A Self-Organizing Approach to MANET Clustering

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Abstract

Clustering has evolved as an important research topic in MANETs as it improves the system performance of large MANETs. As MANETS have a limitation of battery power, cluster formation is expensive in terms of power depletion of nodes. This is due to the large number of messages passed during the process of cluster formation. In this paper, we use the self-organizing principles for binding a node to a cluster. We minimize the explicit message passing in cluster formation. We also used the route message of a proactive routing protocol for keeping track of nodes in cluster. Thus, there is no need for explicit message passing during cluster maintenance. Unlike most conventional methods a cluster head in our method acts only as an identifying label for cluster entity. It does not perform any hierarchical routing or cluster maintenance function and hence is not a bottleneck to the functioning of the cluster. Our scheme also involves low latency in the cluster formation phase. In addition, we choose the cluster gateway during cluster formation avoiding the need to explicitly discover the gateways, thus reducing further the transmission overheads.

1 Introduction

MANETs (Mobile Ad hoc Networks) consist of wireless hosts that communicate with each other in the absence of a fixed infrastructure. Examples include battlefield scenarios, disaster relief and short term scenarios such as public events. The hosts in the MANET have a limited battery power. In the case of large MANETs, a flat structure may not be the most efficient organization for routing between nodes. Instead, many clustering schemes have been proposed that organize the MANET into a hierarchy, with a view to improve the efficiency of routing. It is important that cluster formation and maintenance should not be costly, in terms of resources used such as bandwidth, battery power etc. Otherwise, the purpose of clustering is defeated. In this paper, we try to present a scheme that leads to cluster formation which efficiently uses the resources of the MANETs. We define below, some of the terminology used in the remaining sections.

Cluster Head: A cluster head, as defined in the literature, serves as a local coordinator for its cluster, performing inter-cluster routing, data forwarding and so on. In our self-organized clustering scheme the cluster head only serves the purpose of providing a unique ID for the cluster, limiting the cluster boundaries.
Cluster Gateway: A cluster gateway is a non cluster-head node with inter-cluster links, so it can access neighboring clusters and forward information between clusters.
Cluster Member: A cluster member is a node that is neither a cluster head nor a cluster gateway.

The remaining part of the paper is organized as follows: Section 2 reviews some of the related work and their drawbacks; Section 3 discusses the importance of self-organization principles in MANETs; Section 4 describes our proposal; we conclude with Section 5.

2 Related Work

In this section, we describe some of the most important clustering schemes. Several approaches to cluster formation have been proposed and surveyed in [9]. Here we briefly review the salient features of a few major approaches.

2.1 DS Based Clustering

In this scheme, routing is done based on a set of dominating nodes [1] which function as the cluster heads and relay routing information and data packets. The vertices of a Dominating Set (DS) act as cluster heads and each node in a

MANET is assigned to one cluster head that dominates it. A DS is called a Connected Dominating Set (CDS) if all the dominating nodes are directly connected to each other. Wu's CDS Algorithm [1] gives details for the formation of CDS. Later, Chen's Weakly Connected Dominating Set (WCDS) algorithm [2] was proposed which relaxed some of the rules of Wu's Algorithm to form a Weakly Connected Dominating Set. There are many disadvantages with the CDS algorithm. The cluster head in CDS algorithm dissipates more power as compared to other nodes in the cluster since all inter-cluster routing and forwarding happen through it alone. Hence it has a shorter lifespan than the other nodes in the cluster. The cluster head re-election is done after the cluster head dies or moves out of the range of the cluster. This re-clustering incurs a large communication (and power dissipation) overhead.

2.2 Power Aware Clustering

Vikas and Kumar [3] proposed CLUSTERPOW algorithm in which dynamic and implicit clustering is done on the basis of transmit power level. The transmit power level is the power level required to transmit each packet. The transmit power level to a node inside the cluster is less as compared to the level required to send a node outside the cluster. So here the clustering is done keeping the nodes with lower transmit power level together. The primary drawback of their scheme is that there is no cluster head or cluster gateway. Each node here has routing tables corresponding to different transmit power levels. The routing table for a power level $\boldsymbol{P}_i$ in a node is built by communicating with the peer routing table of the same power level at another node. The next hop to route the packet is determined by consulting the lowest power routing table through which the destination is reachable. Thus, this suggests that each node should know the route to other nodes and also know the transmit power level at which a destination node is reachable. This leads to the overhead of collecting the state information and building many routing tables for each power level in a node. There were also other algorithms such as Wu's Algorithm [4] which try to build the DS keeping power as criteria to choose the cluster head. But this scheme also does not overcome the basic drawback of DS based clustering algorithm.

