Energy Efficient Stable Connected Dominating Set Construction in Mobile Ad Hoc Networks

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Abstract. One of the important issues in ad hoc wireless network is to construct virtual backbone for efficient broadcasting. A Multi Point Relay (MPR) is a set of 1-hop neighbours to cover all 2-hop neighbours of a node. It is a promising approach for broadcasting in ad hoc networks. A Connected Dominating Set (CDS) based virtual backbone has been used where only the nodes in the set relay messages. A node in the CDS consumes more energy and the energy depletes quickly than other nodes. Although previous CDS construction algorithms achieve good results in terms of the size of the CDS, a minimum size CDS does not necessarily guarantee the optimal network performance from an energy efficient point of view. In this paper, we propose a distributed algorithm for energy efficient stable MPR based CDS construction to extend the lifetime of ad hoc wireless networks by considering energy and velocity of nodes. The simulation results show that our algorithm can save a significant amount of energy and increases the lifetime up to 25% than previous works.

Keywords: Connected Dominating Set, Multi Point Relay, Ad Hoc Networks, Energy Efficient.

1 Introduction

Wireless ad hoc networks are self configuring network and they can be deployed for many applications such as automated battlefield, search and rescue and disaster relief. Mobile ad hoc network (MANET) consists of wireless nodes that communicate with each other without any infrastructure. A communication session is achieved either through a single hop radio transmission if he communication parties are within the transmission range, or through relaying by intermediate nodes otherwise. Two important features of an ad hoc network are its dynamic topology and resource limitation. Every node in mobile ad hoc networks can move in any direction at any time and any speed. A temporary infrastructure or a virtual backbone can be formed to provide communication. This virtual backbone may be broken due to the node movement. The resource constraints include battery capacity, bandwidth, and CPU speed, etc. These two features make routing decision very challenging.

A network can be modeled as a Unit Disk Graphs (UDG) where two nodes are connected if they are within each other's transmission range. To support various network functions some wireless nodes are selected to form a virtual backbone. It is

N. Meghanathan et al. (Eds.): CCSIT 2012, Part I, LNICST 84, pp. 63–72, 2012.

proved that multipoint relaying (MPR) is an efficient stated for on-the-fly broadcasting in Mobile Ad Hoc Networks. The relaying nodes which are selected by the source node are responsible for flooding a receiving packet. A connected dominating set (CDS) consists of all the relay nodes. There are many algorithms based on MPR to reduce the size of the CDS [1, 2, 11, 12, 13, 14], where nodes are chosen based on its ID or degree. The CDS selection has to consider other information such as energy, bandwidth and mobility in order to provide suitable links for some specific applications. In this paper, we propose an approach to generate quality connected dominating set based on MPR by considering the energy and link velocity factors. None of the existing works considered the energy of nodes and their mobility together for the CDS construction.

1.1 Problem Definitions

The connected dominating set or virtual backbone is proposed to facilitate routing, broadcasting and establishing a dynamic infrastructure. Minimizing the CDS produces a simpler abstracted topology of the MANET and allows for using shorter routes between any pair of hosts. A wireless network is usually modeled as a unit disk graph G = (V, E) where V is the set of nodes and E is the set of links in the network. Each node has uniform transmission range R. Each node in V is associated with coordination in 2-D Euclidean space. A wireless link $(u,v) \in E$ if and only if the Euclidean distance between nodes *u* and *v* is smaller than transmission range R.

Connected Dominating Set

Let the closed neighbors of a node x is N[x]. A subset $S \subseteq V$ is called a dominating set (DS) of G if S U N[v] = V where $N[v]= S_{u \in S} N[u]$. The subset S is called Connected Dominating Set if the graph G', induced by S is connected i.e, G'[S] is connected.

Multipoint Relay

For a given a graph G=(V,E) and a node $v \in V$, let $N(v)$ and $N_2(v)$ represent the set of 1-hop and 2-hop neighbors of v, respectively. MPR asks for a minimum sized subset S of $N(v)$ such that every node in $N_2(v)$ is within the coverage of at least one node in S.

