Sprinkler	RSCDS
2	3.4	4	8	3
3	5.6	6	13	5.2
5	10.6	10.8	22.4	7.2
10	10.8	11.6	40.2	8.4
15	11	12.8	52.2	9
20	11.4	13.4	64	9.5
25	11.4	13.2	68	9.5
30	11.8	14	81	9.8
35	12.2	13.8	105	10.2
40	12.2	13.8	108.4	10.2
45	12.3	14.2	114.8	10.2
50	12.4	13.6	117.2	10.3

Tables 1 and 2 show the values of Cardinality, Risk factor for node densities. The relationship between node density and CDS parameters such as size, risk factor are plotted and shown in figure 4 and 5

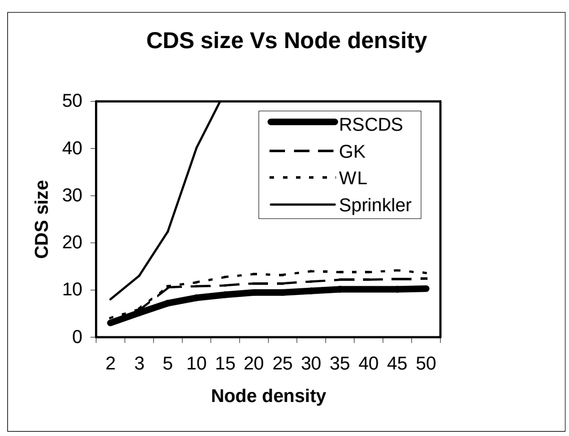

Figure 4. CDS size vs Node density

respectively. An inspection of these plots shows that the proposed algorithms are very effective in generating CDS with reduced size and risk factor.

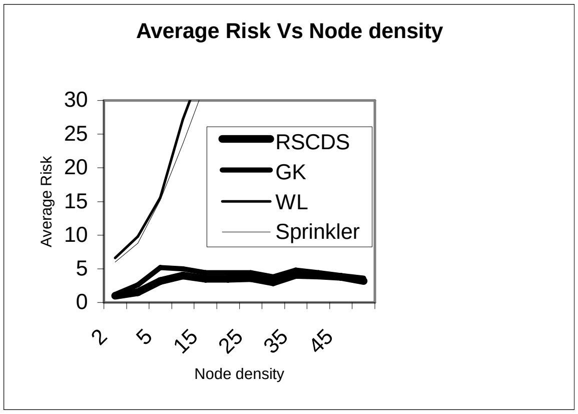

Figure 5. Average Risk vs Node density

6. Conclusion

We presented an overview of existing algorithms for constructing connected dominating sets. We proposed an algorithm named Reduced Size Connected Dominating Size (RSCDS) to generate better quality connected dominating sets for sensor networks. We also presented several experimental results by implementing the proposed algorithm in the java programming language. Finally the results are consolidated effectively to compare various algorithms. These results show that the proposed techniques are effective in generating connected dominating sets of reduced cardinality and reduced risk factor.

Node mobility is not considered. In real situations, nodes may change their position with time. Nodes may also become inactive after a certain time and vice versa. The proposed algorithm does not generate a smaller connected dominating set when the nodes transmission radius is large. At the current stage, our investigation does not include the movement of sensor nodes, since the paper focuses only on determining a MCDS from a WSN. The future work will extend the proposed algorithm to the WSN in which each node has different transmission radius. We need to verify the effectiveness of our approach when the topology of the underlying networks changes.

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