2.3 Mobility Based and Weighted Clustering

Some clustering schemes have been proposed keeping mobility as a metric for cluster construction. In mobility aware clustering, cluster architecture is determined by the mobility behavior of mobile nodes. In such schemes, a cluster is formed by grouping mobile nodes moving with the same velocity. This results in the formation of highly connected intra-cluster links. MOBIC [5] was proposed which takes aggregate local mobility as the metric for cluster formation. Each node broadcasts two hello packets, separated by a time interval, to its neighbors. Every node calculates the relative mobility of each of its neighbors using the signal strength of the hello packets received from each of them. Each node then calculates its aggregate mobility as the average of the relative mobility of its neighbors and broadcasts it to the other nodes. The node with the lowest aggregate mobility is chosen as the cluster head. This requires larger communication overhead and a higher latency in cluster formation. There also exist other approaches like combined metric based clustering such as On Demand Weighted Clustering Algorithm [6]. This approach calculates a combined weight factor and uses this metric for the cluster formation. These metric based clustering schemes require explicit control messages for cluster formation to exchange the metric information, thus leading to more communication overhead.

3 Self-organization in MANETs

A system is said to be self organized if it is organized without any external or centrally dedicated control entity. Here each individual node interacts directly with other nodes in a peer-to-peer fashion. The ubiquitous communication structure of MANETs is well suited to apply the design principles of self-organization. The design paradigms that guide us in building self-organizing networks, as mentioned by Christian and Bettstetter [7], are listed below:

i. Design local behavior rules that should be able to achieve global properties.
ii. Do not aim for perfect coordination, exploit implicit coordination.
iii. Minimize long-lived state information.
iv. Design protocols that should adapt to changes.

Use of local information and minimal state information implies less communication overhead and this directly translates into power efficiency. Thus, self-organizing design paradigms can be applied to efficiently use the limited resources of the nodes in the MANET.

3.1 How Self-organization improves clustering properties

The clustering scheme satisfying the design paradigms of self-organization helps to build energy conserving and adaptable clusters. We list here the self-organizing design paradigms and how our Self-Organized clustering algorithm attempts to satisfy the design paradigm.

i. *Design local behaviour rules that should be able to achieve global properties*: This design paradigm of self-organization tries to distribute the responsibility among the individual entities. No single entity is in charge of the overall organization. In this, if the localized behavior rules are applied to all entities, these rules automatically lead to the desired global property. In our scheme we have tried to use the information obtained from neighboring nodes to help a new node join a cluster. Here in our scheme the local property of cluster formation leads to a global connectivity with the help of gateways used in the cluster.

ii. *Do not aim for perfect coordination, exploit implicit coordination*: In our self-organized clustering scheme we do not aim for perfect coordination. In our scheme, we describe ***k*** as the hop count parameter which specifies the distance of the node with respect to the cluster head. However over time as the nodes move, their hop count could change. In our scheme, however, we do not try to maintain the perfect hop count. Maintenance of the hop count in a perfect way acts as an overhead for cluster maintenance.

iii. *Minimize long-lived state information:* In our clustering scheme we use proactive routing protocol within the cluster to maintain information on membership of the cluster. This helps to minimize the long lived state information in our scheme as compared to a clustering scheme which has to maintain the entire topology of the MANET as in the case of DS [1]. The cluster head in our scheme does not require maintenance of extra state information.

iv. *Design protocols that should adapt to changes:* Cluster maintenance is part of future work and we hope to find solutions that satisfy this property.

4 Self-Organized Clustering Scheme

Here we present our original self-organized clustering scheme. The proposed self-organized clustering scheme can be divided into cluster formation phase and cluster maintenance phase, which are described in following subsections.