The rest of the paper is organized as follows: Section 2 describes the works related to CDS construction; Section 3 describes the energy efficient stable connected dominating set construction algorithm. We describe our simulation environment and the performance metrics in Section 4. Section 5 concludes the paper.

2 Related Works

There are many work on MPR based CDS construction for efficient broadcasting in Manet. Adjih et al [12] proposed a source independent MPR called the MPR-CDS. The algorithm starts by having every node *v* calculate its source dependent MPR. After that every node *v* decides whether it belongs to the MPR-CDS or not according to the following simple rules:

- Rule 1: Node u $\in$ MPR-CDS iff v has the smallest ID in tis 1-hop neighborhood.
- Rule 2: Node v $\in$ MPR-CDS iff v $\in$ w's MPR where w's ID is the smallest in v's 1-hop neighborhood.

In [1] Wu, has noticed that in many occasions nodes added by rule-1 of MPR-CDS algorithms are useless. Moreover the algorithm used to calculate the source dependent MPR does not benefit from Rule-2 of the MPR-CDS algorithm. In [1] Wu modified Rule 1 as follows:

- **EMPR:** node v $\in$ MPR-CDS iff v has the smallest ID in its 1-hop neighborhood and v has at least two unconnected neighbors.

Moreover, Wu modified the MPR calculation algorithm in [12] by having every node *v* start by adding all its free neighbors to its MPR set. A node u is a free neighbor of node *v* iff $u \in$ N(v) and *v* is not the smallest ID neighbor of *u*.

Chen et al [11] observed that the node degree is more related to the size of a CDS than the node ID and three improvements are proposed. They replaced the EMPR rule with two rules based on degree called DEMPR.

- Rule 1: node v $\in$ MPR-CDS if v has the largest node degree among all its one-hop neighbors and v has two unconnected neighbors.
- Rule 2: node v $\in$ MPR-CDS if v has been selected as an MPR and its selector has the largest node degree among its one-hop neighbors.

Badis et al [13], proposed heuristic referred to as the QoS based MPR-1(QMPR-1) follows the same steps as the original MPR heuristic but it modifies the tie breaking procedure. Instead of a maximum node degree, a node with high bandwidth is chosen when multiple choices exist.

There are few works on energy efficient CDS construction. In [6] Kim extended the Mac-layer timer based connected dominating set protocol by considering energy level at each node to construct energy aware CDS. In [7] Ruiyun Yu proposed an energy efficient dominating tree construction (EEDTC) algorithm with two phases, marking phases followed by connection phase. In the marking phase, a Maximal Independent Set (MIS) is constructed and connectors are added to make it as CDS. In [14], Wu proposed a method to calculate power aware connected dominating set. They used degree and residual energy level of nodes to reduce the CDS size to prolong the lifespan of the nodes in the CDS.

Only few works are done in stable connected dominating set construction. In [15], Change proposed Dynamic Power-aware and Stability-aware Multipoint relays which avoid selecting the border nodes as the forwarding nodes. They used power adaptive broadcasting by reducing the transmission range of mobile nodes to save energy. In [4], Meganathan proposed an algorithm to determine stable connected dominating set based on node velocities. His algorithm prefers slow moving nodes with lower velocity rather than the usual approach of preferring nodes with a larger number of uncovered neighbours. They compared their method with another work which is based on node degree.

Although previous CDS construction algorithms achieve good results in terms of the size of the CDS, a minimum size CDS does not necessarily guarantee the optimal network performance from an energy efficient point of view. This motivated us to construct an energy efficient stable connected dominating set prolong the network lifetime.

3 Energy Efficient Stable Connected Dominating Set Construction Algorithm (EES-CDS)

3.1 Notations and Assumptions

We assume that every node in the network has same transmission range R. Two nodes are connected if the Euclidean distance between the nodes is less than R. We used the notations for our algorithm as in Table 1.

