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PERFORMANCE EVALUATION OF CLUSTERING ALGORITHMS IN MOBILE AD HOC NETWORKS (MANETS)

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Abstract— **The Mobile Ad hoc Networks (MANETs) is collection of autonomous mobile hosts connecting by wireless networks. It is infrastructureless and the network topology may change dynamically in an unpredictable manner since nodes are free to move. There are mainly three type of routing protocols: flat, hierarchical and geographic-position-assisted ad hoc routing protocols. In this paper, author mainly concentrated on the clustering approach in MANETs. The main advantage of clustering algorithms over the routing protocols is that they are less dynamic in nature. The author have been compared the various clustering algorithms of mobile ad hoc networks. The performance of these clustering algorithms are evaluated and compared using the NS-2 simulator.**

Keywords— **Mobile Ad hoc Networks (MANETs), Routing Protocols, Clustering, NS-2 simulator**

I. INTRODUCTION

A. *Mobile Ad Hoc Network -*

Since their emergence in 1970's, wireless networks have become increasingly popular in the computing industry. There are currently two variations of mobile wireless networks-infrastructure and infrastructureless networks. The infrastructure networks, also known as cellular network, have fixed and wired gateways [1]. They have fixed base stations, which are connected, to other base stations through wires. Example applications of this type include office wireless local area networks (WLANs). The other type of network, infrastructureless network, is known as Mobile Ad NETwork (MANET) [2]. MANETs is one that comes together as needed, not necessarily with any support from the existing Internet infrastructure or any other kind of fixed stations. An ad hoc network can be defined as an autonomous system of mobile hosts (also serving as routers) connecting by wireless links, the union of which forms a communication network modeled in the form of an arbitrary graph. In a MANET, no infrastructure exists and the network topology may dynamically change in an unpredictable manner since nodes are free to move. As for the mode of operation, ad hoc networks are basically peer-to-peer multi-hop mobile wireless networks where information packets are transmitted in a store-and-forward manner from a source to an arbitrary destination, via intermediate nodes. As the node moves, the resulting change in network topology must be made known to the other nodes so that outdated topology information can be updated or removed. The various applications of MANETs are community networks, enterprise networks, home network, sensor network, emergency response network, vehicle network, military networks etc. [3-6].

B. *Why Routing Protocols are the main issue in mobile ad-Hoc networks?-*

Routing support for mobile hosts is presently being formulated as "mobile IP" technology. Mobile IP form of host mobility requires address management, protocol inter-operability enhancements and the like, but core network functions such as hop-by-hop routing still presently rely upon pre-existing routing protocols operating within the fixed network. In contrast, the goal of mobile ad hoc networking is to extend mobility into the realm of autonomous, mobile, wireless domains, where a set of nodes, which may be combined routers and hosts, themselves form the network routing infrastructure in an ad hoc fashion. Hence, there are need to study special routing algorithms to support this dynamic topology environment [7-9].

II. ROUTING PROTOCOLS IN MANETS

A. *Flat Ad hoc Routing -*

Flat ad hoc routing protocols comprise those protocols that do not set up hierarchies with clusters of nodes, specials nodes acting as the head of a cluster, or different routing algorithms inside or outside certain regions. This category falls into two subcategories:

i) Proactive
ii) Reactive

Proactive protocols set up required for routing regardless of any traffic that would require routing functionality. For example, Distance Sequence Destination Vector (DSDV) [10]. Reactive protocol tries to avoid this problem by setting a path between sender and receiver only if a communication is waiting. For example, Distance Source Routing (DSR), Ad Hoc On-Demand Distance Vector (AODV) [11].

B. Hierarchical Ad hoc Routing -

Algorithms such as DSDV, AODV, and DSR only work for a smaller number of nodes and depend heavily on the mobility of nodes. For larger networks, clustering of nodes and using different routing algorithms between and within clusters can be a scalable and efficient solution [12].

C. Geographic-Position-Assisted Ad hoc Routing -

If mobile nodes their geographical position, this can be used for routing purposes. This improves the overall performance of routing algorithms if geographical proximity also means radio proximity. One way to acquire position information is via the global positioning system (GPS) [13].

