

DEMAC: A Cluster-Based Topology Control for Ad Hoc Networks

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Abstract

The presence of transient network links, mobility and limited battery power of mobile nodes in MANETs poses a hefty challenge for such networks to scale and perform efficiently when subjected to varying network condition. Most of the topology control algorithms proposed have high control overhead to discover and maintain route from source to destination. They also have very high topology maintenance cost. To minimize routing overhead and topology maintenance cost CBRP (Cluster Based Routing Protocol) was developed. It performs better than other approaches in most of the cases.

In this paper, an energy and mobility aware clustering approach is presented. The clustering approach is incorporated in a DSR like protocol for routing in MANET to evaluate the performance improvement gained due to clustering using proposed approach. Rate of cluster head changes, throughput of the network, delay and routing overhead is evaluated using NS2. Simulation results reveal that proposed approach has better performance in comparison with CBRP.

Keyword: *Mobile Ad-Hoc Networks, Topology Control, Clustering*

1. Introduction

A mobile ad-hoc network (MANET) is a collection of mobile nodes that form a wireless network without the existence of a fixed infrastructure or centralized administrative. This type of network can survive without any infrastructure and can work in an autonomous manner. Hosts forming an ad-hoc network take equal responsibility in maintaining the network. Every host provides routing service for other hosts to deliver messages to the remote destinations. As such network does not require any fixed infrastructure; it makes them best for deployment in volatile environment such as battle field and disaster relief situations. Some of the constraints in MANETs are - limited bandwidth, low battery power of nodes and frequent link breaks due to mobility of the nodes. These constraints should be taken into consideration while maintaining the connectivity among the nodes.

Topology control plays an important role in solving such problems. Topology control is the problem of computing and maintaining connected topology among the network nodes. The major goals of topology control are connectivity with energy efficiency, high throughput and robustness to mobility etc. A number of algorithms for topology control are already proposed in the literature [1-4]. These algorithms are mainly of two types: Centralized and Distributed algorithms. Centralized algorithms rely on global topology information to make adaptive decisions where as distributed algorithms rely on partial link state information such as neighbor counts to maintain network connectivity. Centralized algorithms have the problem of high connectivity overhead and scalability. Therefore, distributed topology control algorithms are generally preferred over centralized topology control algorithms.

The main idea behind the energy efficient topology control algorithm is that allow nodes in the network to communicate in its neighborhood to form small groups of nodes which are called clusters. In CBRP, the cluster head election is based on the ID of the nodes and the node with the lowest ID among its neighbors is selected as cluster head. Because of mobility of nodes in ad hoc network this is probable that elected cluster head to be too mobile. Therefore, the lowest ID nodes will be consuming extra battery power for performing functionalities of a cluster head. This will lead to election of inactive or poor energy node as cluster head. The selected lower energy nodes will result in performance degradation in the network and more energy will be consumed indirectly as a result of frequent change of cluster head. Motivation behind introducing degree, energy and mobility aware clustering scheme is to find an alternative efficient way for clustering of MANET that improves the performance of the ad-hoc network and reduces the frequency of change of cluster heads.

This paper proposes a clustering scheme for MANET. The scheme named Degree Energy Mobility Aware Clustering Scheme (DEMAC) is a degree, energy and mobility aware clustering approach.

2. Related Works

Various topology control algorithms are available for mobile ad-hoc networks that try to utilize battery power of mobile nodes in an efficient way. This section briefly reviews some the prior works on topology control.

Local Information No Topology (LINT) proposed by Ramanathan et al. [5] uses locally available neighbor information collected by routing protocols to keep the degree of neighbors bound. All network nodes are configured with three parameters, the desired node degree d_d, a high threshold of the node degree d_h and a low threshold of node degree d_l. A node periodically checks the number of its active neighbors. If the degree is greater than d_d, the node reduces its operational power. If the degree is less than d_d the node increases its operational power. If neither is true then no action is taken.

