Abstract—Routing in wireless mobile adhoc networks should be time efficient and resource saving. One approach to reduce traffic during the routing process is, to divide the network into clusters. Until now, there have been several approaches on cluster-based routing. We propose a voting based clustering strategy to form network with spatial and temporal stability. The selection of cluster head and cluster size is done in a very efficient manner. We present algorithms for creation of clusters and their maintenance in presence of various network events. Our strategy outperforms existing and conventional clustering approaches in terms of number of hops required, at a little cost of overhead during topology updates. The strategy performs very well when density of nodes is high.

I. Introduction

An adhoc network is a dynamic multi-hop wireless network established by a group of mobile nodes on a shared wireless channel without any infrastructure. Efficient clustering and routing in adhoc networks has been a topic of research in the past few years [1], [2], [3], [4]. The literature that deals with adhoc routing identifies two types of networks viz. hierarchical routed networks and flat routed networks. While the former creates a hierarchy among the nodes, the latter treats all nodes equally. Most hierarchical clustering architectures for mobile radio networks are based on the concept of cluster head (CH) [1], [2], [3]. In most of the proposed methods in hierarchical (clustered) networks, much thought has not been given for the selection of the CH. In order to design a stable network, we need to look after features that the clusters should satisfy. In [2], CH is selected based on a node identifier and thus may not be spatially and temporally suitable. The concept of associativity (relative stability of nodes) was used to get long live routes in routing [5]. Associativity provides temporal stability but not spatial. By up-to-date GPS system, location information is available to different mobile computing platforms [6]. Therefore, we intend to address the above-mentioned issues and propose a novel location-aware clustering strategy. The cluster formation scheme should form clusters based on the spatio-temporal stability of the mobile nodes forming the adhoc network. The node elected as the CH should be such that it should satisfy the following constraints:

- Located centrally for spatial stability.
- Should have high energy value relatively to other nodes in the cluster.
- The cluster size also needs to be constrained and we are looking on achieving the following in our protocol design:
  - Overlap between clusters should be minimum.
  - Should satisfy the connectivity constraints.
  - Intra and inter stability should be inherent.
  - Has a maximum size (number of members) constraint.

In view of above constraints, our clustering strategy determines an optimal location of the CH in a cluster using voting algorithm. Using this algorithm, the nodes in a cluster interact with each other and select a CH. We also have to address the different issues that may arise in management of a cluster and the necessary actions to be taken by the CH in this regard.

The paper is organized as follows. Section II introduces system model and novel approach for cluster formation and maintenance using the proposed voting algorithm. Section III discusses the routing strategy for both intra and inter cluster routing. Section IV presents simulation results and Section V concludes the paper.

II. System Model

We consider a system in which all nodes have a prior information of their location. This is valid for adhoc networks as we can append nodes with devices like GPS. We have assumed that nodes transmit at only one power level, i.e, no power control mechanism is used. We will describe our model in two phases:

A. Cluster Formation:

The routing protocol we use takes cluster formation as its basis. Hence, efficient cluster formation is the crux of a routing protocol of this nature. The clusters should be formed in such a way that the resulting network is cluster-connected. A network is cluster-connected if it satisfies the following two conditions:

- The union of the clusters covers all the nodes.
- There is a path from each node to every other node through other clusters.

Routing from one node to another will consist of routing inside a cluster and routing between clusters. Here, we have assumed clusters such that within a cluster each node can directly communicate with the other member nodes. We assume that each node has a unique id (node.id) which is its device address. Also, every node maintains lists of nodes (node.list) and their locations (node.location_list) in its cluster.

As soon as a node becomes active, it looks to join a cluster and follows the following procedure:

- Transmits a hello packet (Broadcast Packet) and waits for a reply for a fixed amount of time (reply.timeout).
- If any CH listens to this hello packet, it replies to the request.
- If the node does not receive any reply before reply.timeout, it will assume that no clusters are present and will become a CH itself.
• If it receives a reply, it will send an ACK to the CH which replied. If it receives more than one reply, it will look for the one with the highest Signal to Interference and Noise Ratio (SINR) value and will send an ACK to that CH.
• The CH after receiving the ACK, informs the newly joined node about the cluster. The cluster head informs the node about the cluster members id and their location.

Using the above procedure we get a basic clustered network. Note that the above procedure may not yield optimal clusters. We use an algorithm where we attempt to achieve optimality by shifting the role of the CH to the most optimal node with time. Also we put constraints on the size of the clusters to get suitable clusters.

