

# Efficient Passive Clustering and Gateway Selection in MANETs

T. Shivaprakash<sup>1</sup>, C. Aravinda<sup>1</sup>, A.P. Deepak<sup>1</sup>, S. Kamal<sup>1</sup>, H.L. Mahantesh<sup>1</sup>,  
K.R. Venugopal<sup>1</sup>, and L.M. Patnaik<sup>2</sup>

<sup>1</sup> University Visvesvaraya College of Engineering, Bangalore 560 001, India

<sup>2</sup> Indian Institute of Science, Bangalore 560 012, India

**Abstract.** Passive clustering does not employ control packets to collect topological information in ad hoc networks. In our proposal, we avoid making frequent changes in cluster architecture due to repeated election and re-election of cluster heads and gateways. Our primary objective has been to make Passive Clustering more practical by employing optimal number of gateways and reduce the number of rebroadcast packets.

## 1 Introduction

Mobile Ad hoc Network (MANET) is an infrastructure-less network which consists of a collection of wireless mobile hosts to form a temporary network without the aid of any base station. Since bandwidth is limited in an ad hoc network, it is important to construct a virtual backbone consisting of only a subset of nodes that have the privilege to forward packets. Such a virtual backbone called *spine* plays an important role in routing, broadcasting and connectivity management in wireless ad hoc networks. An effort should be made to keep this backbone thin and connected [1].

A cluster is a set of nodes which can be treated as a single entity during packet transmission. Each node in a cluster assumes a role depending on its position and other topological information. The most important role in a cluster is played by the *Clusterhead*. A node which belongs to more than one cluster becomes a *Gateway*. A gateway is responsible for routing packets across two clusters as they are reachable from both the clusters in a single hop. Passive Clustering mechanism does not use any explicit control messages to maintain clusters. Instead, it piggybacks the control information on the out-going data packets and has the advantage of reducing the control overhead. The active clustering algorithm was proposed by Lin and Gerla [2] based on Least Id principle. An innovative mechanism for cluster formation called Passive (On Demand) clustering is provided in [3]. This method does not use any explicit control messages. The existing reactive protocols such as DSR [4], AODV [5] have high control overhead and rebroadcast messages.

This paper addresses the issue of scalability with respect to increase in the number of control packets using Passive clustering. A new Gateway Selection Heuristic which eliminates redundant gateways during Passive Clustering has been proposed.

## 2 Problem Definition

Given a wireless network  $G_w(V, E, n)$  of a finite set of nodes,  $V = \{v_1, v_2, \dots, v_n\}$  and a finite set of links  $E = \{(v_i, v_j) \mid v_i, v_j \in V \wedge v_i \neq v_j\}$ , a link is said to exist between two nodes  $v_i$  and  $v_j$  if they are within the transmission range of each other. The objectives are to (i) reduce the number of rebroadcasts by reducing the number of redundant gateways between the overlapping clusters and (ii) reduce the quantity of control information loaded on the data packets.

### 2.1 Topological Problems Associated with Passive Clustering

*Problem 1: An ordinary node may move into other clusters and generate a spurious gateway.*

When a node moves from one cluster to another cluster, it starts receiving packets from the new cluster head. It updates the cluster table with the information about the new cluster head, while retaining the information about the previous cluster head. In this situation, it enters into a gateway ready state and further, it may become a gateway.

This is highly unacceptable, because (i) after the movement, it may not be in the common region of both clusters (ii) it may cause the real gateway candidate to become *ordinary*, resulting in the loss of connectivity between two clusters. (iii) it will have privilege to rebroadcast, which it should not have, resulting in an increase in the number of rebroadcasts and hence an increase in the traffic.

*Problem 2: A gateway may move away from the intersection area into a single cluster without relinquishing the status of the Gateway.*

Ideally, such a gateway must become an ordinary node, since it now belongs to one cluster only. Instead, it continues to assume that it belongs to two clusters and hence it will stay in *gateway* state, rebroadcasting all the incoming packets.

*Problem 3: Spurious generation of multiple gateways.*

In a dense wireless network, there will be a number of nodes in the intersection region of any two clusters. All of them compete for the *Gateway* status and the one with the *least id* wins. However, if all the candidates do not hear from same cluster heads, then all of them become gateways. This creates redundant gateways and causes a broadcast storm [6] in the wireless network.

*Problem 4: Formation of redundant clusters.*

During the initial setup, all the nodes that receive packets from the ordinary nodes, become cluster heads. This results in dense and overlapped clusters.