4.1 Prerequisites and Assumptions

The prerequisite for our self-organizing scheme includes the use of a proactive routing protocol such as DSDV[8] within the cluster. We define a parameter ***k*** that limits the number of hops the node can be away from its cluster head. We assume that the parameter ***k*** is known to each node participating in the cluster formation. This hop limit, ***k***, can be tuned based on empirical results and/or dynamically, keeping the mobility into consideration. If the nodes in a MANET are highly mobile, then, the value of ***k*** for the cluster can be relatively small as compared to a scenario where mobile nodes in a MANET are stable.

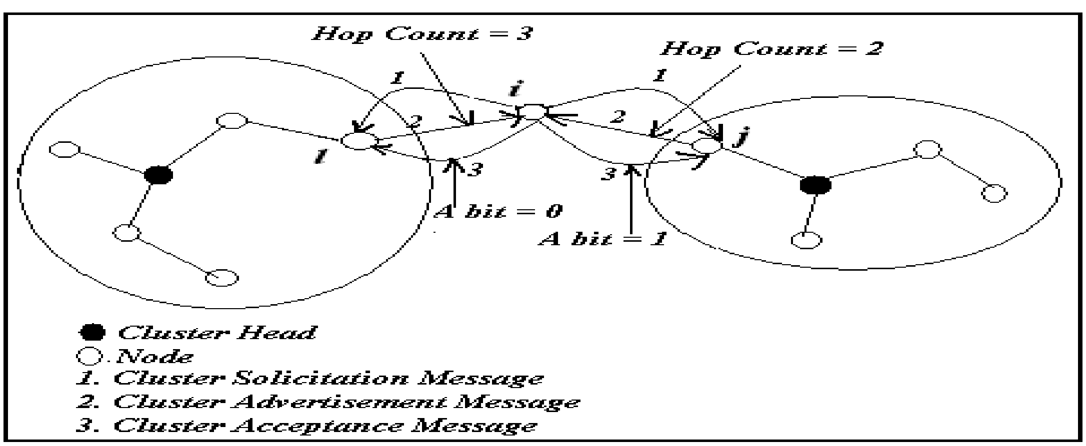

Fig 1 Cluster Formation as described in section 4.2

4.2 Cluster Formation

The cluster formation starts when a node boots up and broadcasts a cluster solicitation message to its immediate neighbors. If it does not get any reply within the maximum attempts, it declares itself a cluster head. If it receives a cluster advertisement, in response to its solicitation it examines the hop count value and if it is less than ***k*** then, it joins the cluster with the minimum hop count to the cluster head. However if the hop count advertised is ***k***, then it declares itself as a cluster head. We describe, below, the steps involved in this process:

