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Clustering Algorithms in Mobile Ad Hoc Networks: A Review

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ABSTRACT:
Routing in MANET is different from routing in wired network. One way to reduce routing overhead is to divide the network into clusters. Clustering of nodes into groups efficiently minimizes routing traffic overhead and also, MANETs raise new challenges when they are used in large scale network that contain large number of nodes. So, many clustering algorithms have been proposed. These clustering algorithms allow the structuring of the network into groups of entities called clusters creating a hierarchical structure. Each cluster contains a cluster head, gateways and ordinary nodes and various performance metrics such as node-id, mobility, node degree, energy etc. are considered for the election of cluster head. Clustering methods allow fast connection and also better routing and topology management for MANETs because in MANETs, the movement of the network nodes may quickly change the topology resulting in the increase of the overhead message in topology maintenance. Clustering schemes ensure efficient performance in MANETs due to number of advantages such as aggregation of topology information, bandwidth efficiency, routing efficiency and resource management. In this paper, we present a literature review of different clustering algorithms in MANETs. Finally we present clustering algorithms comparison using various attributes.
Keywords: Mobile ad hoc network; clustering; cluster head.

I. INTRODUCTION

A Mobile Ad hoc Network consists of a group of mobile nodes that form a network independent of any centralized administration as each mobile node in MANET acts as a router that performs the routing function for establishing communication among different mobile nodes [18]. MANET usually has a dynamic topology due to the mobility of nodes and has limited bandwidth as radio band is limited. Routing is one of the key issues in MANET due to their highly dynamic and distributed nature.

Routing is defined as the process of finding path from source to every destination in the network. Routing can take place either in a flat structure or in a hierarchical structure. In a flat structure, all nodes in the network are in the same hierarchy level and thus have the same role. Although this approach is efficient for small networks, it does not allow the scalability when the number of nodes in the network increases. In large networks, the flat routing structure produces excessive information flow which can saturate the network. Hierarchical routing protocols have been proposed to solve this problem. This approach divides the network into groups called clusters. This results in a network with hierarchical structure. Different routing schemes are used between clusters (inter-cluster) and within clusters (intra-cluster). Each node maintains complete knowledge of locale information (within its cluster) but only partial knowledge about the other clusters. Hierarchical routing is a solution for handling scalability in a network where only selected nodes take the responsibility of data routing. However, hierarchical approaches undergo continual topology changes. Thus, topology management plays a vital role prior to the actual routing in MANET. Cluster based structure (hierarchical structure) in network topology has been used to improve the routing efficiency in a dynamic network.
Clustering is defined as the process that divides the network into interconnected substructures, called clusters [1]. Each cluster has a particular node elected as cluster head (CH) based on a specific metric or a combination of metrics such as identity, degree, mobility, weight, density, etc. The cluster head plays the role of coordinator

within its substructure. Each CH acts as a temporary base station within its cluster and communicates with other CHs [17]. A cluster is therefore composed of a cluster head, gateways and members node as in fig. 1.
Cluster Head (CH): it is the coordinator of the cluster that coordinates the cluster activities.
Gateway: is a common node between two or more clusters or that can hear two or more cluster heads.
Member Node (Ordinary nodes): is a node that is neither a CH nor gateway node. Each node belongs exclusively to a cluster independently of its neighbors that might reside in a different cluster and have direct access only to one cluster head.

