Strategic Location-based Connected Dominating Set for Mobile Ad Hoc Networks

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Abstract—Wireless networks like mobile ad hoc networks are infrastructure-less networks and nodes in that network which communicate via radio propagation. In such networks, a Connected Dominating Set (CDS) can act as a virtual backbone, in order to make the routing efficient. A smaller virtual backbone incurs less communication overhead. Since computing a minimum CDS is NP-Complete, efficient approximation algorithms are used to find a CDS of small size. This work presents the CDS algorithm which is constructed based on strategy and location of the nodes. The mobile ad hoc networks area is partitioned into various regions based on location and homogeneous transmission range. In each region, a strategic node is selected and a CDS is constructed inside that region. A strategic CDS is constructed for the strategic nodes selected in all the regions of the network. These strategic CDS nodes are selected based on factors like location, density, transmission range, velocity, energy, frequency, power back-up and trust ability. The CDS nodes are selected based on the factors like density and velocity. The proposed algorithm can increase the lifetime of a CDS, decrease the time complexity involved in transmitting the message and increases the possibility of finding the routes between the nodes in the network.

Index Terms—mobile ad hoc networks, virtual backbone, CDS, strategy, density and transmission range.

I. INTRODUCTION

A mobile ad hoc network is an interconnection of mobile computing nodes, where the link between two neighbouring nodes is established via radio propagation, when they are within the same transmission range. Communication between non-neighbouring nodes requires a multi-hop routing protocol. The network is ad hoc because it does not depend on any pre-infrastructure, such as access points in wireless networks and routers or switches in wired networks. In such networks access, points or routers plays a major role in routing. Instead, each node in the ad hoc network participates in routing by being an intermediate node and forwarding the data for other nodes. The determination of forwarding nodes called active nodes dynamically changes based on the network state.

The decentralized nature of ad hoc networks makes them appropriate for a variety of applications where central nodes are not relied upon or where scalability is of greater importance. Minimal configuration requirements and easy deployment make ad hoc networks suitable for disaster and military management. Wireless networks consist of static or dynamic hosts that can communicate with each other over the radio.
links. Finding and maintaining the routes in the network is nontrivial, since node mobility causes frequent unpredictable topological changes. Location-based routing [1] is therefore introduced to reduce the communication overhead imposed by flood-based solutions. Each node in the network operates autonomously and determines its own absolute location through the use of GPS or relative location with a collaborative protocol [2]. Design of efficient broadcasting and routing protocols for location based networks is one of the challenging tasks in mobile ad hoc networks. Among various existing location based routing protocols, the ones based on dominating set are found to be very promising.

A. Wireless ad hoc network modelling

The mobile ad hoc network is modeled as a graph on which routing and broadcasting algorithms operate. A vertex in the graph represents a wireless node and an undirected edge between the two vertices represents the link between them. The link is established when they are within the radio range of each other. A directed edge from x to y shows that y is within the radio range of x and not vice versa. If all the nodes in the network have the same radio or transmission range, the graph obtained will be an undirected graph. If the nodes in the network have different transmission ranges, the corresponding graph will be a directed graph. The network can be modelled in two different ways: Unit Disk Graph (UDG) and Unit Ball Graph (UBG) [3]. If all the nodes of the mobile ad hoc networks lie in a plane, a UDG (Fig. 1 (a)) is used. The centre of a circle represents the node position and the radius is equal to the radio range of that node. All the nodes which fall inside the circle are said to be adjacent to the node at the centre. In some situations, the wireless network is modelled in 3-dimensional space (Fig. 2) instead of a plane. For example, in a three-dimensional under water applications, sensor nodes are anchored to the sea bed and group of Autonomous Underwater Vehicles (AUV) are connected in an ad hoc way with sensor nodes and sea surface gateway buoys. The networking protocol would facilitate inter-communication, which enables long range communication, thus offering surveillance applications, remote logon capability and monitoring of ocean phenomena. Such 3-dimensional mobile ad hoc networks are modelled using Unit Ball Graph (UBG). If the nodes of the mobile ad hoc networks lie in a 3-dimensional Euclidian space, a UBG is used. Any two nodes in the network are adjacent if and only if, the distance between the centre of the two nodes is less than or equal to the radio range of each node.