*Problem 5: Problems associated with the cluster head moving out of a cluster.*

If an ordinary node does not receive packets from its cluster head for a long time, it assumes that the cluster head is still present but it has no packets to send. The ordinary node knowing nothing about its cluster head's absence continues

to send packets to the cluster head to route them to the destination resulting in the loss of packets and redundant broadcasts by the source.

### 3 Algorithm: Efficient Passive Clustering (EPC)

In the cluster architecture, a node can be in any of the following states: *initial*, *ordinary\_node*, *gw\_ready*, *gateway*, *dist\_gw*, *cluster\_head*. The algorithm is as follows:

1. All nodes are in the *initial* state and they are assigned a unique ID.
2. A node that first wants to transmit packets becomes the source node. It sends a packet to all its neighbors and declares itself as a Cluster Head.
3. If the *initial* node hears from a *cluster\_head*, it becomes an *ordinary\_node*.
4. If a node (other than *initial* and *cluster\_head*) hears from a non-Cluster Head,
  - (a) It checks whether the sender node was a Cluster Head before. This check is carried out by scanning its cluster table in search of the sending node's ID. (Cluster Table maintains a list of Cluster Heads reachable from the node).
  - (b) If the sender node was a Cluster Head before, then its entry is cleared from the cluster table of the receiving node. Packets from this node are not forwarded henceforth.
  - (c) If cluster set of the node becomes null, the node changes its state to *cluster\_head*.
5. Contention between the Cluster Heads is resolved by the Least ID method. This is because the Cluster Head does not monitor the cluster. The purpose of this step is to have only one Cluster Head per cluster.
6. An *ordinary\_node* receiving packets from more than one *cluster\_head* enters into *gw\_ready* (gateway ready) state.
7. A *gw\_ready* node becomes a *gateway* based on the *Intelligent Gateway Selection Heuristic*.
8. A *gateway* on receiving packets from other *gateway* or *gw\_ready* nodes, may change its state based on the *Intelligent Gateway Selection Heuristic*.
9. If an *ordinary\_node* hears from another *ordinary\_node* or *dist\_gw* of another cluster, and if there are no gateways in the intersection area, it becomes a Distributed Gateway (*dist\_gw*).
10. If a *dist\_gw* hears from *gateway* or *gw\_ready* of the same cluster-pair, it becomes *ordinary\_node*.
11. No node remains in the intermediate state for a long time.
12. If the node times out its state is set to *initial*.

#### 3.1 Intelligent Gateway Selection

The number of rebroadcast packets is directly proportional to the number of gateways. Redundant gateways increase the number of rebroadcasts. Hence, we

give a heuristic that selects a optimum number of gateways. The Intelligent Gateway Selection Heuristic takes into account the history of competitions that a node underwent using  $\text{Competition\_count}(C_c)$ , while deciding its status [7]. The Competition Count ( $C_c$ ) of a node is the number of times a node competes for the *gateway* status. It is set to zero, each time a node acquires either *initial* or Cluster Head status. The Redundancy Factor ( $R_f$ ) of the network is the maximum number of common clusters that any two neighboring gateways can connect. Every node has a data structure called a Cluster Set, which is the set of all cluster heads from which it can receive packets.

*Case 1: Only one node in the intersection area:* When the node receives packets from two cluster heads, it enters into the *gw\_ready* state and it becomes a gateway.

*Case 2: Two or more nodes in the region of intersection of clusters:* When a node receives packets from the other Gateway or *gw\_ready*, it compares its cluster set with that of the sending node. If both the sets are same, then the one with the least ID becomes the gateway.

*Case 3: The cluster-set of one node in the intersection area is a subset of the cluster-set of another node:* Suppose there are two nodes in the intersection area of clusters such that, the cluster-set of one node is a subset of the cluster-set of another node. Then the node with the superset will be selected as the gateway. Every gateway performs this comparison by intercepting the packets from its neighboring gateways.

*Case 4: Two nodes such that  $(\text{cluster-set}(\text{node1}) \sim \text{cluster-set}(\text{node2})) \neq 0$ :* In this case both the nodes have a tendency to declare themselves as gateways when they receive packets from each other. But this may not be optimal, since there may be a difference of just one cluster head between the cluster-sets. This leads to creation of redundant gateways. The receiving node computes the number of clusters that are common to both the sending node's and receiving node's cluster-sets. If this value is less than or equal to the Redundancy Factor ( $R_f$ ), then both nodes are designated as Gateways. Otherwise, the node with the least  $\text{Competition\_count}(C_c)$  is designated as the Gateway. The heuristic intelligently selects the best gateway in the intersection area of two or more clusters.