B. Cluster Maintenance:

Once a basic structure has evolved, the next job is to optimally evolve the clusters. The mobility of the nodes introduces the need to devise algorithms for Cluster fusion, Cluster division and Handoff. We consider all these features in detail later. Let us first look at how we can optimally assign the job of CH to the nodes in the cluster. To do this we propose Voting Algorithm as described below:
• Each node evaluates the best possible position using Eqs. (1) and (2). This position is the weighted location with weights of various nodes inversely proportional to the SINR value for the hello packets (Broadcast Packets) transmitted by corresponding nodes. These packets are transmitted periodically by various nodes and using these packets, each cluster member updates other members about their latest location. Also, nodes utilize these packets to estimate the channel conditions between the transmitting node and themselves and hence evaluate the weights.

\[
x^{(i)}_{\text{optimal},j} = \frac{\sum_{k \in \text{cluster}(i)} x_k w_{j,k}}{\sum_{k \in \text{cluster}(i)} w_{j,k}} \quad (1)
\]

\[
y^{(i)}_{\text{optimal},j} = \frac{\sum_{k \in \text{cluster}(i)} y_k w_{j,k}}{\sum_{k \in \text{cluster}(i)} w_{j,k}} \quad (2)
\]

where \(x^{(i)}_{\text{optimal},j}, y^{(i)}_{\text{optimal},j}\) is the optimal location of the CH as desired by \(j^{th}\) node, \(x_k^{(i)}, y_k^{(i)}\) are the \(x\)-position and \(y\)-position of \(k^{th}\) node in \(i^{th}\) cluster and \(w_{j,k}\) is the weight function between node \(j\) and \(k\) of a cluster. We have taken \(w_{j,k} = \frac{1}{\text{SINR}_{j,k}}\). The weight function can be modified to account for battery power, mobility etc.
• Each of the cluster members periodically votes for the best location of the CH for itself.
• CH receives votes from all the cluster nodes and evaluates their mean to estimate the position for the next possible CH. Thus the optimal CH location will be:

\[
x^{(i)}_{\text{optimal}} = \frac{\sum_{j \in \text{cluster}(i)} x^{(i)}_{\text{optimal},j}}{N^{(i)}} \quad (3)
\]

\[
y^{(i)}_{\text{optimal}} = \frac{\sum_{j \in \text{cluster}(i)} y^{(i)}_{\text{optimal},j}}{N^{(i)}} \quad (4)
\]

where \(N^{(i)}\) is the number of nodes in \(i^{th}\) cluster.
• If the new location is in the current CH’s proximity, it continues to do the job of CH. It informs this to the members by broadcasting a result packet.
• If the optimal location is far away, CH looks for nodes in proximity to this location and elects the nearest.
• It informs the newly selected CH about its new role as a CH and waits for an acknowledgment.
• The newly selected CH sends an ACK packet to the old CH and then broadcasts to the cluster that it has taken over the job of the CH.

The voting algorithm above is timely executed and the new CH is chosen such that it confirms equally to all the nodes in the cluster. Next, we look at the other aspects of cluster maintenance. As the nodes are mobile, the clusters keep on drifting with time. They collapse into each other leading to cluster fusion. Again as the clusters grow and become bigger in size, they divide into child clusters. Also as the nodes are mobile some of them may move from one cluster to another. This phenomenon is termed as Handoff and we will discuss this later.

A snapshot of Novel clustering is shown in Fig. (1).

Fig. 1. Novel Clustering: Diamond with a central dot shows selected CH, asterisk indicates optimal position obtained, circles show cluster boundary

B.1 Cluster Fusion:

Cluster fusion is a phenomenon of combination of two clusters when they come close to each other. We have chosen two criteria for the fusion process to happen:
• A cluster completely moves inside another cluster.
• Around 90% of a cluster nodes are inside another cluster.

In any of the above two circumstances the following procedure is used to achieve cluster fusion:
• The CHs of the two clusters communicate with each other. The CH with less number of members updates the other CH about new members.
• Of the two combining clusters, the CH of the one with more number of nodes plays the role of the immediate CH of the fusion cluster.
The CH thus broadcasts an update packet with the information about the latest status of the cluster.

B.2 Cluster Division:

Cluster division is a phenomenon of splitting of a parent cluster into child clusters. This happens if the number of members in the cluster goes above a fixed threshold (Max_NUM_Cluster_Members). This ensures that load on the CH doesn’t grow. The splitting results using the following algorithm:

1. The CH sorts the location indices of the members using the x and y coordinates. The two sets thus obtained are used to determine the position of the CHs in the child clusters.
2. The CH evaluates the preferable positions for the new CHs by taking the indices of their location as those of the elements in the \( \frac{1}{2} \) and \( \frac{3}{2} \) places of the sorted sets.
3. Now the division of the members is done on the basis of their closeness to the newly formed CHs.

B.3 Handoff:

Due to mobility, the nodes keep on joining and leaving the clusters. We have worked out a procedure to smooth out this process. We have considered two types of handoff, namely, controlled handoff and forced handoff.

- **Controlled Handoff:** When a node moves away from its cluster and reaches the maximum transmission range of the CH, the CH advertises about it to the neighbouring CHs. Hence before the moving node parts away from the parent cluster, it is accepted as a member of another cluster, the one it is moving towards. Thus this is a Make before Break kind of situation.
- **Forced Handoff:** This occurs if the node crosses the maximum transmission range of the CH and there is no cluster to accept this node as a member. In this situation the node forms a new cluster and becomes its CH.

