A Survey of Connected Dominating Set Algorithms for Virtual Backbone Construction in Ad Hoc Networks

P. S. Vinayagam
Assistant Professor,
Department of Computer Science,
Pondicherry University
Community College,
Puducherry, India

ABSTRACT
Ad hoc networks lack pre-designated routers and physical infrastructure, which makes routing in these networks a challenging task. To overcome the problems associated with this, virtual backbone has been proposed as the routing infrastructure of ad hoc networks. A well-known and well researched approach for constructing virtual backbone is Connected Dominating Set (CDS). It overcomes the broadcast storm problem and facilitates routing. In this paper, the focus is on the various CDS construction algorithms that have been put forth in the literature. A comparison of the major works relating to CDS construction is provided, emphasizing the type of algorithm, technique employed, performance metric used and the outcome achieved.

General Terms
Virtual backbone construction

Keywords
Ad hoc network, Connected Dominating Set, Virtual backbone

1. INTRODUCTION
An ad hoc network is a computer network with wireless communication links where each node has the capacity to forward the data to other nodes. The decision for determining which nodes are to forward the data and to whom are made dynamically based on the connectivity in the concerned network [1]. In ad hoc networks, if two hosts which are within the communication range of each other want to communicate, then there is no need for a real routing protocol. Whereas, if two hosts that are not within the communication range of each other want to communicate, then communication is possible only through other nodes that are between the two said nodes in the network. Also, the intermediate nodes should be willing to forward packets for the other nodes [2]. For example, consider the ad hoc network shown in figure 1 [2].

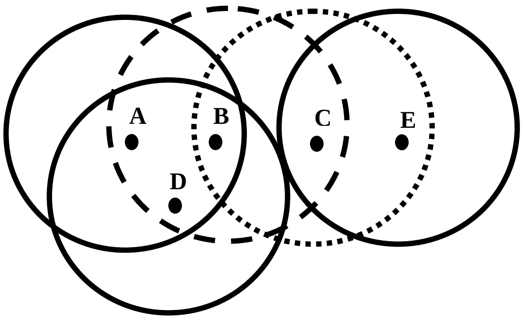

Fig 1. A simple ad hoc wireless network

In Figure 1, host B is within the communication range of hosts A, C and D and hence can directly communicate with these hosts. Host B does not require the cooperation of other hosts to communicate with A, C or D. But, when host B wants to communicate with E, some intermediate host is needed, as host B and E are outside the range of each other's wireless transmitter. Host B may use host C to forward packets to host E, as host C falls within the overlapping transmission range of both host B and E.

Hence, the cooperation of the participating nodes is essential for these networks to function. The nodes in ad hoc networks, however, have limited resources. Also, the lack of pre-designated routers and non-availability of physical infrastructure makes routing in ad hoc networks a challenging task. A possible solution to take care of routing in ad hoc networks is flooding of messages. But flooding of control messages results in contentions and collisions. This is referred to as the broadcast storm problem. Therefore, to facilitate routing in ad hoc networks, some sort of backbone like structure needs to be built. For this, virtual backbone has been proposed, in the literature, as the routing infrastructure of ad hoc networks.

The concept of virtual backbone was first proposed in [3]. Conceptually, a virtual backbone is a set of nodes that can help with routing [4]. A node in a wireless network employing the virtual backbone can either be a backbone node or a non-backbone node. Any non-backbone node has to be adjacent to at least one backbone node. Moreover, the set of backbone nodes need to be connected. Then, the routing path search space for each message is reduced from the whole network to the set of backbone nodes [5].

Virtual backbone provides various benefits. The number of routing-related control messages can be reduced and the amount of wireless signal collision and interference can be decreased, as only the nodes in the virtual backbone will be involved in message routing. As a result, the routing protocol will work much faster and efficiently [6]. By limiting the number of nodes involved in message routing, less nodes need to maintain routing information [5]. The backbone structure can efficiently support unicasting, multicasting and fault-tolerant routing. A network can react quickly to topology changes [4]. More importantly, virtual backbone plays a significant role in saving energy which is usually the first priority for wireless networks [7].

A well-known approach for constructing a virtual backbone in wireless networks is Connected Dominating Set (CDS) [8]. A subset of the nodes of a graph is a dominating set if every node that is not in the subset is adjacent to at least one node in the subset. A dominating set is connected if there exists a path between any two nodes in the set and the path only consists of the nodes in the set. Thus, a CDS is a dominating set that is connected [9].