III. CLUSTERING IN MANETS

Cluster-based routing is an interesting solution to address nodes heterogeneity, and to limit the amount of routing information that propagates inside the network. The basic idea behind clustering is to group the network nodes into a number of overlapping clusters. This enables the aggregation of the routing information, and consequently increases the routing algorithms scalability. Specifically, clustering makes possible a hierarchical routing in which paths are recorded between clusters (instead of between nodes); this increases the routes lifetime, thus decreasing the amount of routing control overhead. A key point in the use of clustering techniques in a mobile environment is the maintenance of the network topology (i.e., nodes grouping, and identification of clusterheads, and gateways, if necessary) in the presence of various network events (mainly, the nodes' mobility). Node mobility is a critical point because the membership of a node to a cluster changes over time due to the node mobility. Rearrangement of clusters may introduce excessive overheads that may nullify clustering benefits. As shown in figure 1, the nodes have been grouped into clusters, where one node in each cluster functions as clusterhead, responsible for routing. By using a maintenance function, the objective is to keep the communication overhead low while still producing large and stable clusters [14-16].

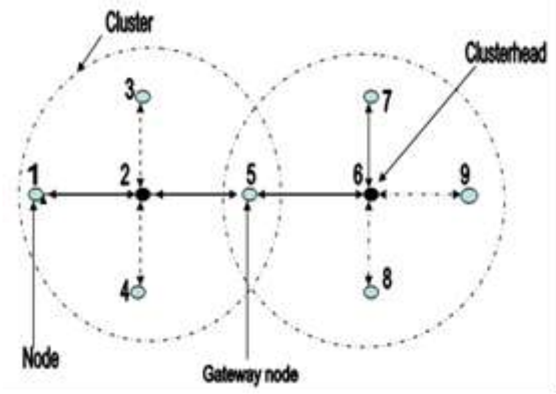

Fig. 1 Clustering

Suppose node 1 wants to communicate with node 9. First, it would be communicated with its clusterhead (i.e. node 2). Node 2 is responsible for routing in cluster 1. Then, this clusterhead of cluster 1 communicated with gateway node (i.e. node 5). Gateway is the node, which is in the communication range of two or more clusterheads of different clusters. Then, this gateway node is communicated with clusterheads (i.e. node 6) of cluster 2. Finally, this clusterhead communicate with node 9. So, in this way, two nodes of different clusters communicate with each other. The main advantage of this clustering scheme over the simple routing scheme is that it is less dynamic in nature [17-18].

IV. COMPARISON OF VARIOUS CLUSTERING ALGORITHMS

There are two heuristic design approaches for management of ad hoc networks. The first choice is to have all nodes maintain knowledge of the network and manage themselves. This circumvents the need to select leaders or develop clusters. However, it imposes a significant communication responsibility on individual nodes. Each node must dynamically maintain routes to the rest of the nodes in the network. With large networks the number of messages needed to maintain routing tables may cause congestion in the network. Ultimately this traffic will generate huge delays in message propagation from one node to another. The second approach is to identify a subset of nodes within the network and vest them with the extra responsibility of being a leader (clusterhead) of certain nodes in their proximity. The clusterheads are responsible for managing communication between nodes in their own neighborhood as well as routing information to other clusterheads in other neighborhoods. Typically, backbones are constructed to connect neighborhoods in the network.
There are various clustering algorithms. In the Linked Cluster Algorithm (LCA), nodes communicate using TDMA frames. Each frame has a slot for each node in the network to communicate, avoiding collisions. For every node to have

knowledge of all nodes in it neighborhood it requires 2n TDMA time slots, where n is the number of nodes in the network.

A node x becomes a clusterhead if at least one of the following conditions is satisfied:

a) x has the highest identity among all nodes within 1 wireless hop of it.

b) x does not have the highest identity in its 1-hop neighborhood, but there exists at least one neighboring node y such that x is the highest identity node in y's 1-hop neighborhood.

Thus, LCA has a definite bias towards higher id nodes while electing clusterheads. Later the LCA heuristic was revised to decrease the number of clusterheads produced in the original LCA and to decrease the number of clusterheads generated in the pathological case. In this revised edition of LCA (LCA2) a node is said to be covered if it is in the 1-hop neighborhood of a node that has declared itself to be a clusterhead.