On the other hand, selective backbone construction for topology control [6] is a backbone based approach. In this approach a chain of connected nodes are constructed. All the other nodes in MANET should be neighbor of a node that participates in construction of the backbone. The backbone construction in SBC starts from a small number of seed nodes and propagates outwards to sweep the network. When a node selects its neighbors to include in the backbone, it also transfers the topology information it knows so far to these neighbors. Thus, the neighbors can make more intelligent coordinator selection decisions based upon more topology information and avoid redundancy. When choosing coordinators, SBC simultaneously considers the energy requirement, movement and location of nodes to maximize energy conservation, and ability to maintain good networking performance. The problem with this scheme is its high topology maintenance cost.

In this paper Cluster Based Routing Protocol (CBRP) [5] will be given more emphasis because the protocol divides the nodes of the ad hoc network into a number clusters. By clustering nodes into groups, the protocol efficiently minimizes the flooding traffic during route discovery and speeds up this process as well. Major advantage of this protocol is its low topology maintenance cost.

3. CBRP Overview

Cluster Based Routing Protocol (CBRP) [7-9] is a routing protocol designed for use in mobile ad hoc networks. The protocol divides the nodes of the ad hoc network into a number of overlapping or disjoint 2-hop-diameter clusters in a distributed manner. A cluster head is elected for each cluster to maintain cluster membership information. Inter-cluster routes are discovered dynamically using the cluster membership information kept at each cluster head. By clustering nodes into groups, the protocol efficiently minimizes the flooding traffic during route discovery and speeds up this process as well [10]. Furthermore, the protocol takes into consideration the existence of uni-directional links and uses these links for both intra-cluster and inter-cluster routing.

3.1 Types of nodes

In CBRP network nodes are categorized as cluster head, cluster member and gateway nodes. A cluster head for each cluster is elected in the cluster formation process for each cluster. A cluster head will have complete knowledge about group membership and link state information in the cluster. All nodes within a cluster except the cluster head are called members of this cluster. Any node a cluster head may use to communicate with an adjacent cluster is called a gateway node.

3.2 Data structures

Each node maintains neighbor table, cluster adjacency table and two-hop database for routing of packets from source to destination nodes. Neighbor table keeps track of the neighbor ID, neighbor status and link status with the neighbor of a node. Cluster adjacency table keeps information about adjacent clusters. Two hop topology databases contain information about the two hop neighbors of a node.

3.3 Cluster formation

The goal of Cluster Formation is to impose some kind of structure or hierarchy in the otherwise completely disorganized ad hoc network. Apart from the states of cluster member and cluster head, a transitional state called cluster undeclared is also defined for smoother operation of cluster formation. "Undecided" means that a node is still in search of its host cluster. Initially all the nodes' status is undeclared.

Each node transmits some packets named "Hello message" to announce its presence to its neighbor nodes. Upon receiving a hello message, each node updates its neighbor tables. Each node enters the network in the "undecided" state. Every node upon receiving hello message from its neighbors compares its own ID with its neighbor's. If a node distinguishes that its own ID is the lowest ID between its neighbors, this node declares itself as cluster head. Every node that has a bi-directional link to this cluster head will be a member of this cluster

Clusters are identified by their respective cluster heads, which means that the cluster head must change as infrequently as possible. The algorithm is therefore not a strict "lowest-ID" clustering algorithm. A non-cluster head never challenges the status of an existing cluster head. Only when two cluster-heads move next to each other, one of them loses its role as cluster head.

3.4 Routing

Routing in CBRP is based on source routing. RREQ is flooded in the network to discover the route. Due to the clustering approach very few nodes are disturbed, only the cluster heads are flooded. If node S seeks a route to node R, node S will send out a RREQ, with a recorded source route listing only itself initially. Any node forwarding this packet will add its own ID in this RREQ. Each node forwards a RREQ only once and it never forwards it to node that already appears in the recorded route. The source unicasts the RREQ to its cluster head. Each cluster-head unicasts the RREQ to each of its bi-directionally linked neighboring clusters, which has not already appeared in the recorded route through the corresponding gateway. This procedure continues until the target is found or another node can supply the route. When the RREQ reaches the target, the target may choose to memorize the reversed route to the source. It then copies the recorded route to a Route Reply packet and sends it back to the source.