## 4 Performance Analysis

Passive clustering is simulated in the NS-2 (version 2.26) simulation environment. Simulation results reveal that there is a reduction in the control overhead and the number of rebroadcasts by the application of the EPC algorithm. The number of gateways and the number of cluster heads are also reduced. The IEEE 802.11 DCF and two-ray propagation model is employed for simulation. The broadcast range for each node is 250 meters and the area of experiment is 2x2 sq. km. Mobility is measured in meters per minute. Both the simple passive clustering and improved passive clustering algorithm are implemented on AODV [5].

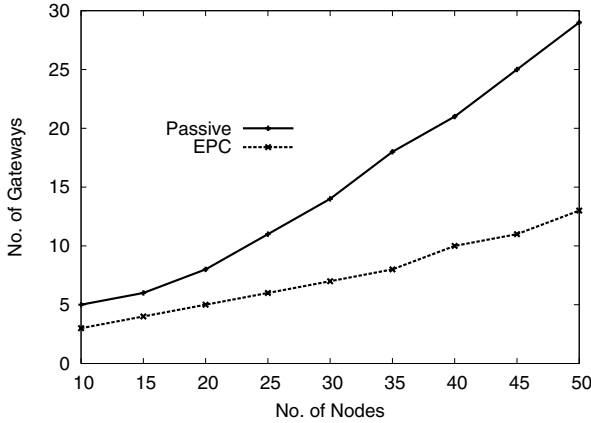


Fig. 1. No. of Gateways vs. No. of Nodes

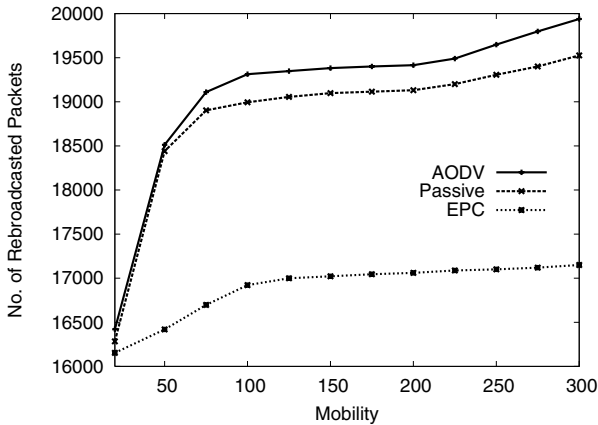


Fig. 2. No. of Rebroadcasted Packets vs. Mobility

By employing the efficient gateway selection heuristic, with the Redundancy Factor set to one, minimal number of gateways are chosen. Not more than one gateway is chosen between two clusters. The gateways form a *thinner* backbone while maintaining the connectivity among all the clusters within the designated area. Also, inclusion of more nodes will not increase the number of clusters and the number of gateways will remain fairly constant. Hence, the gateway curve of our algorithm is linear compared to that of the simple passive clustering as shown in Fig. 1.

The Number of Rebroadcasted Packets (NRP) is the total number of packets that are broadcast and rebroadcast from all the nodes, irrespective of their states. This is a very important parameter because an increase in NRP results in broadcast storm. The number of rebroadcasts is directly proportional to the total number of cluster heads, gateways and distributed gateways in the ad hoc

network. This is because in passive clustering, only the cluster heads, gateways and distributed gateways of a cluster have the privilege to forward the packets they receive. As depicted in Fig. 2, the number of rebroadcasts is the lowest for EPC. With the application of the gateway selection heuristic and other improvements over passive clustering, the number of rebroadcasts is reduced considerably. The curve corresponding to our EPC algorithm is more stable (flatter) than others. The number of rebroadcasts is the highest for AODV since every node forwards the incoming packets. The number of rebroadcast messages in passive clustering is lower than AODV, but much higher than EPC.

## 5 Conclusion

The simulation results show that the EPC clustering algorithm is inexpensive, efficient and stable even under mobile conditions. The number of clusters is found to be optimal in dense wireless networks. This paper has proved that Passive Clustering becomes practically possible by implementing the intelligent gateway selection heuristic and on-demand timeout mechanism. Frequent changes in cluster architecture are avoided by precluding repeated re-election of cluster heads. This improves the network performance. Future work can be carried out by employing distributed gateways to route packets.

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