B. Backbone network

Traditionally, a backbone network is a part of computer network infrastructure which provides a path for the exchange of data between different LANs or sub-networks. Usually, the backbone network’s capacity is greater than that of the networks connected to it [4]. A bus backbone network connects LANs for providing communication among the inter-LAN hosts. Bus backbones usually connect different buildings in an organization. A star backbone connects various LANs through a switch. Star backbones are mostly used as a distribution medium inside a building. The routers and switches are main components of the backbone network at the service provider level. Access points are used as backbones in 802.11 WLAN. This work focuses on ad hoc wireless networks that are simplified to a smaller sub-network (virtual backbone) by assigning only the forwarding or active nodes to route the data.

C. Virtual backbone

Routing related tasks are very difficult in mobile ad hoc networks because there is no predefined physical backbone infrastructure or topology control. This drawback induces a virtual backbone to be employed in mobile ad hoc networks. A virtual backbone is a set of forwarding or active nodes that take on additional responsibility in routing the data. Any non-backbone node can send a message to another destination node by forwarding the message directly to a neighbouring backbone node. Virtual backbone brings several benefits to network routing and management. The routing path search space can be reduced to a smaller sub-network. The backbone structure can efficiently support unicasting, broadcasting, multicasting, and fault-tolerant routing. Any topology changes can be quickly updated. Finally, it reduces the collision problem, which is very serious but unavoidable when flooding-based routing protocols are employed. Before 1987, it was noticed that any of the previous mobile ad hoc networks routing algorithm did not try to employ a structure that was similar to the physical backbone infrastructure of packet cellular networks and the idea of virtual backbone was introduced by Ephremides, A, et al.[5].
D. Dominating set

A Dominating Set (DS) is a subset D of a graph G = (V, E) such that every vertex in G is either in D or adjacent to a vertex in D. The domination number N(G) is the number of vertices in the smallest dominating set for G. Dominating sets are closely related to independent sets. An independent set is also a dominating set if and only if it is a maximal independent set, so any maximal independent set in a graph is also a minimal dominating set. The minimum dominating set in a graph will not necessarily be independent, but the size of a minimum dominating set is always less than or equal to the size of a minimum maximal independent set. The determination of a minimum dominating set is NP-Complete. Fig. 1(b) show possible DS for the graph shown in Fig. 1(a).

E. Connected dominating set

A Connected Dominating Set (CDS) is a subset C of a graph G = (V, E) such that C forms a dominating set and C is connected. If the nodes in the dominating set of a graph are connected, the set is called connected dominating set. Formally, a CDS in a graph G is a subset C (of connected nodes) of all the nodes such that every node in G is either in C or adjacent to a node in C. If S is a connected dominating set, one can form a spanning tree of G in which S is the set of non-leaf nodes of the tree. Conversely, if T is any spanning tree in a graph with more than two vertices, the non-leaf nodes of T form a connected dominating set. Therefore, finding minimum connected dominating sets is equivalent to finding spanning trees with the maximum possible number of leaves. Nodes in the dominating set are called the dominators. The nodes that are adjacent to a dominator are called dominatees. Fig. 1(c) show possible CDS for the graph shown in Fig. 1(a).

![Fig. 1(a). An example unit disk graph of a wireless network.](image1)

![Fig. 1(b). Possible DS.](image2)

![Fig. 1(c). Possible CDS.](image3)

![Fig. 2. An example for 3-dimensional wireless network.](image4)
F. Factors for constructing connected dominating set

The algorithm for constructing the CDS should be efficient, distributed and local information based only. Since finding a minimum CDS for most graphs is NP-Complete, efficient approximation algorithms are used to find a CDS of small size. There are many existing algorithms for broadcasting/routing in mobile ad hoc networks using dominating-set-based approach. In most of the approaches a maximum density node [6] is selected initially and the algorithm is continued until all the nodes in the network are covered. Various other parameters were also considered in selecting the dominatees of the network (Table I).

