

# An Efficient Clustering Algorithm for Topology Maintenance and Energy Saving in MANETs

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**Abstract**—Mobile Ad Hoc NETWORKS (MANETs) consist of wireless mobile nodes, each of which can act as a router to relay data for others without a pre-existing infrastructure. In MANETs, both topology maintenance and energy efficiency are important, but have usually been addressed separately. This paper proposes a new dynamic clustering algorithm to address both energy conservation and topology maintenance simultaneously. Energy is saved by optimizing the organization of the cluster and by reducing the flooding in backbone route discovery. Topology maintenance is achieved effectively by dynamically changing the structure of the network using an adaptive beacon message according to the mobility rate of the nodes.

**Index Terms**—Mobile ad hoc networks, dynamic clustering algorithm, energy conservation, topology maintenance

## I. INTRODUCTION

Mobile Ad Hoc NETWORKS (MANETs) consist of battery powered wireless mobile nodes, which can freely and dynamically self-organize into arbitrary and temporary multihop topologies without pre-existing infrastructure [1, 2]. The movement of the nodes in MANETs may change the topology rapidly and unpredictably. Therefore both energy efficiency and topology maintenance are important in MANETs. A lot of research has been conducted to address these two issues.

The following are some energy saving technologies [3, 4]:

- scheduling active and non-active nodes;
- selecting a route with minimum total energy to relay the data;
- assigning the needed shortest transmission range to each node.

Topology maintenance can be handled by dynamically adjusting the topology according to location updates sent by the nodes.

However previous research has usually addressed topology

maintenance and energy efficiency separately. That is, the energy efficient schemes may not handle topology maintenance effectively and the topology maintenance schemes may not be energy efficient. Furthermore, most proposed energy efficient schemes do not support node movement. That is, they are only applicable for ad hoc networks with stationary nodes such as sensor networks not MANETs.

The proposed topologies for MANETs can be classified into flat and hierarchical structures. In the flat topology, all nodes are peer. One can easily see that the changes of some nodes in this structure may change the topology of the entire network. Obviously, this topology structure is inefficient for MANETs in which the movement of the nodes may change the topology frequently. Hence the hierarchical clustering topology structure was proposed.

In a traditional clustering ad hoc network, the nodes are separated into groups called clusters. One cluster of the network, as shown in Figure 1, generally consists of three types of nodes: clusterheads (CHs), gateway nodes and normal nodes.

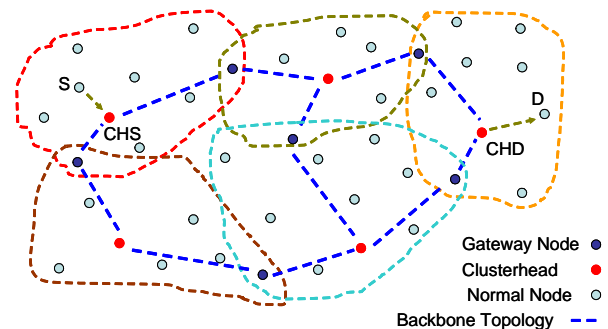


Fig. 1. Clustering ad hoc network.

In each cluster, one node is elected as the CH to act as a local controller and to form the backbone network together with the gateway nodes. Gateway nodes are nodes which belong to more than one cluster, though they are optional in a cluster. The cluster size depends on the transmission range (in a single-hop cluster) or the number of hops (in a multihop cluster) of a cluster.

In clustering ad hoc networks, when a source node (S), as shown in Figure 1, is ready to send data to a destination node (D), it sends the data to its CH (CHS) first using a route-table

based routing protocol. CHS then floods out a route request message to find an efficient route to D. When the route request message reaches CHD, the route information will then be sent back to CHS because CHD has the route information to D. Thus, in traditional clustering networks, intra-clustering communication uses a proactive routing protocol whereas inter-clustering communication uses a reactive routing protocol [18].

In contrast to the flat topology structure, the backbone of hierarchical topology in the network becomes simpler thus reducing the flooding of the route request. The topology becomes more robust because the changes of the nodes only affect the relative clusters and not the entire network [4].