Table 1. Notations

N(u)	Open neighbour set of node u
N[u]	Closed neighbour set of node u N[u] = N(u) $\cup$ {u}
N_2(u)	2-hop neighbour set of node u
Erg_x	remaining residual energy at node x
Vel_x	Velocity of node x
MPR(u)	MPR set of node u
Deg_u	No of uncovered 2-hop neighbours of u

3.2 EES-CDS Algorithm

Our algorithm for energy efficient stable connected dominating set construction (EES-CDS) consists of two phases: Neighbour Discovery Phase and CDS Formation Phase. During the Neighbour Discovery Phase, there is an initial exchange of messages via which a node u, made aware of its N_2 (u). In the CDS Formation Phase, a node *u* locally selects a set MPR(u) of its N(u) as its multipoint relays by using simple greedy algorithm and pruning rules are applied to reduced the connected dominating set size. In [1], Wu proposed a simple decentralized algorithm for the formation of connected dominating set in ad hoc networks. This algorithm is based on marking process. In [14], Dai proposed two rules for power aware CDS construction using node degree and residual energy level of nodes.

In this work, we have modified the rules proposed by [14] with energy level and velocity to prolong the stability and to reduce the size of a connected dominating set generated from the marking process. Let the graph induced by CDS be G'.

Rule 1: Consider two marked vertices *v* and *u* in G'. The marker of *v* is changed to gray if one of the following conditions holds:

i) $N[v] \subseteq N[u]$ in G and $Erg_v < Erg_u$

ii) $N[v] \subseteq N[u]$ in G and $Vel_v > Vel_u$ when $Erg_v = Erg_u$

iii) $N[v] \subseteq N[u]$ in G and $Deg_v < Deg_u$ when $Erg_v = Erg_u$ and $Vel_v = Vel_u$

The above rule indicate that when the closed neighbour set of *v* is covered by that of *u*, vertex *v* can be removed from G' if the energy level of *v* is smaller than u. Velocity is used to break a tie when energy levels of *u* and *v* are same. Degree is used to break the tie if both energy levels and velocity of *u* and *v* are same. Node ID can be used to break the tie, in case all the values are same.

Rule 2: Assume that *u* and *w* are two marked neighbours of marked vertex *v* in G'. The marker of *v* can be changed to Gray if one of the following conditions holds:

1. $N(v) \subseteq N(u) \bigcup N(w)$, but $N(u) \not\subset N(v) \bigcup N(w)$ and $N(w) \not\subset N(u) \bigcup N(v)$ in G
2. $N(v) \subseteq N(u) \bigcup N(w)$ and $N(u) \subseteq N(v) \bigcup N(w)$, but $N(w) \not\subset N(u) \bigcup N(v)$ in G and one of the following conditions holds:
   a. $Erg_v < Erg_u$ or
   b. $Erg_v = Erg_u$ and $Vel_v > Vel_u$ or
   c. $Erg_v = Erg_u$ and $Vel_v = Vel_u$ and $Deg_v < Deg_u$
3. $N(v) \subseteq N(u) \bigcup N(w)$ and $N(u) \subseteq N(v) \bigcup N(w)$, but $N(w) \subseteq N(u) \bigcup N(v)$ in G and one of the following conditions holds:
   a. $Erg_v < Erg_u$ and $Erg_v < Erg_w$ or
   b. $Erg_v = Erg_u < Erg_w$ and $Vel_v > Vel_u$ or $Deg_v < Deg_u$ when $Vel_v = Vel_u$
   c. $Erg_v = Erg_u = Erg_w$ then
      i. $Vel_v > Vel_u$ and $Vel_v > Vel_w$ or
      ii. $Vel_v = Vel_u > Vel_w$ and $Deg_v < deg_u$ or
      iii. $Vel_v = Vel_u = Vel_w$ and $Deg_v = min\{Deg_v, Deg_u, Deg_v\}$

The above rule indicates that when v is covered by u and w; the conditions are

1) if neither *u* or *w* is covered by the other two among *u*, *v* and *w* then *v* is unmarked.
2) if neighbour set of *v* is covered by *u*, *w* and neighbour set of *u* is covered by *v*, *w* but neighbours of *w* are not covered by *u*, *v* then *v* is unmarked if the energy level of *v* is smaller than *u*. Velocity is used to break the tie if energy levels are same. Degree is used to break the tie if both energy and velocity values are same.
3) If neighbour set of *v*, *u* and *w* are covered by the other two among *u*, *v* and *w* then node *v* is unmarked with conditions: energy level of *v* is less than *v* and *w*; the energy level of *v* is same as *u* but smaller than *w*, velocity value is used for unmarking. If velocity values are same then degree of *v* is used to break the tie.