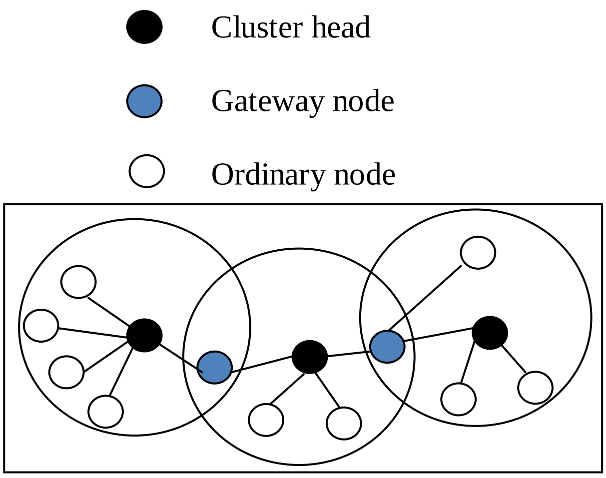

Figure1. Cluster Structure in MANET

A. Advantages of MANET Clustering
The cluster architecture ensures efficient performance with respect to very large dense ad hoc networks. The benefit of cluster structure is as follows [2]:

i. Aggregation of Topology Information
Due to the fact that the number of nodes of a cluster is lower than the number of nodes in the whole network, the clustering process assists in aggregating topology information.

ii. Routing Efficiency
In flat topology, every node bears equal responsibility to act as router for routing the packets to every other node so a great amount of flooding messages takes place in order to obtain better routing efficiency. But, such control packets reduces MAC layer efficiency.

iii. Spatial Reuse of Resources
In cluster structure, each node is assigned with different role and functionality. That is, each cluster is assigned a leader called cluster head and if a node comes within the transmission range of more than one cluster will be acting as a gateway node. Therefore, by this way, the cluster topology facilitates resource management.

iv. Efficiency and Stability
The significant feature of cluster structure is that it causes MANET to seem smaller and more stable. That is, when a mobile node switches its attaching cluster, only nodes residing in the corresponding clusters are required to modify their routing tables.

vi. Bandwidth Efficiency
Only the cluster heads participates in routing process, and the cluster members interact only with its cluster heads, thus avoids unnecessary exchange of messages among the mobile nodes, thus the utilization of bandwidth can be improved.

Rest of the paper is organized in the following manner, section II presents survey of various clustering algorithms in MANET, section III presents the comparison among those clustering algorithms and finally, section IV concludes this paper.

II. LITERATURE SURVEY

Many algorithms have been proposed for the election of CH in mobile ad hoc networks. CH is elected based on various performance factors that may be, node ID, connectivity, mobility, battery power etc. This section gives the review of classification of clustering algorithms: identifier based clustering algorithm, connectivity based clustering algorithm, mobility aware clustering algorithm, low cost of maintenance clustering algorithm, power aware clustering algorithm, and weight based clustering algorithm.

TABLE-1: CLASSIFICATION OF CLUSTERING ALGORITHMS

Clustering Algorithms in MANET					
Identifier based	**Connectivity based**	**Mobility aware based**	**Low cost of maintenance**	**Power aware Based**	**Weight based**
LIC Max-Min d-cluster	HCC K-CONID AMC	MobDhop MPBC	3-hBAC LCC	Power-aware connected dominant set ECEC	WCA EWBCA

IDENTIFIER BASED CLUSTERING

In this, a unique ID is assigned to each node. Nodes know the ID of its neighbors and clusterhead is chosen by following certain rules given below.

A. Lowest ID cluster algorithm (LIC):

LIC [3] is the easiest clustering processed protocol which basically selects cluster head on the basis of unique ID assigned to a particular set node. In LIC, a node with the minimum-ID is chosen as a CH. That is, each node is assigned a unique-ID. Periodically, the node broadcasts the list of nodes that it can hear (including itself). Each node compares the IDs of its neighbors with its own ID. A node decides to become a cluster head if it has the lowest ID among its neighbors IDs. A node with lowest ID will act as a CH.

Disadvantages:

i. It may cause over heading as no number of nodes in a cluster is fixed.
ii. Certain nodes are prone to power drainage due to serving as cluster heads for longer periods of time.
iii. The performance of such a system is unpredictable and random as no network related parameters are in consideration.