4. Degree Energy Mobility Aware Clustering Scheme: DEMAC

In MANET absence of any fixed infrastructure makes network topology more unstable. Random movement of the MANET nodes makes the selection of cluster head in hierarchical algorithm, such as CBRP, very much important. If the cluster head selection is not proper overall performance of the network will be degraded. Therefore, wise cluster head selection can lead to a well performing routing protocol. In CBRP the node having lowest ID among its neighboring nodes will be the cluster head. Obviously, neither the node's residual energy nor the mobility of the node is taken under consideration. As mentioned earlier, in hierarchical cluster-based MANET, cluster heads play the main role in maintaining the cluster structure and standing against the destructive factors namely mobility. In the degree, mobility and energy based approach proposed in this paper, cluster formation mechanism is considered with respect to node speed, residual energy and degree of the node. With this scheme, a node with the highest F-value will be named cluster head.

4.1 Priority function (F)

The algorithm considers three factors for selection of cluster head namely- node speed, residual energy and degree of node. The node speed is important for selection of a cluster head. This is because, if a highly mobile node is elected as cluster head, there is a higher possibility of the cluster head to move out of the neighborhood of the respective cluster which lead to election of a new cluster head. Similarly, the energy is taken into consideration because if a poor energy node is elected as cluster head, the node will be dead shortly and an initiation of cluster head election process will take place more frequently. Degree of the node is taken into consideration so that a cluster contains good number of nodes as member node. Our algorithm uses a function of these three factors to assign a priority level to a node for election of cluster head. The function used for estimation of priority level for cluster head election is given as-

$$F = (\text{residual energy} * \text{degree})/2^{\alpha * \text{speed}} \quad (1)$$

Where α is a constant which represents the degree by which the speed effects the priority. With large α, nodes moving at low speed would be preferred to be selected as cluster heads.

4.2 Hello message and neighbor table

To keep track of neighborhood each node maintains a neighbor table having fields for ID of the neighboring nodes, link status, and role of neighboring nodes and value of F. Continuous updating of the neighbor table is done by periodic transmission and reception of the hello message to and from the neighborhood of a node. Hello message will carry important information regarding the sender such as nodes ID, node status, neighbor table, cluster adjacency table and value of F.

4.3. Methodology

ISSN (Online): 1694-0814
www.IJCSI.org

In order to use the priority given in Eq.(1) for clustering, a two step clustering algorithm is proposed which uses the priority as a basis for cluster head selection. In DEMAC all the nodes send (receive) hello message to (from) their neighbors. On receiving the hello message from its neighbors a node will count number of neighbors it has. Then it calculates the value of F using Eq.(1). All the nodes start in Cluster-Undeclared state. Every node broadcasts its priority in a "hello" message to its 1-hop neighbors, once in every Broadcast Interval (BI) period. If the node is not already in the neighbor table of each neighboring node, it will be stored in the neighbor table of them along with a timeout period (TP) seconds as new neighbor. Otherwise neighboring node's entry in neighbor table is updated. Fig. 1 shows the algorithm in details.

The algorithm is distributed. Thus, a node receives the F-value from its neighbor then compares them with its own. If a node has highest value of F among all its neighbors, it assumes that it has status of cluster head. Then the node broadcasts "hello" packet to introduce itself as cluster head. In case, the priority of two nodes are same, the cluster head selection is base on the lowest ID algorithm, the node with the lowest ID gets the status of cluster head. If a node with cluster member or cluster undecided status moves into the range of another cluster head node with higher mobility, a clustering process will not be triggered because this decreases the stability of the network and overhead for topology control increases.