In this paper, the focus is on the various CDS construction algorithms that have been proposed in the literature for constructing virtual backbone. The rest of the paper is organized as follows. The concept of CDS is discussed in section 2. Section 3 discusses the classification of CDS algorithms. Section 4 elaborates the various algorithms proposed in the literature pertaining to construction of CDS. Section 5 concludes the paper.

2. CONNECTED DOMINATING SET (CDS)

One of the well-known and well researched concepts used to construct virtual backbone in ad hoc networks is CDS. It helps to overcome the broadcast storm problem and facilitates routing [7].

2.1 Definitions

The definitions relating to the concept of CDS are discussed in this section.

(a) Maximal Independent Set (MIS)

An Independent Set (IS) is a set of nodes which are not adjacent to each other [5]. An independent set of graph G = (V,E) is a subset S ⊂ V such that for any pair of vertices in S, there is no edge between them [10]. In other words, an independent set S of G is a subset of V such that for ∀ u,v ∈ S, (u,v) ∉ E [11].

An Independent Set S of G is a Maximal Independent Set (MIS) of G if we add any node from G\S to S, S is not an independent set anymore [5]. In simple words, an MIS is an IS such that adding any node not in the set breaks the independence property of the set [12]. Each node which is not in the MIS is adjacent to at least one node in the MIS [13].

(b) Dominating Set

Given a graph G = (V,E), a Dominating Set (DS) of G is a subset C ⊂ V such that each node either belongs to C or is adjacent to at least one node in C [7]. In other words, a Dominating Set of a graph G = (V,E) is a set of nodes V′ such that ∀(v,w) ∈ E, v ∈ V′ or w ∈ V′ [4]. A Vertex Cover refers to a set of vertices that cover all the edges, whereas a Dominating Set refers to a set of vertices that cover all the vertices.

(c) Connected Dominating Set (CDS)

A Dominating Set is connected if there exist a path between any two nodes in the set and the path only consists of the nodes in the set [9]. A Connected Dominating Set of G = (V,E) is a Dominating Set of G such that the subgraph of G induced by the nodes in this set is connected. The nodes in a CDS are called the dominators. The nodes other than the dominators are called the dominatees. The size of a CDS is equal to the number of dominators [4]. Each dominatee is dominated by a dominator [14]. In the CDS C, the nodes in C can communicate with any other node in the same set without using nodes in V – C [15].

A maximal independent set is a dominating set. If we connect the nodes in an MIS, it forms a CDS [13]. However, since nodes in a dominating set may be adjacent to each other, not every dominating set is an MIS [16].

(d) Minimum Connected Dominating Set (MCDS)

Among all CDSs of graph G, the one with minimum cardinality is called a Minimum Connected Dominating Set (MCDS) [17]. The problem of constructing a MCDS is NP-hard [18].

In CDS based routing, the dominator nodes alone maintain the routing information. A dominatee node in order to send a message to another dominatee, will send it to its dominator. Then the search space for the route is reduced to only within the CDS. When the message reaches the destination's dominator, the message is delivered to the destination via the said dominator [13].

2.2 Real-life Example

Figure 2 [19] depicts a real-life example of dominating set concept by defining a school bus route within a school district. In the figure, black nodes are the dominators and the white nodes are the dominatees. A bus route is defined based on certain rules. One such rule may be that no student shall have to walk farther than half a mile to a bus pickup point. In addition, the route is connected. It is desirable that the length of the route be as short as possible [19].

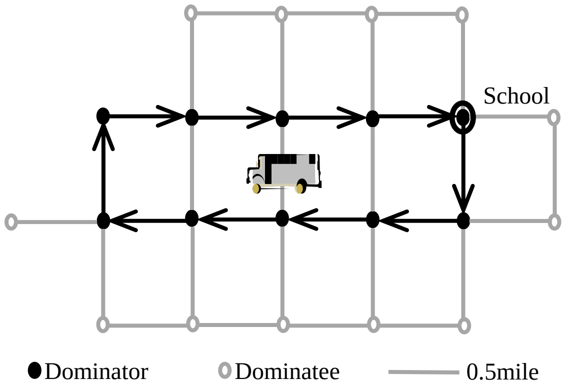

Fig 2. Real-life example of Dominating Set

2.3 Properties of CDS

The properties of a good CDS protocol are discussed below:

(a) The resulting CDS should be as small as possible [20]

Size of the CDS plays an important role in measuring the quality of the CDS. In wireless networks, the communication channel is shared among each node and its neighbours. A smaller virtual backbone results in lesser interference. Authors in [4] state that smaller CDS performs more efficiently in routing, reduces the number of control messages and also makes the maintenance of the virtual backbone easier. Further, smaller CDS incur less communication and storage overhead [21]. Therefore, the size of the CDS needs to be as small as possible.