B. Max-Min d-cluster formation algorithm:

In many papers the cluster head election is done in such a way that no node can be more than one hop away from its cluster head. The main drawback of nodes being 1-hop away from the cluster head is the generation of a large number of cluster heads within the network causing a congestion problem. Therefore, in the Max-Min heuristic [4], clusters are formed by nodes that can be at most d-hops away from the cluster head. A d-neighborhood of a node consists of the node itself and the set of all nodes located within d-hops away from the node. In this heuristic d is defined as the maximum number of hops away from the nearest cluster head ($d \geq 1$). This value is an input to the heuristic allowing control over the number of cluster heads to be selected. Nodes participate in the cluster head election algorithm based on their node id rather than their degree of connectivity. As the network topology changes slightly the node's degree of connectivity is much more likely to change than the node's id relative to its neighboring nodes. If a node A is the largest in the d-neighborhood of another node B then node A, A will be elected a cluster head, even though node A may not be the largest in its d-neighborhood. This provides a smooth exchange of cluster heads rather than an erratic exchange. This method minimizes the amount of data that must be passed from an outgoing cluster head to a new cluster head when there is an exchange and maximizes the number of gateways in order to obtain a backbone formed by multiple paths between neighboring cluster heads. In this way, congestion can be eased.

2. Connectivity based clustering

A. Highest Connectivity Clustering algorithm (HCC):

Gerla and Tsai proposed a protocol called Highest Connectivity Clustering (HCC) [3] based on the degree of connectivity to construct clusters. The degree of a node is computed based on its distance from others. In this protocol the node with maximum number of neighbors (i.e., maximum degree) is selected as the cluster head. If two nodes or more have the same degree of connectivity, the node with the lowest ID is elected as a cluster head. HCC generates a limited number of clusters. In mobile environment, this algorithm increases the number of re-affiliations of CHs because their degree changes very frequently and as a result; the highest-degree node (the current cluster head) may not be re-elected to be a cluster head even if it loses one neighbor. All these drawbacks occur because this approach does not have any restriction on the upper bound on the number of nodes in a cluster. In comparison with Lowest-ID scheme, it is basically the power of nodes is calculating based on its gap formed from each others. Each node floods its connectivity value under its transmission operational range. So, within their operational transmission range, a node declares to be a CH or remain constant as cluster node by comparing the connectivity value of its closest cell with its previous value. The operating node with such a highest connectivity value in its vicinity will become CH. Connectivity-based clustering follows the same circumstances of ID-based regarding to cluster size and performance degradation.

B. K-hop connectivity ID clustering algorithm (K-CONID):

K-CONID [5] combines two clustering algorithms such as LID and HCC. In order to select CHs, connectivity is considered as a first criterian, and lowest ID is considered as a second criterian. The main aim is to minimize the number of clusters formed in the network and in this way obtain dominating sets of smaller sizes. Clusters in the K-CONID approach are formed by a cluster head and all nodes that are at distance at most k-hops from the cluster head. In the starting of the algorithm, a node initiates a flooding process in which a clustering request is transmits to all other nodes. In case of the Highest-degree heuristic, by which degree of the node is only measures connectivity for 1-hop clusters. K-CONID forms a link which is generalized for a k-hop neighborhood. Thus, when k = 1 connectivity is the same as node degree. Every node in the network is assigned a pair did = (d, ID) where, d is a node's connectivity and ID is the node's identifier. A node is selected as a cluster head if it has the highest connectivity. In case of equal connectivity, a node has cluster head which contains priority if it has lowest ID. The fundamental theme is that every node broadcasts its clustering decision once all its k-hop neighbors with larger cluster head priority have done so.

C. Adaptive multihop clustering (AMC):

It is a multihop clustering scheme with load-balancing capabilities [6]. Each mobile node periodically broadcasts information about its ID, Cluster head ID, and its status (clusterhead/ member/gateway) to others within the same cluster. With the help of this broadcast, each mobile node obtains the topology information of its cluster. Each gateway also periodically exchanges information with neighboring gateways in different clusters and reports to its cluster head. Thus, a cluster head can know the number of mobile nodes of each neighboring cluster. Adaptive multihop clustering sets upper and lower bounds (U and L) on the number of cluster members within a cluster that a cluster head can handle. When the number of cluster members in a cluster is less than the lower bound, the cluster needs to merge with one of the neighboring clusters. In order to merge two clusters into one cluster, a cluster head always has to get the cluster size of all neighboring clusters.