Due to the advantages, many clustering schemes have been proposed to improve the performances of MANETs. However few clustering schemes addressed energy saving for MANETs.

This article proposes a novel dynamic clustering algorithm to address both energy saving and topology maintenance in MANETs simultaneously.

The paper is organized as follows: Previous clustering schemes are summarized in Section II; a new dynamic clustering algorithm (DCA) is proposed in Section III; summary of the paper and future work is given in Section IV.

## II. CLUSTERING SCHEMES REVIEW

Many clustering schemes have been proposed for ad hoc networks. Clustering schemes improve energy efficiency for ad hoc networks with stationary nodes (such as sensor networks) by optimizing cluster size [5-10], distributing power consumption [5, 11-17]. Though most of these original schemes do not support mobility, their design ideas are still applicable to MANETs.

Topology maintenance can be handled by dynamic clustering and/or backbone algorithms [18-25] as well as mobility management [26, 27].

### A. Energy saving

Clustering schemes save energy by optimizing the organization of the clusters and balancing power consumption amongst nodes.

### Optimizing Cluster Organization

Cluster organization details how to partition clusters and select CHs, how to define cluster size and how to assign transmission ranges to the nodes, all of which will affect the power consumption of the network. The following technologies are summarized in optimizing cluster organization:

- minimizing the sum of distances between the normal nodes and their respective CHs [5];
- assigning the lowest transmission power to normal nodes for intra-cluster communication. In addition assigning the needed lowest power to the gateway node for inter-

cluster communication [6];

- organizing the nodes into different power level clusters so that the route with minimum power can be used to relay the data [7];
- optimizing the number of hops in the cluster to tradeoff the backbone complexity and the power consumption of the cluster [8-10].

### Averaging Power Consumption

The normal nodes in a cluster only transmit their data to their CH and also relay the data in case of a multihop cluster. In addition to transmitting its own data, a CH also receives data from the normal nodes and relays it. The CH consequently consumes more energy than the normal nodes, and when the CH runs out of energy the cluster breaks down.

The lifetime of the cluster can then be prolonged by averaging power consumption among these nodes through:

- rotating the role of CH among the nodes in the cluster [5, 11-13, 15];
- assigning approximately the same number of nodes to each CH [14].

### B. Topology maintenance

The movement of the nodes in MANETs may change the topology quickly. Many clustering schemes have been proposed to handle topology maintenance. We classify them into the following categories.

### Mobility-adaptive clustering

Movement of the normal nodes in the cluster and the CHs in the backbone changes the network topology. By using a dynamic clustering and/or backbone approach to adapt to these changes, the network may perform topology maintenance [18-25].

### Mobility Management

Mobile nodes will leave their clusters and join new clusters. The algorithms in mobility management try to predict the movement of the nodes to adaptively adjust the topology of the network according to the changes of their locations to handle topology maintenance [26, 27].

### C. Analysis of existing clustering schemes

Although many clustering schemes for energy saving are reviewed in this section, as was explained, most of them do not support the mobility of the nodes and the original designs are not applicable to MANETs. Also, most of the introduced clustering schemes for topology maintenance are not energy efficient. Despite the fact that there is one scheme that tries to address both energy saving and topology maintenance for MANET simultaneously [17], it only limits to the maximum number of the nodes in the clusters causing unequal burden among clusters. Furthermore, the route request flooding needs to be reduced.

All of these weaknesses lead us to propose a new efficient algorithm to save energy and to perform topology maintenance simultaneously for MANETs.

### III. DYNAMIC CLUSTERING ALGORITHM

Based on the analysis of the existing schemes, a single-hop dynamic clustering algorithm is proposed to improve the performances of the clustering ad hoc networks in terms of energy saving and topology maintenance.

#### A. Overview of Dynamic Clustering Algorithm

Dynamic Clustering Algorithm (DCA) improves energy efficiency by optimizing the organization of the clusters to evenly distribute power consumption throughout the network. In addition it reduces flooding by combining the reactive and proactive routing protocols in backbone route discovery.