(b) The CDS protocol should take into account the energy level of each node [20]

Another important property of a CDS is the energy level of the nodes in the CDS, which decides the lifespan of the CDS. In routing and collision avoidance protocols, CDS nodes forward packets and contribute to traffic management of the network. Thereby, the CDS nodes use more energy than the non-CDS nodes. The energy consumption should be evenly distributed to all the nodes in the network by the CDS protocol. This way, the network will be operational for longer periods of time.

(c) The protocol should avoid introducing extra messages

Bandwidth is a precious resource in wireless networks. The CDS protocol should avoid introducing extra messages. Extra messages usually result in performance degradation of the system [20].

(d) The protocol should adapt to topology changes

The network topology keeps on changing in ad hoc networks. As authors in [22] state, a good CDS construction protocol should maintain a CDS in order to save the network resource, rather than reconstructing the whole set from scratch every time the network topology is changed. In addition, authors in [20] opine that the protocol should maintain and incrementally adjust the CDS when network topology changes, because of nodes either leaving or joining the network after the construction of CDS.

2.4 Advantages of CDS

Some of the advantages of CDS based routing protocols are:

- CDS is useful in routing, broadcast and collision avoidance [22]
- CDS based routing reduces the path-searching and routing process to the subnetwork induced from the CDS. Only dominators need to maintain routing information [9]
- Efficiency of multicast routing can be improved through CDS [12]
- Restricting the routing to the CDS reduces the message overhead associated with routing updates. CDS has formed an underlying architecture used by protocols including media access coordination, unicast, multicast/broadcast, and location-based routing, energy conservation, and topology control [16]
- Energy consumption, a critical concern in wireless networks, can be reduced by using CDS as forwarding nodes [8]
- Virtual backbone formed by dominating set can propagate link quality information for route selection for multimedia traffic and can serve as database servers [16]

3. CLASSIFICATION OF CDS CONSTRUCTION ALGORITHMS

CDS construction algorithms can be divided into two categories as shown in Figure 3 [12]:

(a) Centralized algorithms

(b) Decentralized algorithms

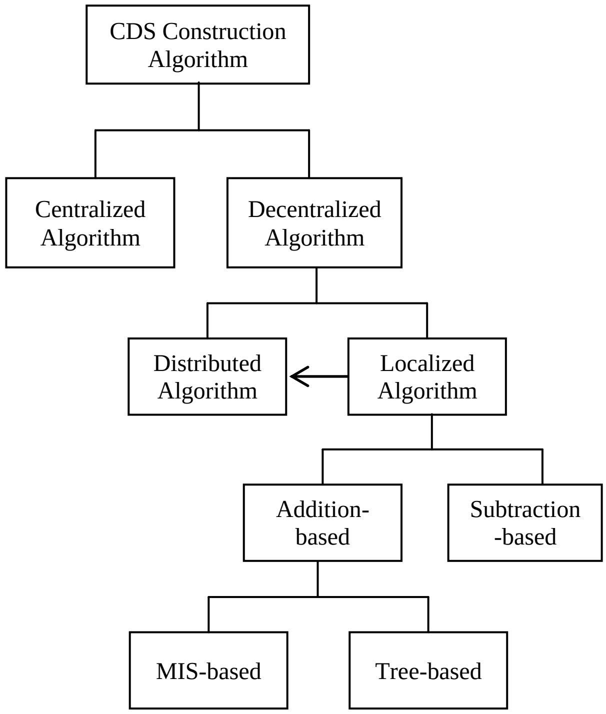

Fig 3. Classification of CDS construction algorithms

(a) Centralized algorithms

Knowledge about the network-wide information is essential for centralized algorithms. As compared to decentralized ones, centralized algorithms give a smaller size CDS. These algorithms assume that the complete network topology information is available, which is usually not practical in the case of mobile wireless networks. Moreover it is not always feasible to control the nodes in wireless networks from a centralized authority.