Starting from the lowest id node to the highest id node, a node declares itself to be a clusterhead if among the non-covered nodes in its 1-hop neighborhood, it has the lowest id. So, LCA2 favors lower id node while electing clusterheads.

Other solutions base the election of clusterheads on degree of connectivity, not node id. Each node broadcasts the nodes that it can hear, including itself. A node is elected as a clusterhead if it is the highest connected node in all of the uncovered neighboring nodes. In the case of a tie, the lowest or highest id may be used. As the network topology changes this approach can result in a high turnover of clusterheads. This is undesirable due to the high overhead associated with clusterhead change over.

The other algorithm, the Max-Min heuristic was developed to extend the notion of 1-hop clusters (as in the case of LCA2 and degree-based) and generalizes cluster formation to d-hop clusters. The rules for Max-Min heuristic are similar to those for LCA but converges on a clusterhead solution much faster at the network layer, 2d rounds of messages exchanges.

Once again a node x becomes a clusterhead if at least one of the following conditions is satisfied:

a) x has the highest identity among all nodes within d wireless hop of it.

b) x does not have the highest identity in its d-hop neighborhood, but there exists at least one neighboring node y such that x is the highest identity node in y's d-hop neighborhood.

Max-Min and LCA generate different solutions because in case (b) for Max-Min if a node becomes a clusterhead it will consume all nodes that are closer to it than any other elected clusterhead. This is a major difference between the two heuristics. However, like LCA, Max-Min also favors higher id nodes while electing clusterheads.

Differences between these algorithms are described as in table I.

Table -1 Comparison among LCA2, Highest-Connectivity and Max-Min D-Cluster Algorithms

Algorithm	Properties	Complexity	Strengths	Weaknesses
Lowest -ID (LCA2)	**Clusterhead selection based on node ID Clusterhead is directly linked to any other node in the cluster.**	**Constant time complexity, message complexity increase with denseness of graphs.**	**Fast and simple algorithm, Relatively stable clusters.**	**Small clusters, Some clusterheads likely to remain for long time.**
Highest-connectivity	**Clusterhead selection based on highest degree, otherwise same as LCA2.**	**Same as LCA2.**	**The nodes with highest degree are good candidates for clusterheads.**	**Very unstable clusters.**
Max-Min D-cluster	**Cluster radius d, where d is a constant.**	**O(d) time and storage complexity**	**Large and stable clusters.**	**High number of messages sent.**

V. PERFORMANCE EVALUATION OF CLUSTERING ALGORITHMS

The performance of the clustering algorithms of ad hoc networks is evaluated in NS2 simulator. Some of the simulations statistics measured are: Number of clusterheads, Clustered duration, Cluster size, and Cluster member duration.

- *Number of clusterheads* **-** The mean number of clusterheads in a network for a sample. The number of clusterheads should not be less, as they will be overloaded with too many cluster members. Nor is it good to have a large number of clusterheads, each managing a very small cluster.
- *Clusterhead duration* **-** The meantime for which once a node is elected as a clusterhead, it stays as a clusterhead. This metric is a measure of stability; the longer the duration, the more stable the system.
- *Cluster size* **-** The mean size of a cluster. This value is inversely proportional to the number of Clusterheads. The clusters should not be large that they will overload their clusterheads, or so small that the clusterheads are idle a good part of the time.

- *Cluster member duration* - The mean contiguous time a node stays a member of a cluster before moving to another cluster, clusterheads are considered cluster members, also. This statistic is a measure of stability like the Clusterhead duration, but from the point of view of nodes that are not clusterheads.