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name of the authors and reference</th>
<th>Factors selecting the dominatee</th>
<th>Parameters used for CDS evolution criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Dandan Liu, Xiaohua Jia, I.Stojmenovic [7]</td>
<td>Location Prediction</td>
<td>Success Rate, Update Cost, Maintenance Overhead, Update Times</td>
</tr>
<tr>
<td>3.</td>
<td>Narmathan Velumyllum, Natarajan Meghanathan [8]</td>
<td>Identity</td>
<td>CDS node size, CDS edge size, CDS lifetime, Hop Count per path</td>
</tr>
<tr>
<td>4.</td>
<td>Pervis Fly, Natarajan Meghanathan [9]</td>
<td>Edge weight</td>
<td>CDS node size, CDS edge size, CDS lifetime, Hop Count per path</td>
</tr>
<tr>
<td>5.</td>
<td>Natarajan Meghanathan [10]</td>
<td>Velocity</td>
<td>CDS node size, CDS edge size, CDS lifetime, Hop Count per path</td>
</tr>
<tr>
<td>7.</td>
<td>Natarajan Meghanathan, Michael Terrell [12]</td>
<td>Strong neighbourhood</td>
<td>Effective CDS lifetime, CDS node size, CDS edge size, Hop count per path, CDS diameter, CDS energy index</td>
</tr>
<tr>
<td>11.</td>
<td>Ling Ding, Xiaofeng Gao [16]</td>
<td>Routing cost</td>
<td>Maximum routing path length, Average routing path length</td>
</tr>
<tr>
<td>12.</td>
<td>Jie Wu, Fei Dai, Shuhui Yang [17]</td>
<td>Interference</td>
<td>CDS size, packets received per node</td>
</tr>
<tr>
<td>13.</td>
<td>Pushpalakshmi, Vincent Antony Kumar [18]</td>
<td>Trust ability, probability of future contact</td>
<td>Trust value</td>
</tr>
<tr>
<td>14.</td>
<td>Ali Kies, Zoulikha Mekkakia [19]</td>
<td>Connectivity, energy</td>
<td>Average number of dominant nodes, dominant rate, number of control packets, total energy consumption</td>
</tr>
<tr>
<td>15.</td>
<td>V.Ceronmani Sharmila and A.George [20]</td>
<td>Strategy</td>
<td>CDS node size, CDS edge size, CDS circuit size</td>
</tr>
</tbody>
</table>

II. Related Work

The criteria for selection of an algorithm for constructing the CDS should be efficient, distributed and local information based. Dandan Liu, et al. [7] proposed quorum and connected dominating set based location service algorithm for mobile ad hoc networks. CDS was used as an alternative to grids. Location updates and destination searches are restricted to backbone nodes. The efficiency of the algorithm was evaluated using the parameters’ success rate, update cost, maintenance overhead and update times. Simulation results show that the proposed algorithm can achieve higher success rate with less communication overhead than grid-based approaches.

Natarajan Meghanathan [6] proposed a maximum density-based CDS (MaxD-CDS) algorithm for mobile ad hoc networks. The density factor was used for constructing the CDS. The efficiency of the algorithm was evaluated using the parameters’ CDS node size and CDS edge size. Simulation results show that the proposed algorithm achieved average number of nodes and edges in the CDS.

Velumyllum and Meghanathan [8] proposed an identity-based CDS (ID-CDS) algorithm for mobile ad hoc networks. The identity factor was used for constructing the CDS. The efficiency of the algorithm was evaluated using the parameters’ CDS node size, CDS edge size, CDS lifetime and hop count per path. Simulation results show that the proposed algorithm achieved lower average hop count and end-to-end delay than maximum density CDS.

Natarajan Meghanathan [10] proposed a minimum velocity-based CDS (MinV-CDS) algorithm for mobile ad hoc networks. The velocity factor was used for constructing the CDS. The efficiency of the
algorithm was evaluated using the parameters’ CDS node size, CDS edge size, CDS lifetime and hop count per path. Simulation results show that the proposed algorithm achieved longer lifetime, lower average hop count, lower end-to-end delay and improved the fairness of node usage than maximum density CDS.

Ceronmani Sharmila and George [20] proposed four CDS algorithms for mobile ad hoc networks. The strategy chosen was used as a factor for constructing the CDS. A strategic node can be a source, DNS, web proxy, internet provider, gateway or doorway, beacon, security key provider, repeater, rescuer, router etc. The efficiency of the algorithm is evaluated using the parameters CDS node size, CDS edge size and CDS circuit size. Simulation results show that the proposed algorithm gives the freedom to have any node as the starting node, without any significant change in number of nodes and number of edges.