(b) Decentralized algorithms

In the case of decentralized algorithms, local network information is essential. These algorithms can be further categorized as [12]:

(i) Distributed algorithms

(ii) Localized algorithms

In distributed algorithms, the decision process is decentralized. In the case of localized algorithms, the decision process is distributed with the additional requirement of a constant number of communication rounds [4]. Localized CDS algorithms are further divided into two types [12]:

- Addition-based CDS construction
- Subtraction-based CDS construction

Addition-based CDS construction

The initial subset of nodes chosen by addition-based CDS algorithms is usually disconnected. These algorithms then add additional nodes to form the CDS. Depending on the type of the initial subset, these algorithms can be classified into two types: MIS-based CDS algorithms and Tree-based CDS algorithms [12].

MIS-based CDS algorithms: MIS-based CDS algorithms are two-stage algorithms. These algorithms form the CDS by connecting an MIS. In the first stage, the MIS of the network topology is constructed distributedly. The nodes with the most number of neighbours locally are selected. These selected MIS nodes form the skeleton of the CDS. In the second stage, in order to connect the nodes in the MIS, additional nodes are added by employing a localized search. Thereby the CDS is formed.

Tree-based CDS algorithms: In these types of algorithms, a subset of nodes called initiators is first chosen. Then from each of these initiators, a CDS tree is constructed. These algorithms work in three phases. In the first phase, a number of initiators are elected from the given network. Then using the timer, each initiator grows a tree so that the nodes with more number of neighbours are added to the tree. In the third phase, the previously generated neighbouring trees are connected by utilizing additional bridge nodes.

Subtraction-based CDS construction

These algorithms start with the set of all nodes in the network. Then, nodes are systematically removed in order to form the CDS. As compared to subtraction-based CDS construction algorithms, addition-based algorithms produce smaller size CDS [12].

4. CDS CONSTRUCTION ALGORITHMS: A SURVEY

Connected Dominating Set (CDS) has been widely used in the literature for constructing virtual backbone in ad hoc networks. The concept of virtual backbone was first proposed in [3]. Later, authors in [23] proposed two approximation algorithms for the CDS construction. The first one is a greedy algorithm, for which efficient implementation is also provided. The second one is the improvement of the first algorithm. It involves finding a dominating set in the first phase and connecting the dominating set in the second phase.

For efficient routing in ad hoc networks, authors in [24] present a self-organizing, dynamic infrastructure called a spine. The authors approximate an MCDS for use as the spine. Only partial topology information at each spine node is needed by the algorithm. The proposed spine based routing is shown to yield good routes with low overhead.

A distributed algorithm to construct CDS in ad hoc wireless networks is proposed in [2]. The authors employ a marking process, where all the vertices are unmarked initially. Then, through the marking process, every vertex is either marked or unmarked. All the marked vertices then form a CDS. The authors have proposed two rules which are used to further reduce the size of the CDS.

Authors in [25] apply the concept of localized dominating sets to reduce the communication overhead of a broadcasting task. To improve existing dominating sets, the authors use node degrees instead of their IDs as primary keys. The authors state that dominating set based broadcasting, enhanced by neighbour elimination scheme and highest degree key, yields reliable broadcast.

Two distributed heuristics for constructing CDS are provided in [26]. Both the algorithms need only single-hop neighbourhood information. The first one is the ID-Based algorithm, where information about own ID and IDs of all neighbours is maintained by each node. In the second algorithm known as the Level-Based algorithm, each node maintains information about its own ID and level, along with the IDs and levels of all its neighbours.

Authors in [27] provide a method of constructing power-aware CDS. It is based on a dynamic selection process, where a node with higher energy level is given preference. CDS is selected considering the node degree and the energy level. Authors in [17] focused on constructing virtual backbone for ad hoc wireless networks and put forth a distributed algorithm to construct CDS with smaller size. There are two phases in the algorithm proposed by them. A maximal independent set (MIS) is built in the first phase and then Steiner tree is used to connect all vertices in the set.

The first message-optimal distributed approximation algorithm for constructing MCDS is presented in [28]. It is a fully localized algorithm, wherein each node requires the knowledge of single hop neighbours and a constant number of 2-hop and 3-hop neighbours alone. There are two phases in the algorithm. In the first phase, the MIS is constructed. The second phase comprises of connecting each dominator to all dominators within three-hop distance. The dominators and the connector nodes together form the CDS.

Authors in [29] provide distributed algorithm to construct CDS, which consists of two phases. In the first phase, MIS is constructed and in the second phase, a dominating tree is constructed, whose internal nodes become a CDS. The algorithm is shown to be message optimal.

A completely localized one-phase distributed algorithm, r-CDS, for constructing CDS is proposed in [13]. It uses MIS for constructing CDS and each node requires only the knowledge of connectivity information within its 2-hop neighbourhood. The proposed algorithm is found to construct a CDS with smaller size.