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A node x receives a "hello" packet from y:
x searches its neighbor table;
if (y is already in the neighbor table of x) then
  -calculate the F-value of node x using (1);
  -update neighbor table's field of node x for node y;
  -update the cluster adjacency table of node x;
  -update 2-hop database of node x;
  -update the number of cluster head related to x;
  if (x is a cluster head in proximity of other cluster head)
then
     if (F-value of x is greater than node y) then
        -node x remains cluster head;
        -node y gives up cluster head role and becomes a
         member node of x;
        -return;
     else if (F-value of node x is equal to node y) then
           if (x has a lower ID) then
              -x remains cluster head;
              -y becomes a member of x;
              -return;
           else
               - x is member of neighbor cluster head;
                -return;
```

Fig. 1 Cluster formation algorithm for DEMAC

In DEMAC, each node transmits some packets named "Hello message" to announce its presence to its neighbor nodes. In the example when node 1 receives a hello message from its neighbor node 2 it updates its neighbor table's entry corresponding to node 2. Node 1 also updates its cluster adjacency table and 2-hop neighbor database. Upon receiving a hello message, node 1 counts the number of neighbor nodes. It also measures its speed and residual energy. Then it computes its F-value using Eq.(1) and compares it with F-value of its neighbors. Let node 1 has highest value of F among its neighbors nodes (2, 3, 4, 5) and none of its neighbor is cluster head, it declares itself a cluster head and sends a hello message to its neighbors. Nodes 2,3,4,5 will become the member of the cluster whose cluster head is node 1. Node 2 is also the member of cluster 6. Therefore, in the example node 2 is a gateway node. Node 3 and 9 maintains connectivity between cluster 1 and 8. Therefore node 3 and 9 are also gateway nodes. Similarly node 7 and 11 are also gateway nodes.

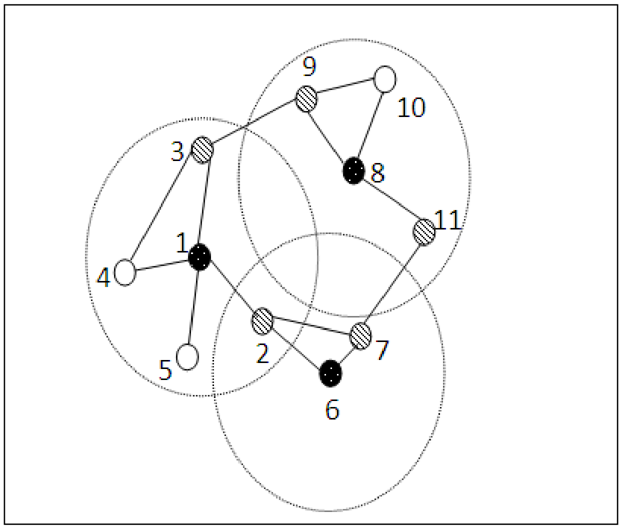

Fig. 2 Example of DEMAC

5. Simulation and Performance Analysis

The proposed protocol is simulated in NS-2.31 network simulator [11]. The mobility scenarios were randomly generated using the random waypoint mobility model with input parameters such as maximum speed, number of nodes, area size, etc. NS-2 CBR generator is used to generate traffic. There are simultaneously 10 CBR traffic flows associated with randomly selected disjoint source and destination node. Packet size is 512 bytes. The CBR rate in the network