III. DEFINITIONS

- **CDS-Node-List**: Nodes that are members of the CDS.
- **CDS-Edge-List**: Edges that exist between any two CDS nodes.
- **Covered-Nodes-List**: Nodes that are in the **CDS-Node-List** and all nodes that are one hop to at least one member of the **CDS-Node-List**.
- **CDS-Circuit-List**: Circuits that are formed by the nodes from the **CDS-Node-List**.
- **Density**: A node’s maximum number of uncovered neighbours.
- **Homogenous network**: A network in which all nodes function under the same fixed transmission range \( R \).
- **Open neighbourhood of a node \( i \) (ON\( i \))**: The set of neighbour nodes such that the physical Euclidean distance between node \( i \) and each node \( j \) in this set is \( \leq R \). Every node \( j \in \text{ON}_i \) is simply referred to as a “neighbour” of node \( i \).
- **Threshold Neighbour Distance Ratio (TNDR)**: The maximum value of the ratio of the physical Euclidean distance between a node \( i \) and a node \( j \) in its open neighbourhood and the transmission range \( R \).
- **Strong Neighbourhood of a node \( i \) (SN\( i \))**: The subset of nodes in its open neighbourhood, such that the ratio of the physical Euclidean distance between node \( i \) and any node \( j \) in \( \text{SN}_i \) is less than or equal to the TNDR.
- **Edge Weight (EW)**: The ratio of physical Euclidean distance between the nodes constituting the edge to the fixed transmission range \( R \) of the nodes.
- **Node Stability Index (NSI)**: The sum of predicted expiration times of the links (LETs) with the neighbour nodes that are not yet covered by a CDS node.
- **Static Network Graph**: A snapshot of the network topology at a particular time instant.

IV. CONSTRUCTION OF STRATEGIC LOCATION-BASED CONNECTED DOMINATING SET

The mobile ad hoc network area is divided into various regions based on location and homogeneous transmission range as shown in Fig 3. Here two mutually perpendicular axes are considered as the \( x \) axis and \( y \) axis. It is better to have the partition in such a way that each region will be having more number of nodes than a fixed minimum.

From each region a strategic node is selected and these strategic nodes will have maximum power backup and dual frequency (one frequency for strategic CDS nodes and another frequency for other nodes within the region). Further the movement of each strategic node is restricted to that particular region from which it is selected. The transmission range of the strategic nodes is such that it will reach any point of the immediate neighbourhood regions from any point of the region from which that particular strategic node is selected. The security of the network is enhanced by strengthening the trusted ability of the strategic nodes. Each region is further more divided into various sections based on homogeneous transmission range. In each section CDS is constructed based on density and velocity.

**A. Algorithm for constructing strategic location-based CDS**

The input to all the algorithm is a snapshot of the network as shown in Fig. 4. In that nodes are symbolized as circles and the numerical number inside the circle represents the density of the node and the numerical number outside the circle represents the ID of the node.
Fig 3. An example for partition of a mobile ad hoc network area.

**TABLE II. PARAMETER VALUES**

<table>
<thead>
<tr>
<th>Identity</th>
<th>Density</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1.2</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>0.6</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>1.9</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>6.3</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>3.2</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>7.5</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>6.7</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>4.5</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>7.0</td>
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<tr>
<td>10</td>
<td>4</td>
<td>9.8</td>
</tr>
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<td>11</td>
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<td>3.8</td>
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<td>15</td>
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<td>16</td>
<td>6</td>
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<tr>
<td>17</td>
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<tr>
<td>18</td>
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<td>23</td>
<td>3</td>
<td>8.4</td>
</tr>
<tr>
<td>24</td>
<td>3</td>
<td>9.9</td>
</tr>
</tbody>
</table>

In the following figures, nodes which are symbolized as dotted circles with a plus symbol are qualified to be part of *CDS-Node-List*, the edges between any two CDS nodes in the *CDS-Node-List* are qualified to be a part of *CDS-Edge-List* and the nodes which are represented as dotted circles are qualified to be a part of *Covered-Nodes-List*. 