A one-step greedy approximation for Minimum Connected Dominating Sets (MCDS) is provided in [30]. A distributed algorithm to construct MCDS for wireless ad hoc networks is proposed in [15]. The proposed algorithm is based on MIS and is fully localized. Knowledge of 1-hop neighbours alone is needed by every node. The authors show that the algorithm performs better with respect to MCDS size.

Authors in [31] propose CDS construction algorithms that provide diameter reduced, risk reduced and interference aware dominating sets, without increasing CDS size. They report that, while constructing CDS, other quality issues of dominating sets should also be considered, along with considering the number of nodes as the criteria.

A distributed algorithm for constructing CDS is provided in [32]. The authors present an improved analysis of the relationship between the size of a MIS and a minimum CDS. Authors in [20] propose Timer-based Energy aware Connected Dominating Set (TECDS) protocols. There are two phases in TECDS: initiator election and CDS construction. Energy level at each node is considered during CDS construction. The authors state that the proposed protocols yield smaller CDS size and extend network lifetime.

Authors in [33] present distributed CDS construction algorithm that efficiently reduces the CDS size and the computation complexity at the same time. Constructing a virtual backbone for ad hoc wireless networks is examined in [11]. The authors provide two distributed message/time efficient algorithms to construct a minimum CDS. The first one grows a tree from a unique leader, while the second one is initiated by multiple locally elected leaders. Authors in [14] present a self-stabilizing distributed approximation algorithm to construct MCDS.

Algorithms to construct quality CDS in terms of size, diameter and Average Backbone Path Length (ABPL) is provided in [4]. Two centralized CDS construction algorithms, viz., CDS-BD-C1 and CDS-BD-C2, and a distributed algorithm, CDS-BD-D, which is a distributed version of the second centralized algorithm, are proposed. The algorithms consider energy to extend network lifetime. A Breadth First Search (BFS) tree is built and then an MIS based on the BFS tree is found. Then the MIS nodes are connected to form the CDS. The algorithm proves to be efficient in formation of a virtual backbone when compared to other previous works.

A distributed algorithm to form a stable CDS is proposed in [9]. The algorithm is a link-stability-based CDS-forming algorithm, which forms a CDS by keeping a node with many weak links from being selected as a member of CDS. The criteria used in the algorithm are: less number of danger links, lower average received power strength and smaller node identifier.

Authors in [34] provide a distributed local algorithm to compute CDS. The nodes are assumed to have information about their locations. In order to make decisions locally, the authors use a sort of ordering, which ensures that the decisions made by a node only depend on the nodes within a certain distance. When local computation of the CDS is done, each node that belongs to the CDS runs a local pruning test to reduce the CDS size. The authors show that their algorithm is computationally efficient and scalable.

A distributed algorithm for constructing CDS in wireless ad hoc networks is presented in [10]. The proposed Area algorithm is localized, wherein the nodes are partitioned into different areas and the dominators that are two or three hops away are selectively connected.

Authors in [35] provide a Distributed Single-Phase CDS construction algorithm (DSP-CDS) for ad hoc networks. The strength of the proposed algorithm is that it constructs a CDS in a single phase. The 1-hop neighbourhood information is used by each node to take a local decision about joining the dominating set. The proposed algorithm is shown to produce a CDS of small size.

Authors in [21] propose timer-based CDS protocols, wherein a number of initiators are first elected distributively and then, using timers, CDS is constructed from the initiators with the localized information. Based on the number of initiators, two versions of the protocols are presented, viz., Single-Initiator and Multi-Initiator. To overcome the single point of failure (reconstructing CDS when the Single-Initiator leaves the network) in Single-Initiator, the Multi-Initiator version is proposed. The authors show that both the protocols produce CDS of competitive size.

An energy efficient CDS construction algorithm is presented in [36]. The proposed algorithm is a distributed one that considers the node’s mobility and residual energy to create a stable MCDS. The authors state that the proposed algorithm is good both in dense and sparse networks, and that it yields smaller size MCDS.

Authors in [37] provide a distributed CDS construction algorithm. Nodes with more energy and closer nodes are given priority while selecting the backbone nodes. The proposed algorithm is shown to extend network lifetime and lower the delay. A centralized algorithm for constructing CDS is put forth in [38]. The algorithm involves two phases. In the first phase, MIS is constructed by using the sequence MIS algorithm and then the MIS nodes are connected by adding intermediate nodes to construct CDS. Some of the major research works with respect to CDS construction are outlined in Table 1.