III. Protocols Used

A. **Medium Access Control**

We have used Carrier Sensing Multiple Access (CSMA) as MAC protocol in our analysis. Any CSMA-based medium access scheme has two important components, the listening mechanism and the backoff scheme. The constant listen periods are energy-efficient, and the introduction of random delay provides robustness against repeated collisions.

B. **Routing**

The routing strategy has to take care of both intra and inter cluster routing. We have used existing protocols for both types of routing. We have used Destination-Sequenced Distance Vector (DSDV) [7] for intra cluster routing and Ad-hoc On-demand Distance Vector (AODV) [8] for inter cluster routing. These protocols are briefly described below:

B.1 DSDV:

In our novel clustering strategy we have assumed that within a cluster every node is directly accessible from any other node. Thus any node can communicate to its cluster members in a single hop. The DSDV protocol requires each mobile node to advertise its cluster members, about its own presence in the cluster, using hello packets for instance. The position of the node may change dynamically over time, so the advertisement must be made often enough to ensure that every mobile node can almost always locate every other mobile node of the cluster.

B.2 AODV:

The routing protocol uses a data structure called cluster adjacency table (CAT) to support the routing process. The CAT stores information about neighbouring clusters. Route discovery is done using source routing. The CHs are flooded with route request messages (Route-REQ). Initially, node S broadcasts a Route-REQ containing its ID, the destination address, the neighbouring CHs and the cluster address list which consists of the addresses of the CHs forming the route. If the Route-REQ reaches the destination node D, it contains the loose source route [S,J1,..,Jk,D]. Then, D sends a route reply message (Route-REP) back to S using the reversed loose source route [D,Jk,..,J1,S]. Every time a cluster head receives this Route-REP, it updates the routing table.

IV. Performance Comparison

We have used standard models for the channel state and the mobility of the mobile. Below we describe each of them in detail:

A. **Mobility Model**

We have chosen a mobility model suitable for urban and vehicular environments [9]. A number of vehicular users move around the simulated area and their initial directions in degree are generated by the uniform distribution \( U(0,360) \). The velocity of users is fixed. After the negative exponentially distributed amount of time, with mean equal to 60 seconds, the direction of a user is changed. The new direction is generated by a Gaussian distribution with mean equal to the user's old direction and standard deviation 30 degrees.

B. **Channel Model**

We used the shadowing model for the radio propagation models. The overall shadowing model is represented by:

\[
\frac{P_r(d)}{P_r(d_0)} = -10\beta \log \left( \frac{d}{d_0} \right) + X_{AB} \quad (5)
\]

where \( X_{AB} \) is a Gaussian random variable with zero mean and standard deviation of 6.8dB (factory, obstructed environment) and \( \beta \) is 4 (urban environment). The model is also...
known as a log-normal shadowing model.

C. Simulation Results:

The simulations have been performed in MATLAB. We have compared our Novel clustering strategy with Fixed clustering strategy. For a fair comparison, we have kept the number of clusters in both the strategies to be the same. The constant parameters chosen for the simulation were:

Number of nodes: 100
Area of the network: $1 \times 1$ for 16 clusters; $1 \times 0.75$ for 12 clusters (in sq. units)
Max. Num. Cluster Members: 15
Velocity of a node: 0.01 units/sec
Time for simulation: 2000 sec

The simulations have been performed to carry out a detailed comparison of performance of DSDV and AODV routing protocols when implemented with our Novel clustering strategy and existing Fixed clustering strategy. Square and rectangular fields were considered as they are optimal for Fixed clustering since cluster boundaries matches perfectly. We have carried out the simulation by varying the number of clusters in both the strategies. This is done in order to have the same routing overheads in both the clustering strategies. We have compared the two strategies for cases of 12 and 16 clusters. The performance parameters chosen are throughput and normalized power spent per packet, i.e., number of hops required per successfully transmitted packet. The packet arrival process was taken as Poisson for varying values of load in Erlangs. These parameters are evaluated for various load values in both the strategies.

It was observed during the simulation that number of CH swapping and handoff required were very less in Novel clustering than in Fixed, which is due to temporal and spatial stability achieved. The throughput performance is almost same in both the strategies as shown in Figs. (3), (4). Our strategy performs better at low load but performance slightly degrades as load increases. Also as expected, throughput increases as the number of clusters increases.

In case of power required per packet, Novel clustering sur-
a simple approach of Fixed clustering is more suitable for low density.

For the same number of clusters, the Novel clustering strategy is able to cover the same area, with smaller transmission range required than the Fixed clustering. Thus, comparatively less power is required while transmitting a packet. Thus, Novel Clustering performs much better and is suitable for a network having high node density. If power control is available at each node then power can be further optimized.

V. Conclusion

We have succeeded in achieving the goals for cluster framework stability and have shown that Novel Clustering Strategy outperforms Fixed clustering strategy. We were able to achieve similar throughput performance and substantial power saving. Our strategy doesn't assume any specific type of field. It is very adaptive and thus there are no issues on dividing the field into clusters. The overhead involved during the voting process, though is an issue of concern.

REFERENCES