It prevents that the number of cluster members in the merged cluster is over the upper bound. On the contrary, if the number of cluster members in a cluster is greater than the upper bound, the cluster is divided into two clusters. However, Adaptive multihop clustering does not address how to select a proper node to serve as the clusterhead for the newly detached cluster. Although AMC mentions that the upper and lower bounds should be decided by network size, mobility etc.

3. Mobility aware clustering

A. Mobility-based d-hop clustering algorithm (MobDhop):

MobDhop [7] partitions an ad hoc network into d-hop clusters based on mobility metric. The objective of forming d-hop clusters is to make the cluster diameter more flexible. MobDhop is based on mobility metric and the diameter of a cluster is adaptable with respect to node mobility. This clustering algorithm assumes that each node can measure its received signal strength. In this manner, a node can determine the closeness of its neighbours. Strong received signal strength implies closeness between two nodes. The MobDhop algorithm requires the calculation of five terms: the estimated distance between nodes, the relative mobility between nodes, the variation of estimated distance over time, the local stability, and the estimated mean distance. A node calculates its estimated distance to a neighbour based on the measured received signal strength from that neighbour. Relative mobility corresponds to the difference of the estimated distance of one node with respect to another, at two successive time moments. This parameter indicates if two nodes move away from each other or if they become closer.

MobDhop is executed in three stages: Discovery Stage, Merging Stage and cluster maintenance stage. During the discovery stage, mobile nodes with similar speed and direction are grouped into the same cluster. The merging phase is invoked in order to either merge clusters together or join individual nodes to a cluster. The cluster maintenance process is invoked when a node switches on and joins the network or a node switches off and leaves the network.

B. Mobility prediction based clustering (MPBC) algorithm:

Ni et al proposed MPBC algorithm [8] for MANETs with high mobility nodes. The basic information in MPBC is the relative speeds estimation for each node in the whole network. During the clustering stage, all nodes broadcast the Hello packets periodically to build their neighbors lists. Each node estimates its average relative speeds with respect to its neighbors based on the Hello packets exchanges. Nodes with lowest relative mobility are selected as CHs. During cluster maintenance stage a prediction-based method is to solve the problems caused by relative node movements, including the cases when a node moves out of the coverage area of its current CH, and when two CHs move within the reach of each other, one is required to give up its CH role. This approach extends the connection lifetime which results in stable clusters.

4. Low cost of maintenance clustering

A. 3-hop between adjacent cluster heads (3-hBAC):

Yu and Chong proposed 3-hBAC [9] which creates a 1-hop non-overlapping clusters structure with three hops between neighboring cluster heads by the introduction of a new node status, named "clusterguest". Cluster guest node is a mobile node that cannot directly connect to any cluster head, but can access some clusters with the help of a cluster member. During cluster formation, the nodes having the highest degree are declared as CHs. All one hop neighbors join as member nodes. The neighbor nodes of these member nodes that cannot directly join any cluster will be declared as cluster guest. For cluster maintenance, this algorithm keeps the adjacent clusterheads at least two-hops away. So when two cluster heads move into the reach range of each other, one is required to give up its cluster head role. With the help of cluster guest, 3Hbac does not raise ripple effect when re-clustering, which means the cluster head re-election will have no affect on the status of mobile nodes outside these two clusters. For another case, when a mobile node moves out of the ranges of all clusters, it can join a cluster as a cluster guest if it can reach some cluster member(s) of that cluster. Hence, there is no need to form new clusters in order to cover such a single node as in LCC and the cluster topology does not change. This can reduce the number of clusters and eliminate small unnecessary clusters.