LCA2, and Degree based heuristics generate 1-hop clusters while Max-Min heuristic perform a d-closure on the connectivity topology before running each of these heuristics. The d-closure yields a modified graph in which nodes A and B are 1-hop neighbors if they were at most d-hops away in the actual topology graph. Here, d is either 2 or 3. When LCA2 and Degree based heuristics are run on this graph, they form clusters where each node is at most d wireless hops away from its clusterhead. The LCA2 heuristic elects clusterheads that may be adjacent to one another while Degree based heuristics do not allow clusterheads to be adjacent to one another.
Observing the simulation results of figure 2 shows that Max-Min, LCA2 and Degree-based heuristics never produce more than 3 clusterheads, when 2-hop clusters are formed and the wireless range is equal to 20 length units. Furthermore, as more nodes are added the number of clusterheads produced by these heuristics remains almost unchanged. The LCA2 heuristic produces a maximum of 13 clusterheads. LCA2 plot shows that the slope, approximately 0:17 for high-density networks will generate a clusterhead for every 5.8 newly added nodes. This is an unnecessarily large number of clusterheads. Similar trends are exhibited for other combinations of hop count and wireless range [19].

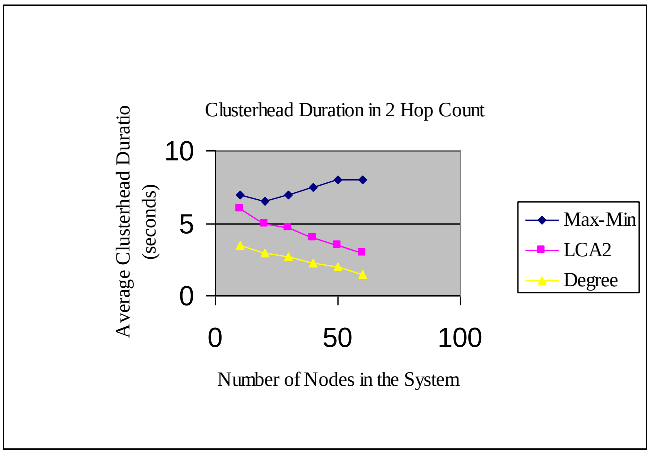

Fig. 3 Impact of network density on clusterhead duration

Figure 4 shows the Degree-based and LCA2 heuristics produce the largest cluster sizes followed by the Max-Min. The Degree and Max-Min heuristics produce clusters whose sizes increase by 3.1, 3.1 and 2.3 nodes per 10 nodes respectively. While the LCA2 heuristic clusters sizes is very flat and only increase slightly as the network density increases. Combining the number of clusterheads and number of cluster sizes results, LCA2 heuristic is producing a large number of small clusters, as the system size gets larger. This indicates that the LCA2 heuristic very often suffers from a pathological case where a node becomes a clusterhead under somewhat false pretences. This can happen when a node becomes a clusterhead because it is the largest node in one of its neighbor's neighborhoods.

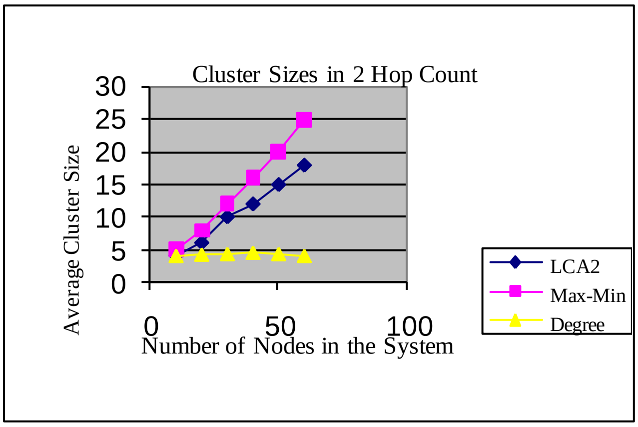

Fig. 4 Impact of network density on cluster size

Figure 5 shows LCA2 and Max-Min with the highest cluster member durations followed Degree. Here, LCA2 heuristics show a slight increase in cluster member duration as the network becomes denser. Max-Min has become fairly flat at 3.7 seconds for dense networks, while the Degree heuristic show a steady decline to about 2 seconds, the sampling rate of the simulation.