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Table II is created for representing the values of identity, density and velocity for the initial static graph with 24 nodes and 44 edges. The edge weight is represented as a real number.

The specific criterion of this algorithm is to select a node with minimum density (greater than one). If there is a tie or the density of all the nodes present in the Covered-Nodes-List is less than two, choose a node with minimum velocity. This algorithm is illustrated below with an example.

Any node in the strong neighbourhood network can be selected as the starting node. In this example node 7 is chosen which has density 5 as shown in Fig. 4(a), and it is included in the CDS-Node-List and Covered-Nodes-List. Then node 7’s covered neighbours (node 3, 4, 8, 11, 12) are added into the Covered-Node-List. The density of the start node (node 7) is changed to 0 and the density of all other nodes is computed as shown in Fig. 4(b).

Then the node which has minimum density (greater than one) is chosen from the Covered-Node-List as shown in Fig. 4(b), and the process is continued until all the nodes are covered as shown in Fig. 4(b), Fig. 4(c), and Fig. 4(d). The nodes which are represented as dotted circles with a plus symbol are qualified to be part of CDS-Node-List and the edges between any two CDS nodes in the CDS-Node-List are qualified to be a part of CDS-Edge-List as shown in Fig. 4(e). The number of CDS nodes in CDS-Node-List is 11 and the number of edges in CDS-Edge-List is 10 as shown in Fig. 4(f).

### B. Pseudo code for constructing strategic location-based CDS

Begin

```
    for each region select_strategic_node;
    for each region construct_CDS (strategic_node i);
        select_strategic_node i based on application and need;
        construct_CDS (strategic_node i);
    End;
```

```
construct_CDS(node)
begin
    if (node == NULL)
        return;
    else if
        begin
            find_all_neighbour_node (node);
            add neighbour_node with min_density to CDS;
            if (there is more than one neighbour with min_density)
                add neighbour_node with min_density and min_velocity to CDS;
            end
        end
    construct_CDS (neighbour_node);
end
```

**END**

### IV. CONCLUSION

**A. Performance Metrics**

Five parameters were used for the evaluation of CDS. The five parameters were CDS node size, CDS edge size, CDS lifetime, diameter and Average Path length (APL).

(a) **CDS node size**: It is the number of nodes in the CDS. Since each node in a mobile ad hoc network shares its communication channel with its neighbours, a smaller CDS suffers less from the interference problem. In addition, minimum number of nodes in the CDS reduces the number of control messages and performs more efficiently. It also makes the maintenance of the CDS easier. The problem of computing minimum size CDS was proven to be NP-Hard [21], therefore heuristic algorithms were used to solve it.
Fig. 4. Example to construct Strategic CDS, (a) Initial static network graph, (b) Iteration # 1, (c) Iteration # 2, (d) Iteration # 3, (e) Iteration # 12 (Last Iteration), (f) CDS nodes, edges and circuits

(b) CDS edge size: It is the number of edges connecting the nodes that are part of the CDS.
(c) CDS lifetime: It is the time elapsed between the construction and destruction of a CDS.
(d) Diameter: It is the length of longest shortest path between a pair of nodes in the graph. The diameter is computed for the sub-graph induced by the CDS nodes. Thus, the diameter refers to the longest path a message may have to follow in order to reach its destination. In wireless networks, error rate increases rapidly when messages travel longer path. Hence, for better performance, it is desirable that the diameter be minimized.
Average path length: It is the average distance travelled by a packet before reaching its destination. It is desirable to have a network with smaller APL, so that the average cost of communication can be reduced. Communication cost can be in terms of average number of intermediate hops, processing power, bandwidth usage, battery power etc. APL of a CDS is the sum of the hop distances between any pair of nodes p and q (p, q lies in CDS) divided by the number of all the possible pair of nodes. A CDS with smaller APL will consume less energy in transmission of the message, so its significance cannot be neglected.

The CDS constructed in this way will be highly efficient since it will,
- increase the lifetime of CDS.
- decrease the time complexity in transmitting the message.
- increase the possibility in finding the routes between the nodes in the network.

REFERENCES