B. Least cluster change algorithm (LCC):

Chiang et al [10] proposed LCC, an improved versions of LCA algorithm which adds a maintenance step to minimize the cost of re-clustering. In LCC the clustering algorithm is divided into two steps: cluster formation and cluster maintenance. The cluster formation simply follows LIC, i.e. initially mobile nodes with the lowest ID in their neighborhoods are chosen as cluster heads. Re-clustering is event-driven and the reconstruction of clusters is invoked in only the following two cases:

- If two cluster heads are neighbors, then the one with the highest ID gives up the role of cluster head.
- If a non CH node moves outside its cluster and does not join an existing cluster then it will become cluster head forming a new cluster.

Hence, LCC significantly improves cluster stability by relinquishing the requirement that a clusterhead should have some special features in its local area. But the second case of re-clustering in LCC indicates that a single node's movement may still invoke the complete cluster structure recomputation and thus results in large communication overhead.

5. Power-aware clustering

A. Power-aware connected dominant set:

It is an energy efficient clustering scheme which decreases the size of a dominating set (DS) as in shown in figure2 without impairing its function [11]. The unnecessary mobile nodes are excluded from the dominating set saving their energy consumed for serving as clusterheads. Mobile nodes inside a DS consume more battery energy than those outside a DS because mobile nodes inside the DS bear extra tasks, including routing information update and data packet relay. Hence, it is necessary to minimize the energy consumption of a DS. In this scheme Energy level instead of ID or node degree is used to determine whether a node should serve as clusterhead. A mobile node can be deleted from the DS when its close neighbor set is covered by one or two dominating neighbors, and at the same time it has less residual energy than the dominating neighbors. This scheme cannot balance the great difference of energy consumption between dominating nodes (clusterheads) and non-dominating nodes (ordinary nodes) because its objective is to minimize the DS rather than to balance the energy consumption among all mobile nodes. Hence, mobile nodes in the DS still likely deplete their energy at a much faster rate.

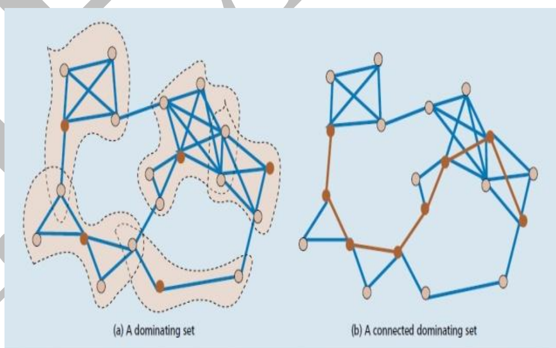

Figure2. Dominating Set [19]

B. Enhance Cluster based Energy Conservation (ECEC) algorithm:

ECEC [12] is an enhancement of Cluster based Energy Conservation algorithm (CEC). The authors presented a new topology control protocol that extends the lifetime of large ad hoc networks while ensuring minimum connectivity of nodes in the network, the ability for nodes to reach each other and conserve energy by identifying redundant nodes and turning their radios off. During cluster formation phase, nodes with the highest estimated energy values in their own neighborhoods are elected as CHs. After CHs election process, ECEC then elects gateways to connect clusters. ECEC reduces power consumption which leads to a longer network lifetime. However, this scheme exchanges more overhead to elect the CHs and getaways.

6. **Weight based clustering**

A. Weighted clustering algorithm (WCA):

WCA [13] selects clusterheads by considering important aspects related to the efficient functioning of the system components. Therefore, in order to optimize battery usage, load balancing and MAC functionality a node is chosen to be a clusterhead according to the number of nodes it can handle, mobility, transmission power and battery power. To avoid communications overhead, this algorithm is not periodic and the clusterhead election procedure is only invoked based on node mobility and when the current dominant set is incapable to cover all the nodes. To ensure that clusterheads will not be over-loaded a pre-defined threshold is established in order to specify the number of nodes each clusterhead can ideally support. This parameter corresponds to δ. WCA selects the clusterheads according to the weight value of each node. The weight associated to a node v is defined as: Wv = w1v + w2Dv + w3Mv + w4Pv