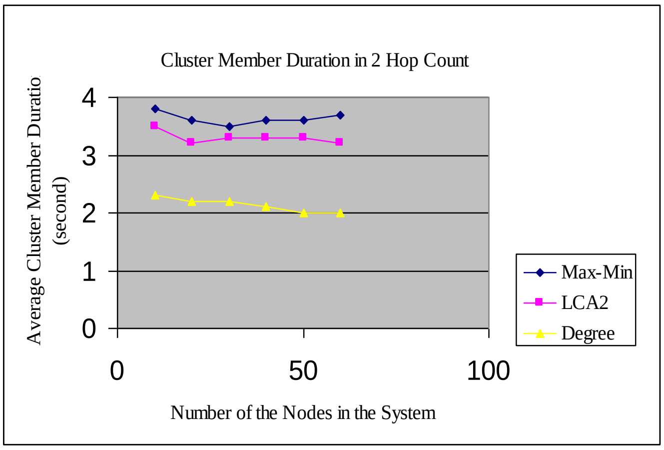

Fig. 5 Impact of network density on cluster member duration

Finally, figure 6 shows that Max-Min produces the highest percentage of re-elected clusterheads.

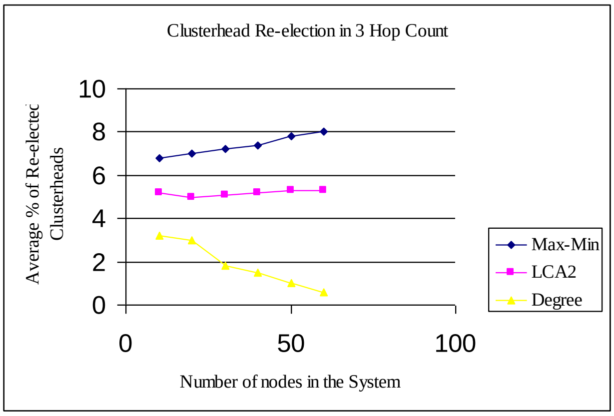

Fig. 6 Impact of network density on re-elected clusterheads

As a result, figure 7 shows that Max-Min elects only a fraction of the total number of nodes as leaders during the entire simulation run of 150s. This supports the idea that Max-Min will try to re-elect existing leaders. The Degree-based heuristics elected every node or one short of every node as leader at least once during each simulation run of 150s. So, their plots are superimposed on each other and cannot be distinguished. While LCA2 does not elect every node a clusterhead in each simulation run, it still elects a much higher number of clusterheads than Max-Min. It is not desirable to change leadership too frequently as this causes the exchange of leadership

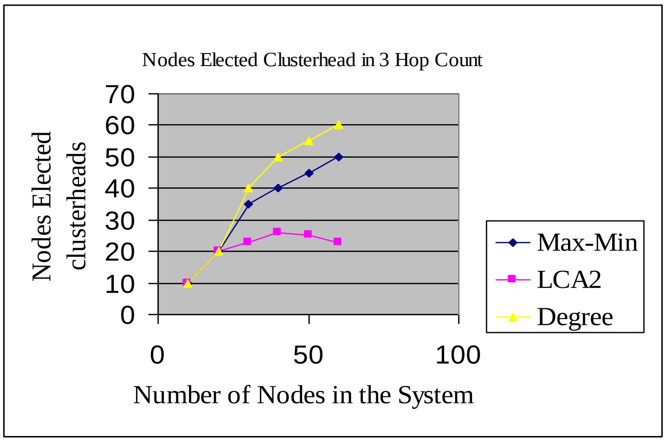

Fig. 7 Impact of network density on number of nodes elected as clusterheads during the entire simulation

VI. CONCLUSION

To improve efficiency of mobile ad hoc networks, it is essential to model the performance of existing clustering algorithms. The author compared the performance of Least Clustering Algorithm (LCA), LCA2, Highest-Connectivity and Max-Min D-Cluster Algorithms for mobile ad hoc networks. The Max-Min heuristic produces fewer clusterheads, much larger clusters, and longer clusterhead duration on the average as compare to LCA2 heuristic. The Degree-based heuristic suffers greatly in clusterhead duration, and cluster member duration. The LCA2 heuristic produces clusterheads that are comparable in number to that of Max-Min. However, Max-Min has clusterhead durations that are approximately 100% larger than that of LCA2 for dense networks. Furthermore, the Max-Min clusterhead duration continues to increase with increased network density, while the LCA2 heuristic clusterhead duration decreases with increased network density. In short, the Max-Min heuristic provides the best all around clusterhead leader election characteristics.

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