is taken as 8 pkts/s. The initial energy of each node is 500 Joules. Each Node will consume 0.002 w for transmission, 0.00175 w for reception, 0.00005 while idling. CMUPriQueue is used for implementing the interface queue. Size of the buffer is set to 50. DEMAC is implemented by doing the required modification on the implementation of CBRP in ns-2 environment. The Simulation parameters are listed in table(1).

Table1. Simulation Parameters

Parameter	***Meaning***	***Value***
N	Number of Nodes	50
m x n	Size of the scenario	500 x 500
Max Speed	Maximum Speed	5,10,15,20,25 (m/s)
Tx	Transmission Range	90 m
P.T	Pause Time	0.0 sec

The simulation has been run for 100 seconds. The results are averaged over 5 randomly generated nodal topologies. The performance of DEMAC is compared with CBRP considering number of cluster head changes, throughput, delay and routing overhead with respect to maximum speed of the node.

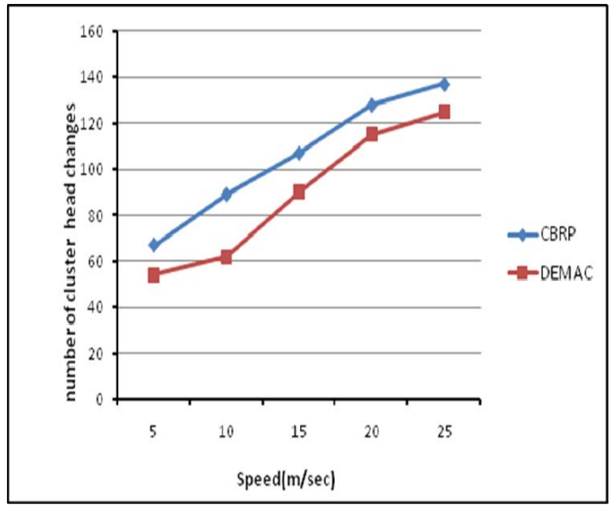

Fig. 3 Number of Cluster Head Changed vs. Speed

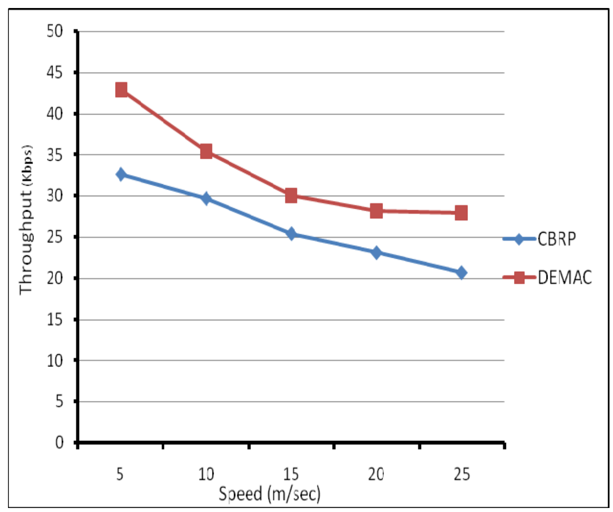

Fig. 4 Throughput vs Speed

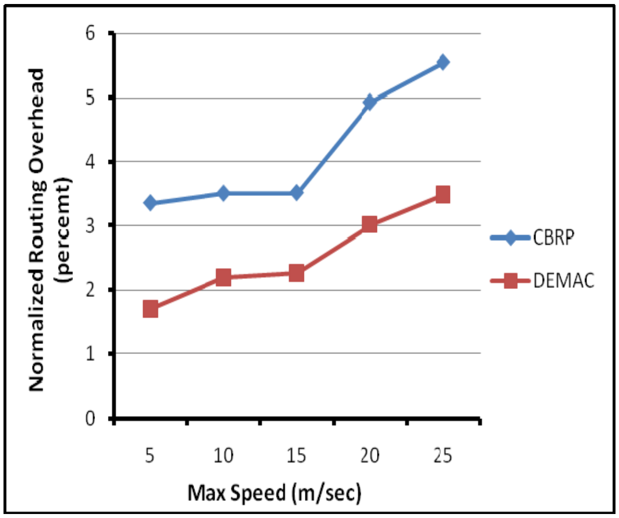

Fig. 5 Normalized Routing Overhead vs Speed

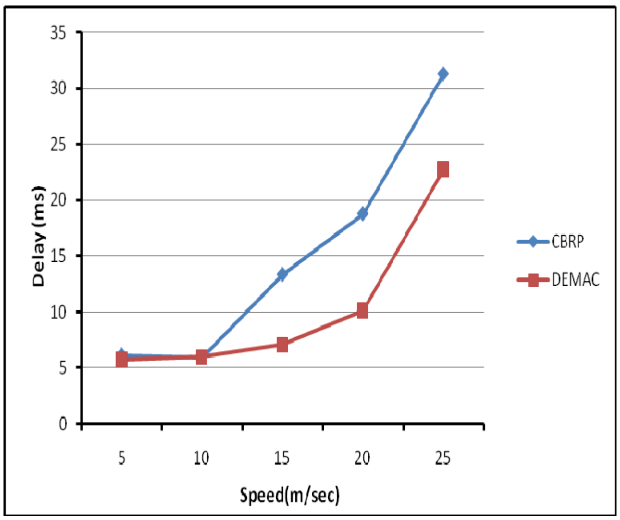

Fig. 6 Average End-to-end Delay vs. Speed

In simulation a scenario with rate of 10 pkts/sec is used. Maximum speed of the node has been considered 5, 10, 15, 20, 25 m/s. The scenario is tested for both CBRP and DEMAC. Fig3 represents the effect of varying mobility on the number of cluster head changes in the ad-hoc network considering both DEMAC and CBRP. It can be seen from Fig.3 that DEMAC outperforms CBRP by average 15.5% improvement for cluster head changes. It is very clear that DEMAC yields a very good gain over CBRP because it has taken degree, residual energy and speed of the node. From the cluster head changes vs mobility curve, it can be said that DEMAC is more suitable for cluster formation than CBRP.
Throughput is defined as the average number of data packets received at destinations during simulation time. Fig.4 demonstrates the results of the measured throughput for CBRP and DEMAC. It can be seen from Fig.4 that DEMAC outperforms CBRP by average 25%.

Normalized routing overhead is the percentage of routing packets with respect to cbr packets. Fig.5 demonstrates the results of the measured normalized overhead for CBRP and DEMAC. It can be seen from Fig.5 that DEMAC outperforms CBRP by average 39%. Average end-to-end delay is the average time required for a packet to reach the destination from source. It can be observed from Fig.6 that though in low node speed the end-to-end delay of CBRP is almost equal to that of DEMAC but when the node speed increases the end-to-end delay of CBRP becomes more than DEMAC. DEMAC outperforms CBRP by average 31.5%.