The node with the minimum weight is selected as a clusterhead. The weighting factors are chosen so that w1 + w2 + w3 + w4 = 1. Mv is the measure of mobility. It is taken by computing the running average speed of every node during a specified time T. Δv is the degree difference. Δv is obtained by first calculating the number of neighbours of each node. The result of this calculation is defined as the degree of a node v, dv. To ensure load balancing the degree difference Δv is calculated as |dv − δ| for every node v. The parameter Dv is defined as the sum of distances from a given node to all its neighbours. This factor is related to energy consumption since more power is needed for larger distance communications. The parameter Pv is the cumulative time of a node being a clusterhead. Pv is a measure of how much battery power has been consumed. A clusterhead consumes more battery than an ordinary node because it has extra responsibilities. The clusterhead election algorithm finishes once all the nodes become either a clusterhead or a member of a clusterhead. The distance between members of a clusterhead, must be less or equal to the transmission range between them. No two clusterheads can be immediate neighbors

B. Efficient weight based clustering algorithm (EWBCA):

EWBCA [14] aims to improve the usage of scarce resources such as bandwidth and energy by producing stable clusters, minimizing routing overhead, and increasing end to end throughput. Each node has a combined weight (Number of Neighbors, Battery Residual Power, Stability and Variance of distance with all neighbors) that indicates its suitability. Each node is: NUL, CH, member node, getaway node. Initially all nodes are in the NUL state. Each node calculates its combined weight and broadcasts it to its neighbors. The node with highest combined weight is elected as CH. Cluster maintenance is invoked when a node moves outside the boundaries of its cluster and/or when cluster head consumes most of its battery energy.

III. COMPARISON

In this section, we show the comparison of different types of clustering algorithms for MANET in table 2.Comparison is done by considering different metrics such as CHs election, cluster radius, overlapping clusters, clusters number, CH change, cluster stability and total overhead.

IV. CONCLUSION

We have surveyed several clustering algorithms classified into six categories such as identifier based clustering algorithm, connectivity based clustering algorithm, mobility aware clustering algorithm, low cost of maintenance clustering algorithm, power aware clustering algorithm, and weight based clustering algorithm for MANET as Clustering is the best solution for large and dense mobile ad hoc networks with high mobility. Selecting appropriate clusterhead is the main task to be researched. In this paper, we also compare several types of clustering algorithms by considering different attributes.

TABLE 2: CLUSTERING ALGORITHMS COMPARISON

Clustering algorithms	Based on	CHs Election	Cluster Radius	Overlap-ping Clusters	Clusters Number	CH Change	Cluster stability	Total Overhead
LIC [3]	ID-Neighbor	Lowest ID	One-hop	Possible	High	Very high	Very low	High
Max-Min d-cluster [4]	ID-Neighbor	Node ID	K-hop	No	High	Moderate	Low	Very high
HCC [3]	Topology	Highest degree	One-hop	No	High	Very high	Very low	High
K-CONID [5]	Topology	Highest degree	K-hop	No	Low	Low	High	Very high
AMC [6]	Topology	Highest degree	K-hop	No	Moderate	Low	Very high	Low
MobDhop [7]	Mobility	Lowest mobility	K-hop	No	Low	Low	Very high	Low
MPBC [8]	Mobility	Lowest mobility	One-hop	Yes	Relative-ly low	Low	High	Low
3-Hbac [9]	Topology	Highest degree	One-hop	No	Moderate	Relatively High	Low	Very high
LCC [10]	ID-Neighbor	Lowest ID	One – hop	Possible	High	High	Low	High
ECEC [12]	Energy	Highest energy	One-hop	Yes	Moderate	Low	Relatively high	Relatively High
WCA [13]	Weight	Combined Weight Metric	One-hop	Possible	Low	Low	High	High
EWBCA [14]	Weight	Combined Weight Metric	One-hop	No	Low	Low	Very high	Relatively Low

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