Table 1. Research work pertaining to CDS construction

Study	Technique	Performance Metric	Proposed Algorithm	Outcome
Guha and Khuller (1998) [23]	Find Dominating Set in first phase and connect the DS in the second phase	CDS size	Two approximation algorithms	Small size CDS
Wu and Li (2001) [2]	CDS construction using geographical distances and Marking process	Number of gateway nodes	Distributed algorithm	Small size CDS
Alzoubi et al. (2002) [26]	Distributed heuristics using single-hop neighbourhood information	Approximation factor, Message Complexity, Time Complexity	ID-based algorithm and Level-based algorithm	Constant performance ratios
Wu et al. (2002) [27]	Node degree and energy level given preference	CDS size, Number of intervals	Power-aware CDS	Small size CDS, Longer lifespan of the network
Li et al. (2004) [13]	MIS construction using 2-hop neighbourhood information	CDS size	Localized one-phase Distributed algorithm r-CDS	CDS with smaller size and constant performance ratio
Wan et al. (2004) [29]	MIS construction and dominating tree construction	Approximation factor, Message Complexity, Time Complexity	Distributed algorithm	Message optimal
Gao et al. (2005) [15]	MIS based using 1-hop localized neighbourhood information	CDS size	Distributed algorithm	Small size CDS with with constant approximation ratio
Kim et al. (2005) [20]	Initiator election and CDS construction using energy level of node	CDS size, Energy	Timer-based Energy aware CDS (TECDS)	Smaller CDS size and extended network lifetime
Kassaei et al. (2009) [34]	Uses location of nodes	CDS size, Average shortest path length	Distributed local algorithm	Small size CDS with constant performance ratio
Kim et al. (2009) [4]	Energy-efficient CDS using BFS tree and MIS	CDS size, Diameter, Average Hop Distance, Network lifetime, Energy	Centralized and distributed algorithms – CDS-BD-C1, CDS-BD-C2, CDS-	Small size CDS and prolongs network lifetime

			BD-D	
Yin et al. (2011) [35]	Uses 1-hop neighbourhood information	CDS size, CDS diameter	Distributed Single-Phase CDS construction algorithm	Small size CDS
Chakradhar and Yogesh (2013) [36]	Based on node's mobility and residual energy	CDS size	Energy efficient CDS	Stable CDS
Ting-jun et al. (2014) [37]	Uses nodes with more energy and gives preference to closer nodes	Energy consumption, CDS size	IPCDS	Network life longer and delay smaller

The survey reveals that both centralized and distributed algorithms have been proposed for CDS construction. However, more emphasis has been given to distributed algorithms, as practically in ad hoc networks, centralized solutions do not fit well. Further, most of the algorithms work in two phases, with few works focusing on single-phase solutions to construct CDS. Majority of the two phase algorithms construct a MIS in the first phase, with their unique solution being incorporated in the second phase. The main performance criterion that has been focused is the size of the CDS. Other performance metrics include energy consumption and network lifetime, among others. Some of the algorithms have focused on providing solutions using localized information, preferably using single-hop neighbourhood information, to construct CDS. As nodes in ad hoc networks have limited energy, energy-aware protocols have also been attempted at.

5. CONCLUSION

The lack of predefined routers and physical infrastructure in ad hoc networks makes routing difficult. If flooding of messages is used to overcome the problem, it results in broadcast storm problem. So, virtual backbone has been proposed, in the literature, as a viable solution to facilitate routing in ad hoc networks. One of the well-known approaches for constructing virtual backbone is CDS. This paper focused on the various existing CDS algorithms for virtual backbone construction in ad hoc networks. A comparison of the major works relating to CDS construction has also been provided. It is observed that the algorithms proposed for CDS construction are largely distributed ones, as distributed algorithms fit well with the working of the ad hoc networks. Most of the solutions involve two phases for CDS construction. The major performance metric that has been considered is the size of the CDS. As part of future research, CDS maintenance algorithms that target adaptability of CDS to network topology changes could be explored. The use of CDS as virtual backbone in specific routing protocols could also be examined in the future.

6. REFERENCES

[1] Prasad, R., & Mihovska, A. (2009). *New Horizons in Mobile and Wireless Communications, Volume 4: Ad Hoc Networks and Pans*. Boston, London: Artech House.

[2] Wu, J., & Li, H. (2001). A dominating-set-based routing scheme in ad hoc wireless networks. Telecommunication Systems, 18(1-3), 13-36.