In DCA, topology maintenance is also handled by updating information of the nodes. However in contrast to the traditional clustering schemes, the beacon message in this algorithm is not sent out periodically but it is adaptive. That is, when the mobility rate is high, the period of the beacon message is shortened; when the mobility rate is low, the period is prolonged. This adaptive beacon message can not only reduce the unnecessary flooding beacon message under low mobility rate but also help the network to handle the topology maintenance efficiently under high mobility rate which requires frequent information updates by the nodes.

#### B. Cluster organization

Dynamic clustering algorithm organizes the clusters using the following steps. Initially, some CHs are automatically generated. These CHs flood their announcement to their neighboring nodes to get the information such as ID, residual energy etc. During the flooding process, the size of each cluster is limited to a maximum value. However there may still be some nodes that are not organized in any clusters, the second step is to re-distribute the nodes in the clusters so that the number of nodes in each cluster is limited between a minimum and a maximum value so as to balance the power consumption among clusters. Considering that the CHs have more burden compared to other nodes, the last step is to rotate the role of the CH to distribute the power consumption evenly among the nodes in the cluster.

#### Generating raw clusters with maximum size limitation

In this step, all nodes have a probability  $P$  to become a CH. That is, some CHs will be automatically generated. The probability  $P$  is adaptive to different networks: if the network needs more clusters, the probability will be higher, otherwise it will be lower. The CH floods out its own information such as ID number and residual energy together with its CH announcement to the neighboring nodes. When the neighboring nodes receive the information, they store it and will not receive other announcements from any other CHs. The

nodes that store the information of the CH announcement will then send their own information back to their CH. The CH then confirms them as its normal nodes.

However if a CH has already sent out an announcement message receives any announcement from other CHs, this CH will become a normal node. That means the automatically generated CHs are at least two hops away.

The size of the cluster is an important parameter which affects the power consumption and the topology complexity of the backbone network.

In MANETs, one can assume the data traffic is evenly distributed throughout the network. If the sizes of the clusters are limited to approximately the same values, the burden of each cluster can also be even.

During the organization of the cluster, a CH gets information of its normal nodes like ID number and the residual energy. The sizes of the raw clusters formed can range from 1 to  $n$  ( $n$  is the preset maximum size of the clusters). The following will then re-distribute the nodes in the entire network to limit the number of normal nodes in each cluster between a minimum and maximum value.

#### Re-distributing the nodes in the clusters

The clusters formed only guarantee the maximum number of nodes in each cluster. There may be some clusters that have far fewer nodes than the minimum value, as shown in Figure 2 (assume that the minimum and maximum numbers of nodes in the cluster are 6 and 8, respectively). Consequently, the nodes should be re-distributed to make all clusters have approximately the same size so as to distribute the burden of each cluster evenly amongst the clusters.

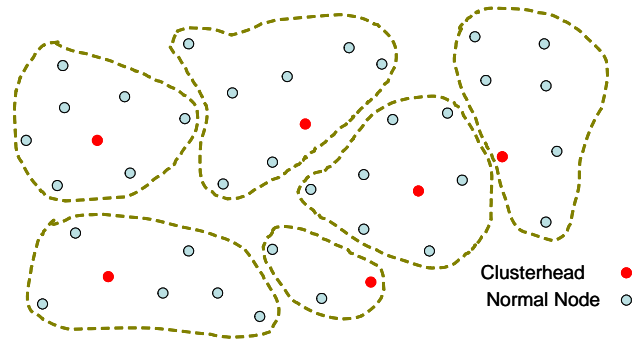


Fig. 2. Cluster has fewer nodes than the minimum value 6.

A Chief-CH (CCH- the CH with the minimum total hops to reach all other CHs) in this algorithm is elected to re-distribute the nodes into clusters. That is, DCA has three tiers as shown in Figure 3. All normal nodes in clusters are first level nodes. All CHs are second level nodes and form the backbone multi-hop cluster. The highest level is the CCH.

After the CCH is selected, all CHs will then send their information of the normal nodes to the CCH. When this information is forwarded to the CCH, it will be stored in each CH along the route to the CCH. A CH then gets the

information of its neighboring CHs. The CCH can then redistribute the normal nodes to the CHs. Thereafter, a distributed topology can be achieved with approximately the same number of normal nodes in each cluster, as shown in Figure 4.

