Connected Dominating Set Construction Algorithm for Wireless Sensor Networks – A Survey

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Abstract— Energy efficiency plays an important role in wireless sensor networks. All nodes in sensor networks are energy constrained. Clustering is one kind of energy efficient algorithm. To organize the nodes in better way a virtual backbone can be used. There is no physical backbone infrastructure, but a virtual backbone can be formed by constructing a Connected Dominating Set (CDS). CDS has a significant impact on an energy efficient design of routing algorithms in WSN. CDS should first and foremost be small. It should have robustness to node failures. In this paper, we present a general classification of CDS construction algorithms. This survey gives different CDS formation algorithms for WSNs.
***Keywords**:* Wireless Sensor Networks, Connected Dominating Set, Construction Algorithms

I. INTRODUCTION

Sensors are used to examine and control the physical environment. A Wireless Sensor Networks (WSN) consists of large number of sensor nodes that are deployed densely. Sensor nodes compute various parameters of an environment and transmit the collected data to the sink by means of hop by hop communication. The sink progresses the sensed data and forwards it to the users. The applications of WSN have significantly increased over many areas such as biomedical and healthcare applications, habitat monitoring, and defense, etc. [11] Energy management in WSNs is an important issue. Energy conservation is one of the most active research fields in WSN. This problem is focused on how we can prolong the lifetime of wireless sensor network and also how to improve reliability of the link. [13]

The lifetime elongation and network management are the most considered issues in WSN. Connected Dominating Set (CDS) is known to be an efficient strategy to reduce overhead, control network topology, and extend network lifetime. The CDS backbone increases the bandwidth efficiency and decreases the overall energy consumption. [7] Backbone will remove unnecessary transmission links through shutting down some of redundant nodes. CDS backbone will guarantee network connectivity in order to provide efficient data delivery in WSN. In virtual backbone WSNs, some nodes are selected as dominator node (backbone node) in the CDS construction process.

A backbone is a subset of nodes that are able to perform special tasks and also it serve nodes which are not in the backbone. Therefore the backbone construction depends on the task to be carried. In WSNs, a backbone (CDS) could be the set of active sensors and the rest of the sensors are tends to sleep state. The backbone of a network is required to be connected, so that the backbone nodes are able to communicate to perform special tasks. Efficient routing and broadcasting can performed through the connected backbone.

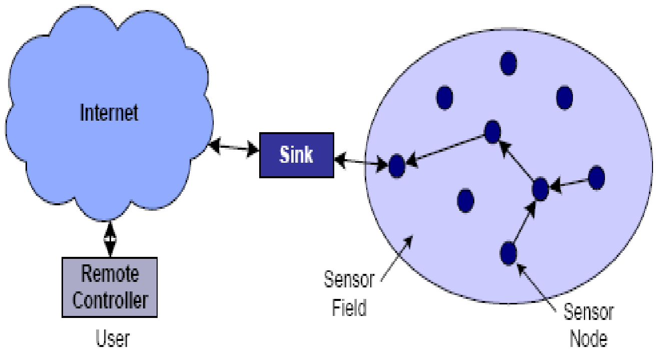

Fig.1: Sensor Network Architecture

The nodes which are present in the CDS are called dominator (backbone node) and other nodes are called dominatee (non-backbone node). With the help of CDS, routing is easier and can adapt quickly to network topology changes. It is desirable to construct a minimum CDS in order to reduce the traffic during communication.[7] Constructing a CDS algorithm for WSNs is very challenging task. This paper gives a review on connected dominating set construction techniques for wireless sensor networks.

II. CDS CONSTRUCTION ALGORITHMS

A. *Dominating Set*

Consider G = (V, E) is a subset D of V such that every vertex not in D is joined to at least one member of D by some edge.

B. *Connected Dominating Set*

In a given graph, subset of nodes such that it forms a dominating set in the graph and the sub graph induced is connected. It involves two properties,

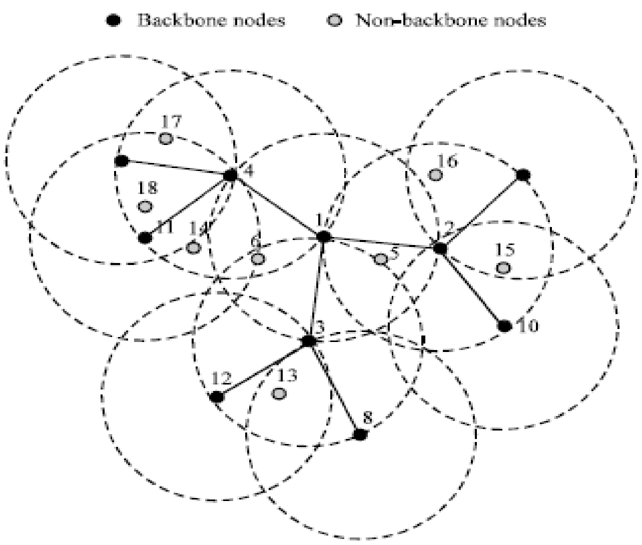

Fig. 2: CDS Construction Schematic Diagram

(1) Any node in D can reach any other node in D by a path that stays entirely within D. That is, D induces a connected sub graph of G.
(2) Every vertex in G either belongs to D or is adjacent to a vertex in D. It implies that D is a dominating set of G.