[3] Ephremides, A., Wieselthier, J. E., & Baker, D. J. (1987). A design concept for reliable mobile radio networks with frequency hopping signaling. Proceedings of the IEEE, 75(1), 56-73.

[4] Kim, D., Wu, Y., Li, Y., Zou, F., & Du, D. (2009). Constructing minimum connected dominating sets with bounded diameters in wireless networks. IEEE Transactions on Parallel and Distributed Systems, 20(2), 147-157.

[5] Kim, D., Gao, X., Zou, F., & Wu, W. (2011). Construction of fault-tolerant virtual backbones in wireless networks. In Y. Xiao, F. H. Li & H. Chen (Eds.), Handbook of Security and Networks (pp. 465-486). Singapore: World Scientific.

[6] Wang, W., Kim, D., An, M. K., Gao, W., Li, X., Zhang, Z., & Wu, W. (2013). On construction of quality fault-tolerant virtual backbone in wireless networks. IEEE/ACM Transactions on Networking, 21(5), 1499-1510.

[7] Li, Y., Wu, Y., Ai, C., & Beyah, R. (2012). On the construction of k-connected m-dominating sets in wireless networks. Journal of Combinatorial Optimization, 23(1), 118-139.

[8] Zhang, N., Shin, I., Zou, F., Wu, W., & Thai, M. T. (2008). Trade-off scheme for fault tolerant connected dominating sets on size and diameter. Proceedings of the 1st ACM International Workshop on Foundations of Wireless Ad Hoc and Sensor Networking and Computing (FOWANC'08). Hong Kong SAR, China (pp. 1-8).

[9] Sheu, P., Tsai, H., Lee, Y., & Cheng, J. (2009). On calculating stable connected dominating sets based on link stability for mobile ad hoc networks. Tamkang Journal of Science and Engineering, 12(4), 417-428.

[10] Han, B., Zhang, L., & Jia, W. (2010). Connected dominating set for topology control in ad hoc networks. In L. T. Yang, A. B. Waluyo, J. Ma, L. Tan, & B. Srinivasan (Eds.), Mobile Intelligence (pp. 26-42). New Jersey: Wiley.

[11] Cheng, X., Ding, M., Du, D. H., & Jia, X. (2006). Virtual backbone construction in multihop ad hoc wireless networks. Wireless Communications and Mobile Computing, 6(2), 183-190.

[12] Yu, J., Wang, N., Wang, G., & Yu, D. (2013). Connected dominating sets in wireless ad hoc and sensor networks – A comprehensive survey. Computer Communications, 36(2), 121-134.

[13] Li, Y., Zhu, S., Thai, M., & Du, D. (2004). Localized construction of connected dominating set in wireless networks. Proceedings of US National Science Foundation International workshop on Theoretical Aspects of Wireless Ad Hoc, Sensor and Peer-to-Peer Networks (TAWN'04). Chicago, USA.

[14] Kamei, S., & Kakugawa, H. (2007). A self-stabilizing distributed approximation algorithm for the minimum connected dominating set. IEEE International Parallel and Distributed Processing Symposium (IPDPS 2007). Rome (pp. 1 – 8).

[15] Gao, B., Ma, H., & Yang, Y. (2005). A new distributed approximation algorithm for constructing minimum connected dominating set in wireless ad hoc networks. In

J. Cao, L. T. Yang, M. Guo, & F. Lau (Eds.), Parallel and Distributed Processing and Applications (pp. 352–356). Berlin Heidelberg: Springer.

[16] Blum, J., Ding, M., Thaeler, A., & Cheng, X. (2004). Connected dominating set in sensor networks and MANETs. In D. Z. Du & P. Pardalos (Eds.), Handbook of Combinatorial Optimization (pp. 329 – 369). US: Springer.

[17] Cardei, M., Cheng, X., Cheng, X., & Du, D. (2002). Connected domination in multihop ad hoc wireless networks. Proceedings of the 6th Joint Conference on Information Science (JCIS). North Carolina (pp. 251-255).

[18] Garey, M. R., & Johnson, D. S. (1979). Computers and Intractability: A guide to the theory of NP-completeness New York: W. H. Freeman & Co.

[19] Wu, J. (2002). Dominating-set-based routing in ad hoc wireless networks. In I. Stojmenovic´ (Ed.), Handbook of Wireless Networks and Mobile Computing (pp. 425-450). New York: Wiley.