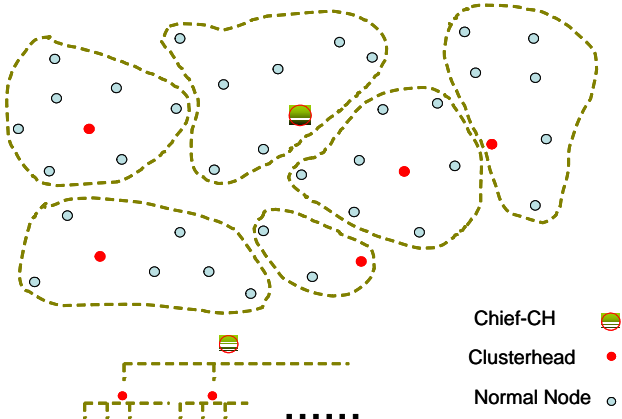


Fig. 3. Topology structure of DCA.

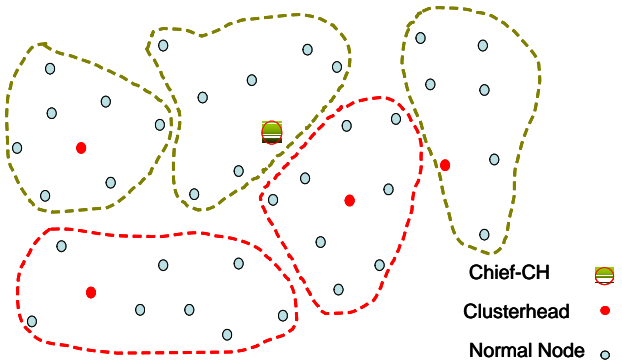


Fig. 4. Re-distributing nodes among clusters by CCH.

### Rotating the roles of CHs

The CHs have more burden than normal nodes and will run out of energy sooner. The roles of CHs should then be rotated to balancing the burden among the nodes.

Many prior schemes elect or rotate the roles of CHs according to the residual energy or ID number of the node. However if a CH is at the edge of the cluster, the nodes need more transmission range (single hop clusters) or more hops (multi-hop cluster) to send the packets to their CHs. Energy is then wasted. A detailed single-hop cluster example is shown in Figure 5 to explain why energy is wasted when the edge node of the cluster is selected as a CH.

Two clusters, (a) and (b), are shown in Figure 5, each containing nine nodes. Two methods of selecting the CHs are shown in the figure. The first method is to select node 9 as the CH as shown in cluster (a), the second method is to select node 4 as the CH as shown in cluster (b).

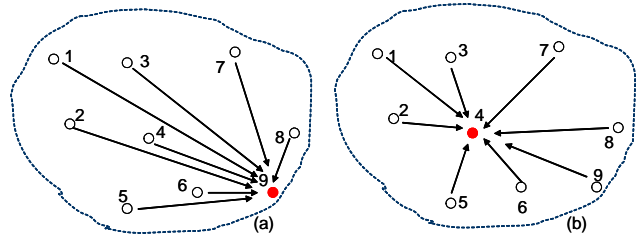


Fig. 5. Energy wasted if CH at edge of the cluster.

Both cluster (a) and (b) are single-hop clusters. From Figure 5, the normal nodes in cluster (a) need higher transmission power compared to that of the nodes in cluster (b) to transmit the packets to the CH by only one hop. Therefore, energy can be saved in cluster (b) by reducing the transmission power. This objective can be achieved by preventing neighboring nodes from being the CHs in the first step.

Setting the CH at the center of the cluster can save energy. However the residual energy of the nodes should also be considered for the selection of the CH. The nodes with extremely low residual energy cannot be selected as a CH and will not be included in the competition to be a CH.