III. CLASSIFICATION OF CDS CONSTRUCTION ALGORITHMS

A. CDS Construction Algorithms

According to different aspects, CDS construction algorithms can be classified into different types. Some of the classifications are described below.

B. UDG and DGB

The CDS construction algorithm can be classified into two types. They are Unit Disk Graph (UDG) based algorithms and Disk Graphs with Bidirectional links (DGB). The link between any pair of nodes is bidirectional in both UDG and DGB. In UDG, nodes transmission ranges are same, but in DGB nodes transmission ranges are different. [2][6][7][8]

C. MIS Based and Non-MIS Based

Independent set (IS) of a graph G is a subset of vertices so that no two vertices are adjacent i the subset. Maximal Independent Set is an IS, so that it is not a subset of any other IS. In an undirected graph an MIS is also a Dominating Set (DS). The selection of optimal nodes is based on some criteria such as node degree, residual energy, and node id, etc. [4][7][9][10]

D. Centralized Algorithms and Decentralized Algorithms

CDS construction algorithms can be divided into two types. They are centralized algorithms and decentralized algorithms. The centralized algorithms result in a smaller CDS with a better performance ratio when compared with decentralized algorithms. The decentralized algorithms are further divided into two types. They are distributed algorithms and localized algorithms. The decision process is decentralized in distributed algorithms. In localized algorithms, the decision process is not only distributed and also it requires only a constant number of communication rounds. [3][4][5][9][10]

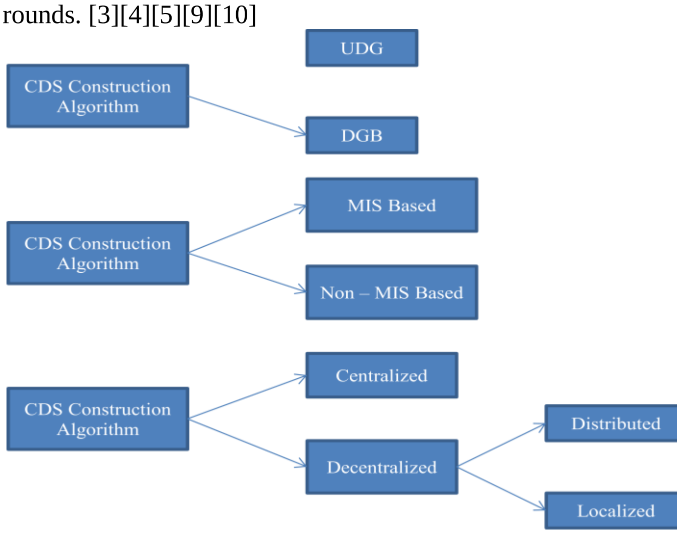

Fig. 3: Classification of CDS Construction Algorithms

E. Pruning Based Algorithms

To reduce the redundant nodes of backbone some algorithms use pruning rules. In these algorithms for creating CDS, all nodes in the network are to be considered as backbone nodes. Then the redundant nodes are pruned to create minimum CDS. [2][7][10]

IV. EXAMPLES OF CDS CONSTRUCTION ALGORITHM

Guha et al. [5] proposed two CDS construction algorithms. First algorithm begins through marking all vertices white. Initially the algorithm selects the node with the maximum number of white neighbors. The selected vertex is marked black and its neighbours are marked gray. The algorithm iteratively seeks the gray node or the pair of nodes, whichever has the maximum number of white neighbors. The selected node or the selected pair of nodes is marked black, also their white neighbours marked gray. The algorithm terminates, when all of the vertices are marked gray or black. Finally all black nodes form a CDS.

Second algorithm begins through coloring all nodes white. A piece is defined to be either a connected black component, or a white node. This algorithm includes two phases. The first phase iteratively selects a node that yield the maximum reduction of the number of pieces. A node is marked black and its white neighbors are marked gray, when it is selected. The first phase terminates when no white node left. A steiner tree is constructed to connect all black nodes through coloring chains of two gray and black nodes.