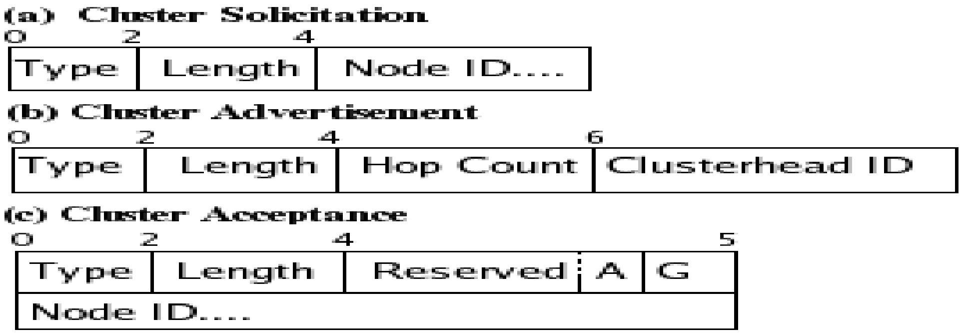

Fig 2 Cluster Formation Packet Format

Step 1: As shown in Fig 1 when a node ***i*** does not belong to any cluster and wants to join a cluster it broadcasts a cluster solicitation message (whose format is shown in Fig 2(a)) to its immediate neighbors.
Step 2: Node ***j*** and node ***l*** which receive the cluster solicitation message send out a cluster advertisement message whose format is shown in Fig 2 (b). The cluster advertisement of the node ***j*** and the node ***l*** contains information such as the cluster head ID of the corresponding cluster. It also contains information regarding the number of hops the new node ***i*** will be away from the cluster head. Each node maintains its approximate hop count. As shown in Fig 1 the hop count sent by node ***j*** to node ***i*** in the cluster advertisement is having the value 2 that is its own hop count incremented by one. Similarly the hop count value in the cluster advertisement sent from node ***l*** to node ***i*** is 3.
Step 3: The node ***i,*** after receiving the cluster advertisement(s), first check whether the hop count value in cluster advertisement message is less than ***k*** value. Then it chooses the cluster head of the node with the minimum hop count in its advertisement, as its cluster head. Then it sends a cluster acceptance message as shown in Fig 2(c) to the nodes whose cluster advertisements have been received. It sets the **A** bit to indicate acceptance of advertisement. If the hop count value is the same in two or more cluster advertisements then one of them can be selected randomly.
Step 4: When the new node ***i*** receives two or more cluster advertisements from nodes that belong to different clusters, it declares itself as a cluster gateway. It sets the **G** bit, in the cluster acceptance message. This is shown in Fig 1with message labeled 3.
Step 5: If the new node ***i*** does not receive any cluster advertisement after sending the cluster solicitation message multiple times or it receives all advertisements with maximum hop count, it declares itself as a cluster head.

4.3 Cluster Maintenance

After the new node has chosen its cluster head, the new node is included in the route table of the neighboring node. If the new node declares itself as the cluster gateway then there is a column in the route table of mobile nodes in the cluster which will be marked as 1. Within each cluster, a proactive routing protocol such as DSDV [8] is used. Thus, every node in the cluster knows about every other node in its own cluster. When a new node joins the cluster, it starts advertising itself and after a short time, all nodes in its cluster will have an entry for this node in their routing table.

When a node moves out of the range of the cluster, it becomes unreachable to the nodes in the cluster. Thus the entry for this node is deleted from each node's route table within the cluster. Hence the mobility of the node does not cause any ripple effect of re-clustering in cluster maintenance as it occurs in DS [1] based clustering scheme. When a node becomes unreachable to a cluster it can join another cluster by following the cluster formation steps as discussed above.

4.4 Analysis and Discussion

Here we try to analyze our scheme to see how it performs as compared to other clustering schemes. We also discuss some exceptional situations which are not described in the above clustering scheme. The previous clustering schemes have a large overhead of explicit message passing for cluster formation and cluster maintenance. The new self organized clustering scheme tries to minimize the explicit message passing for cluster formation. It does not need to have any explicit passing of control messages for cluster maintenance since we use the intra-cluster proactive routing information for cluster maintenance. Reducing the explicit control messages in the cluster formation and cluster maintenance phase helps in slower power dissipation of each node in MANET. This increases the lifespan of each node in MANET and hence of the network as whole. In our self-organizing scheme the cluster head does not have any extra overhead of routing all packets of its cluster. Thus the power dissipation of the cluster head is the same as that of any ordinary node inside the cluster. The cluster head in our scheme does not contain any explicit information regarding the cluster; so, the movement of the cluster head should not be a bottleneck for the cluster. There is no need to calculate any metric for our scheme. Our scheme finds the cluster gateway during cluster formation phase of the cluster. This reduces the overhead by eliminating the explicit messages needed to determine cluster gateways. Thus, our scheme aims to perform better in terms of explicit message passing, power usage, latency in cluster formation and assignment of roles (clusterhead, clustergateway, clustermember) to the nodes in the cluster. There are some scenarios that are still to be handled in our scheme of self-organization. The scenario when the cluster head moves out of the cluster has not been worked through yet. Here a new cluster head has to be re-elected. The re-election of a cluster head in a partitioned cluster without degenerating the overall structure of the MANET, is yet to be handled by our proposed scheme.

5 Conclusion and Future Work

The self-organizing scheme proposed in this paper, is feasible in the practical world. As our scheme is self-organized it does not require any central control to start the clustering. It also does not require knowledge of the entire MANET and its topology to cluster the nodes. Our clustering scheme does not involve latency in cluster formation. The clustering parameter ***k*** helps in adapting the formation of the cluster to its environment. When the nodes in a MANET are having high mobility the ***k*** value can be smaller as compared to the case when the nodes are stable. Simulation experiments can be done with different mobility to arrive at an approximate empirical value of ***k*** under different conditions. Thus our future work aims to simulate the proposed scheme. We will also try to find solutions to the scenarios of the cluster maintenance phase as part of our future work.

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