### C. Route discovery

#### Combining reactive and proactive protocols in backbone route discovery

In dynamic clustering algorithm, when a node sends packets to the destination in another cluster, the latest backbone route information will be stored in its CH. Whenever the normal node is ready to send packets, it sends the data to its CH first. The CH then checks whether it has the route information to the destination. If it does not, it will then flood a route request message. If it has, it then checks whether the route is still available. If the topology is not changed quickly, the latest route is usually available. In this situation, the data will be sent out quickly using the stored route. However, the movement of the nodes may result in the stored route being unavailable. In this situation, the CH will flood a route request message.

In contrast to the traditional route discovery in clustering topology which uses a proactive protocol in intra-clustering communication and a reactive protocol in inter-clustering communication, if the route information expires in a quite long period, this algorithm can find a backbone route more efficiently and reduce flooding significantly when the mobility rate of the wireless nodes is not significantly high.

#### Selecting Energy efficient routes

Many schemes for energy saving are proposed by selecting the minimum total energy route or assigning the minimum power for each hop based on evaluating or calculating the distance of each hop. However the movement of the nodes may change the topology quickly resulting in a serious delay in route discovery due to the large number of calculations in each hop.

In our algorithm, after the available routes have been found, the shortest route (with the least number of hops) will be selected to forward the packets in order to avoid the delay caused by the calculation. In the case that several routes have the same least hops, the route that consists of the nodes with higher residual energy will be determined to forward the packets. The energy deficient CHs then avoid relaying the packets, hence power consumption is then balanced.

#### D. Topology maintenance

Some existing clustering schemes handle topology maintenance by periodically broadcasting the beacon- "Hello" message to sense topology changes or by predicting the movement of the nodes. In dynamic clustering algorithm, we also apply the beacon "Hello" message. However in contrast to the traditional design, the beacon message in this algorithm is not sent out periodically, but according to the realistic change of the topology.

In dynamic clustering algorithm, the CH stores the ID numbers of the normal nodes. If it finds the successive records of the ID number of the normal nodes are quite different, it can know that the mobility rate of the nodes is high and will shorten the period of the "Hello" message. Otherwise, a longer period will be applied.

After the "Hello" message has been sent out, the following scenarios will be checked: (1) normal nodes leave the cluster, (2) normal nodes join the cluster, (3) CHs (CCH) leave the cluster, (4) CHs (CCH) join the cluster, (5) the number of the normal nodes in the cluster is more than the maximum value or less than the minimum value.

#### Normal nodes leave the cluster

The CH sends out the "Hello" message to its normal nodes. After the normal nodes receive the message, they send a message back to the CH.

If the CH doesn't receive the response within a bounded time, it then assumes that the node has left the cluster. It will then delete the ID number stored in its database.

#### Normal nodes join the cluster

If the CH receives a new ID number of the mobile node, it will then ask it to join the cluster as a normal member and keeps its information.

#### Clusterheads leave the cluster

The normal node (CH) is supposed to receive the "Hello" message within the bounded time from the CH (CCH). If it does not, it then assumes that the CH (CCH) has already left the cluster and the new CH (CCH) should be selected.

#### Clusterheads join the cluster

If a CH (CCH) gets a response from another CH, it assumes that it has already moved out of the cluster it belongs to and will join this new cluster as a normal member.

#### Cluster size is too large or too small

The CH keeps the ID records of the normal nodes in its cluster. If the number of nodes in the cluster is more than the maximum value or less than the minimum value, the CH will then send a request to the CCH to apply for a re-distribution of the number of nodes.

#### IV. SUMMARY AND FUTURE WORK

Energy efficiency and topology maintenance are two crucial issues of MANETs.

This article proposes a dynamic clustering algorithm to improve the performances of MANETs using the following methods.

Firstly, it maximizes the lifetime of MANETs by:

- evenly distributing the power consumption among clusters by limiting the number of nodes in each cluster between a minimum and maximum values;
- reducing the flooding in backbone route discovery;
- preventing energy deficiency CHs from relaying the data;
- minimizing the total power consumption within the clusters.

Secondly, it reduces delay in backbone route discovery by combing both reactive and proactive protocols when the mobility rate of the nodes is low.

Thirdly, it handles topology maintenance using an adaptive beacon message.

Further work will focus on the performance evaluations of dynamic clustering algorithm.

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