[20] Kim, B., Yang, J., Zhou, D., & Sun, M. (2005). Energy-aware connected dominating set construction in mobile ad hoc networks. Proceedings of 14th International Conference on Computer Communications and Networks (ICCCN 2005). San Diego, CA, USA (pp. 229-234).

[21] Sakai, K., Huang, S. C. H., Ku, W., Sun, M., & Cheng, X. (2011). Timer-based CDS construction in wireless ad hoc networks. IEEE Transactions on Mobile Computing, 10(10), 1388-1402.

[22] Zhou, D., Sun, M., & Lai, T. (2005). A timer-based protocol for connected dominating set construction in IEEE 802.11 multihop mobile ad hoc networks. Proceedings of the 2005 Symposium on Applications and the Internet (SAINT’05). Trento, Italy (pp. 2-8).

[23] Guha, S., & Khuller S. (1998). Approximation algorithms for connected dominating sets. Algorithmica, 20(4), 374-387.

[24] Sivakumar, R., Das, B., & Bharghavan, V. (1998). The clade vertebrata: spines and routing in ad hoc networks. Proceedings of Third IEEE Symposium on Computers and Communications (ISCC '98). Athens (pp. 599-605).

[25] Stojmenovic, I., Seddigh, M., & Zunic, J. (2002). Dominating sets and neighbor elimination-based broadcasting algorithms in wireless networks. IEEE Transactions on Parallel And Distributed Systems, 13(1), 14-25.

[26] Alzoubi, K. M., Wan, P., & Frieder, O. (2002). Distributed heuristics for connected dominating sets in wireless ad hoc networks. Journal of Communications and Networks, 4(1), 22-29.

[27] Wu, J., Dai, F., Gao, M., & Stojmenovic, I. (2002). On calculating power-aware connected dominating sets for efficient routing in ad hoc wireless networks. Journal of Communications and Networks, 4(1), 59-70.

[28] Alzoubi, K. M., Wan, P., & Frieder, O. (2002). Message-optimal connected dominating sets in mobile ad hoc networks. Proceedings of the 3rd ACM International Symposium on Mobile Ad Hoc Networking & Computing (MobiHoc'02). EPFL Lausanne, Switzerland (pp. 157 – 164).

[29] Wan, P., Alzoubi, K. M., & Frieder, O. (2004). Distributed construction of connected dominating set in wireless ad hoc networks. Mobile Networks and Applications, 9(2), 141-149.

[30] Ruan, L., Du, H., Jia, X., Wu, W., Li, Y., & Ko, K. (2004). A greedy approximation for minimum connected dominating sets. Theoretical Computer Science, 329(1-3), 325-330.

[31] Mohammed, K., Gewali, L., & Muthukumar, V. (2005). Generating quality dominating sets for sensor network. Proceedings of the Sixth International Conference on Computational Intelligence and Multimedia Applications (ICCIMA’05). Las Vegas, Nevada (pp. 204 – 211).

[32] Funke, S., Kesselman, A., Meyer, U., & Segal, M. (2005). A simple improved distributed algorithm for minimum CDS in unit disk graphs. IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob'2005). Canada (pp. 220 – 223).

[33] Zongkai, Y., Dasheng, Z., Yuming, W., & Jianhua, H. (2005). An efficient distributed algorithm for connected dominating set construction in wireless sensor networks. Journal of Electronics(China), 22(6), 671-675.

[34] Kassaei, H., Mehrandish, M., Narayanan, L., & Opatrny, J. (2009). A new local algorithm for backbone formation in ad hoc networks. Proceedings of the 6th ACM Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks (PE-WASUN'09). Tenerife, Canary Islands, Spain (pp. 49-57).

[35] Yin, B., Shi, H., & Shang, Y. (2011). An efficient algorithm for constructing a connected dominating set in mobile ad hoc networks. Journal of Parallel and Distributed Computing, 71(1), 27-39.

[36] Chakradhar, P., & Yogesh, P. (2013). Energy efficient minimum connected dominating set algorithm for MANETs. 2013 International Conference on Recent Trends in Information Technology (ICRTIT). Chennai (pp. 270 – 276).

[37] Ting-jun, S., Xu, S., & Xu-ming, F. (2014). A virtual backbone construction algorithm based on connected dominating set in wireless sensor networks. International Conference on Computer, Communications and Information Technology (CCIT 2014). Beijing, China (pp. 156-159).

[38] Fu, D., Han, L., Liu, L., Gao, Q., & Feng, Z. (2015). An efficient centralized algorithm for connected dominating set on wireless networks. Procedia Computer Science, 56, 162-167.