6. Conclusion and Future Work

In this paper DEMAC is proposed as a degree, energy, mobility aware clustering scheme in MANET. Due to its improved cluster head selection algorithm DEMAC outperforms CBRP with respect to number of cluster head changes, throughput, delay and routing overhead. From the simulation results, it is observed that the proposed method has up to 15.5% less number of cluster head changes in comparison with CBRP. Similarly, considering throughput a gain of 25% is recorded in DEMAC over CBRP. Further DEMAC also have 39% less routing overhead and 31.5% less average end-to-end delay as compared to CBRP. Therefore it can be concluded that DEMAC is more suitable than CBRP for MANET. Future works remain for performance evaluation of DEMAC in different network densities and different transmission range keeping the mobility same.

References

[1] Kenneth J. Supowit, "The relative neighbourhood graph with application to minimum spannig trees", Journal of theACM, Vol. 30, No. 3, 1983, pp. 428-448.
[2] Ning Li, Jennifer C Hou and Lui Sha, "Design an Analysis of an MSTBased Topology Control Algorithm", in INFOCOM, 2003.
[3] Nicos Christofides, Graph Theory : An Algorithmic Approach, Academic press, 1975.
[4] Hu L, "Topology control for multihop packet radio networks", in Communications, IEEE Transactions on, Vol. 41, Iss. 10, 1993, pp. 1474- 1481.
[5] Ramanathan R. and Rosales-Hain R., "Topology control of multihop wireless networks using transmit power adjustment," in Proc. IEEE INFOCOM, 2000.
[6] Haitao Liu and Rajiv Gupta, "Selective Backbone Construction for Topology Control in Ad Hoc Networks", IEEE, 2004, pp. 41-50.
[7] Chien-Chung Shen, Chavalit Srisathapornphat, Rui Liu,

Zhuochuan Huang, Chaiporn Jaikaeo, Sand Errol L. Lloyd, "CLTC: A Cluster-Based Topology Control Framework for Ad Hoc Networks", IEEE TRANSACTIONS ON MOBILE COMPUTING, Vol.3, Issue1, JANUARY-MARCH 2004, pp. 18-32

[8] P.Basu, N. Khan, and T.D.C. Little, "A Mobility Based Metric for Clustering in Mobile Ad Hoc Networks", MCL Technical Report No. 01-15-2001

[9] M. Jiang, J. Li, and Y.C. Tay, "Cluster Based Routing Protocol," IETF Draft**,** August 1999.

[10] J. Mingliang, Y.C. Tay and P. Long, "CBRP: A Cluster-based Routing Protocol for Mobile Ad hoc Networks", National University of Singapore. http://www.comp.nus.edu.sg/~tayyc/cbrp/hon.ppt.

[11] Network simulator ns-2 http://sourceforge.net/projects/nsnam/files/allinone/ns-allinone-2.31/ns-allinone-2.31.tar.gz