The procedure for the energy efficient CDS construction algorithm is given in Table 2.

Table 2. Algorithm for Energy Efficient Stable CDS Construction

Algorithm: EES-CDS

Input: An undirected graph G(V, E)

Output: EES-CDS

- **Neighbour Discovery phase**

  Nodes periodically exchange *hello* messages for neighbour discovery. Every node sends and receives *hello* messages but does not forward them. A *hello* message generated by a node u contains its ID, Energy (Erg_u), Velocity (Vel_u) and list of neighbours N(u). This one hop neighbourhood exchange enables every node *u* to obtain its two hop neighbourhood information.
- **CDS Formation Phase**

  1. MPR Selection
     1. Initially all nodes are in White colour
     2. Every node *v* assigns its N(*v*) to MPR(*v*) if it has two unconnected neighbours.
     3. Marks all the nodes in MPR(*v*) to Black Colour
     4. Marks all the neighbours of MPR(*v*) to Gray Colour
  2. Apply Proposed Rule 1 and Rule 2 to construct minimum size CDS.

It is clear that node *u* only has to wait for the information about its two hop neighbours. The set of all MPR is a connected dominating set of the entire network. The node terminates the construction phase by communicating its final decision to all its neighbours Figure.

4 Simulation Results and Analysis

4.1 Simulation Environment

In this section, the simulation results are reported and analyzed. We implemented our algorithm EES-CDS in ns-2.34. To evaluate the performance of our algorithm, we also implemented the approach proposed by Wu in [1] and Meganathan in [4]. To generate a network, *n* nodes are randomly placed in a 1000m x 1000m region. Each node has uniform transmission range 250m and is associated with an initial energy values from 1J to 15J. In our simulations, the number of nodes *n* has been assigned the values 50, 100, 150, 200, 250. This allows us to test our algorithm from sparse to dense networks. Any two nodes distance less than the transmission range are considered neighbours. Each node moves randomly in this area with a speed in the range [0..V_{max}] and a pause time of 10s. The values of V_{max} are 5, 10 and 25m/s. Each simulation is conducted for 600s and it is repeated 10 times. The parameters used in our simulation are listed in Table 3.

Table 3. Simulation Parameters

Network Area	1000m
Number of Nodes	50..250
Transmission Range	250m
Mobility Speed	5m/s, 10m/s, 25m/s
Initial Energy	1J..15J.
Energy for transmission	1.4W
Energy for Receiving	1.0W
Idle energy	0.013W
Pause time	10s
Simulation Time	600s
Propagation Model	Two-ray Ground
MAC	IEEE 802.11
Antenna	Omni Antenna
Mobility Model	Random Way Point

We implemented this algorithm by using three messages: The first message is for exchanging the list of neighbours, the second is used by a node *u* to communicate to a neighbour *v* for which *u* is the MPR selector and the final one is used by a node to make every neighbour aware of its final decision.

4.2 Result Analysis

We measured the performance of our work in terms of

- Average CDS Size
  It describes the no of nodes included in the CDS to act as broadcast relay nodes. Figure 1 (a-c) shows the average no of nodes included in the CDS with different mobility values 5m/s, 15m./s and 25m/s. The results show that CDS generated by our algorithm is larger than Wu[1] and less than Meganathan [4]. In [1], Wu used node degree for selection and Meganathan in [4] selected nodes with only lower velocity. The average size of the CDS increases with network density.

- CDS Stability
  The simulation stops when the energy level of at least one node becomes 0. Figure 2 (d-f) shows the comparison of our work with Wu [1] and Meganathan [4] in terms of lifetime. Our work outperforms well than the other two works because nodes in the CDS generated by our algorithm has high energy level and minimum velocity. The CDS stability is high when the node velocity is low. In [4], priority is given to slow moving nodes but they don’t consider the energy level of the nodes.