Das et al. [4] proposed two CDS construction algorithms. In first algorithm one node with maximum degree can form a CDS. In the graph a node must know the degree of all nodes. Each step selects either a one-or-two edged path from the current CDS. Then the nodes in the CDS should know the number of unmarked neighbors for all nodes one and two hops from CDS.

In the second algorithm, they compute a Dominating Set (DS) and select additional nodes to connect the set. An unmarked node compares its effective degree, with the effective degrees of all its neighbors in two-hop neighbourhood. When a DS is achieved, the first phase terminates. In the second phase, a distributed minimum spanning tree algorithm is used to connect the components.

Alzoubi et al. [3] provided a distributed leader selection algorithm to construct a rooted spanning tree. A labeling strategy is used to divide the nodes in the tree to be either gray or black, according to their ranks. The rank of a node is the arranged pair of its level and its id. The labeling process begins from the root node and finishes at the leaves. At first, the node with the lowest rank marks itself black and broadcasts a DOMINATOR message. The marking process continues based on the following rules:

– If the node receives a DOMINATOR message as first message, then it marks itself gray and broadcasts a DOMINATEE message.
– If DOMINATEE messages are received by a node from all its lower rank neighbors, it marks itself black and sends a DOMINATOR message.

The marking process finishes when it reaches the leaf nodes. Then the set of black nodes form an MIS. In the final phase the nodes connect in the MIS to form a CDS through INVITE and JOIN messages.

Acharya et al. [1] proposed a distributed algorithm “Energy-Aware Virtual Backbone Tree” (EVBT) for constructing a backbone in WSN. This algorithm chooses only nodes with enough energy levels as the member of the virtual backbone. Also, it uses a concept of threshold energy level for members of virtual backbone. According to this concept, only nodes with energy levels above a predefined threshold are included in the EVBT. An undirected graph is used to represent a WSN. A sensor that does not belong to the backbone is termed as *leaf node*. Every node in the network has an EVBT node. The EVBT node is denoted as dominator of the corresponding leaf node.

Li et al. [6] proposed an algorithm for constructing CDS. The algorithm is called as Approximation Two Independent Sets based Algorithm (ATISA). The ATISA has three phases: (1) constructing a connected set (CS) (2) constructing a CDS (3) pruning the redundant dominators of CDS. ATISA constructs the smallest size CDS compared with some well-known CDS construction algorithms. The ATISA can be implemented in two ways: centralized and distributed. The centralized algorithm consists of three phases, which are CS construction phase, CDS construction phase, and pruning phase.

In the centralized algorithm, the initial node is selected randomly. Then the algorithm executed several rounds. No black nodes are generated in the network when the first phase is ended. The generated black node set is formed a CS. If a white node has black neighbors then, it will select its dominator the black neighbor with the minimum id and it change its color into gray. If a white node only has the gray neighbors then, the white node will send an invite message to the gray neighbor with the minimum id and it change its color into gray.

In the second phase, constructs a CDS and all the nodes are either black or gray. Finally, there is no white node left in the network. According to the final phase, if a black node with no children and if the neighbors of the black node are all adjacent to at least two black nodes, then the black node is joined into connected set.

In the distributed implementation, initially all nodes are white. At the end of first phase, there are white nodes, gray nodes, and black nodes. In the second phase, there are black nodes, gray nodes and there may be white nodes. Gray nodes can change their states into black and also white nodes can change their states into gray. In the final phase, the redundant black nodes are deleted.

Stojmenovic et al. [15] proposed three synchronized distributed CDS construction algorithms. In all these algorithms, the CDS includes of two kinds of nodes: the border-nodes and the cluster-heads. The cluster-heads form a minimum independent set. If a node is not a cluster-head but there are at least two cluster-heads within its 2-hop neighborhood, then it is a border-node. The set of cluster-heads is selected based on three rankings such as: the id only, an ordered pair of degree and id, and an order pair of degree and location.

The selection of the cluster-heads is given by means of a synchronized distributed algorithm. At first all nodes are colored white. In each stage of the synchronized distributed algorithm, all white nodes which have the lowest rank among all white neighbors are colored black. Then all adjacent white nodes to these black nodes are colored gray. Finally, the ranks of the white nodes are updated. The algorithm ends, after all nodes are colored either black or gray.

V. CONCLUSION

The effective construction of CDS has proven that it solve a variety of problems that arise in WSNs. In this paper, we classified CDS formation algorithms and a few examples of these classifications. Also, we have surveyed some backbone formation algorithms. A backbone increases the bandwidth efficiency, reduces the communication overhead, decreases the overall energy consumption, and finally increases network effective lifetime in a WSNs.

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