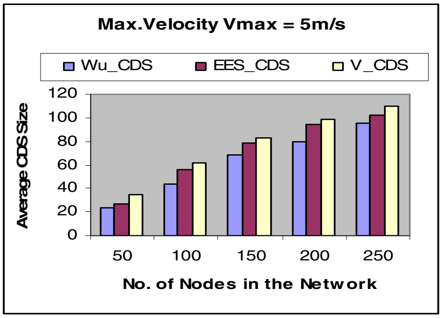

Fig (a)

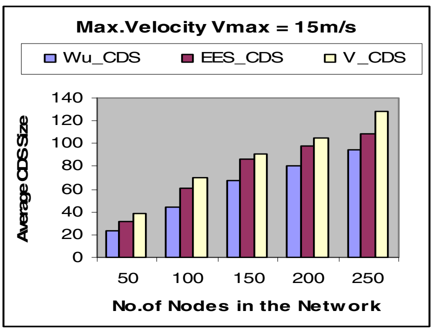

Fig (b)

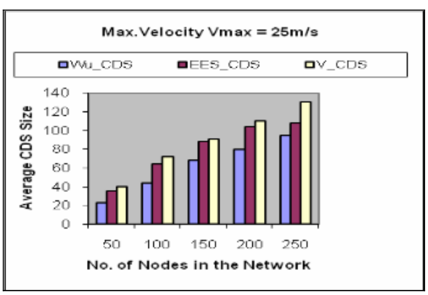

Fig (c)

Fig. 1. (a-c) Average CDS Size with Velocity V_{max}= 5, 15, 25m/s

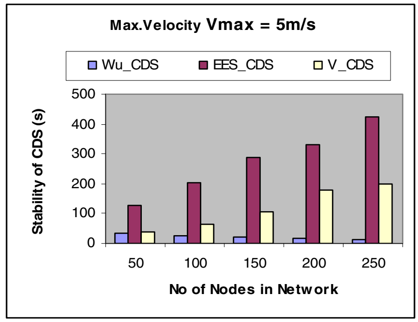

Fig (d)

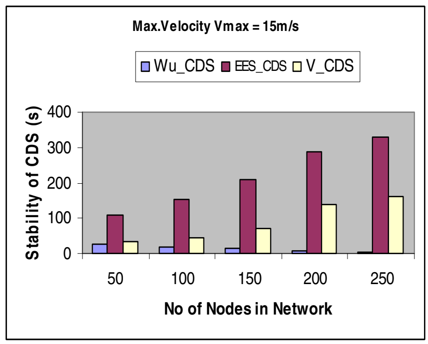

Fig (e)

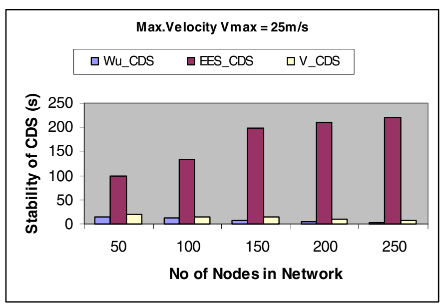

Fig (f)

Fig. 2. (d-f) Stability of CDS with Velocity V_{max}= 5, 15, 25m/s

5 Conclusion and Future Work

In this paper, an algorithm for power efficient stable connected dominiating set construction is proposed. We have proposed two rules to reduce size of the connected dominating and to prolong the life span of the nodes. Our algorithm is based on resuidual energy level, velocity and degree to construct the connected dominating set so that the life of the backbone can be stable. The results from the siumation show that our work outperforms in terms of stablity and it increases the lifetime by 25% to 30%. We plan to perform energy efficient broadcasting through the generated CDS as our future work.

Acknowledgement. The authors would like to thank the Project Coordinator and Project Directos of TIFAC-CORE in Network Engineering, Kalasalingam University for providing the infrastructure facilities in Open Source Techhnolgy Laboratory and also thank Kalasalingam Anadam Ammal Charities for providing financial support for this work.

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