An Overview of Weight-Based Clustering in MANETs

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Abstract: ***Clustering in Mobile Ad-Hoc Networks (MANETs) is an important method to overcome some MANET challenges, such as scalability and power efficiency. This paper gives an overview of weight-based clustering algorithms, which is a flexible category of algorithms for selecting clusterheads in MANET clusters. These algorithms use clever techniques to increase the network stability (reduce the number of required reclustering and reaffiliation operations. They use multiple weighted parameters (such as mobility and residual power) to select the most suitable clusterhead in each cluster. Parameters' weights can be adjusted to fit different application scenarios.***

Keywords: clustering algorithms, clusterhead, MANET, WCA, weight-based clustering

1. Introduction

Mobile Ad Hoc Network (MANET) is a group of mobile nodes that form a dynamically changing network; this is done without using an existing infrastructure and with no central management. The nodes can move randomly, changing the topology quickly [1].

Unlike cellular networks, there is no Base Station (BS) to coordinate mobile nodes in a MANET, but this idea can be used in MANETs by creating clusters of nodes, with one node (called a clusterhead) controlling the access and allocating bandwidth in each cluster. Node insertion, removal, and mobility can change the topology rapidly, so the clusters must be updated periodically, causing management overhead [2].

2. Benefits of Clustering

Clustering can solve or reduce the impact of some MANET challenges [3]:

- Scalability: Each node doesn't need to know details about all nodes in the network, only details about its neighboring nodes are needed, this allow the network to expand without creating huge routing tables and without flooding the network with control messages.
- Energy Efficiency: Transmission power can be reduced to only reach neighboring nodes, this can greatly reduce the power consumption of the nodes; less control messages also means less power is consumed for the control message overhead.

Clustering has several advantages for different layers of MANETs, it enhances the performance of the Medium Access Control protocols by improving the spatial reuse, throughput, scalability and power consumption. It also improves routing in the network layer by reducing routing table sizes and by decreasing routing table updates after topology changes.

Because the number of cluster nodes is smaller than the number of all network nodes, each node only needs to store a small chunk of the entire network information [4].

3. Important Definitions

Here are some important definitions related to clustering algorithms [2], some of them are illustrated in Figure 1 [5]:

- **Cluster Head:** Cluster head is a node that is responsible for managing the cluster and routing cluster messages both in cluster and with the rest of the network.
- **Gateway Node:** A gateway node is a node that can communicate with more than one clusterhead, but is it not a clusterhead itself; some algorithms utilize gateway nodes for inter-cluster communication.
- **Node Neighbors:** Node neighbors are the nodes that can send and receive packets from and to the node directly, which means they are nodes that lie within the node's transmission range.
- **Node Power:** Node power is an indicator of how much power left in the node's battery, some algorithms use other methods of calculations or only take the full capacity into account.
- **Connectivity:** Node connectivity (also called degree), is the number of all the node's neighbors.
- **Mobility:** Node mobility is an indicator of node's movement, which can be its displacement, speed, or acceleration.
- **Distance:** Node distance is the physical distance between two nodes; lower distance means easier communication and lower power consumption during transmission.
- **Reaffiliation:** Reaffiliation happens when a node can no longer stay attached to its clusterhead, so it finds a new cluster, and attach itself to this new cluster.
- **Reclustering:** Reclustering is the invocation of the clustering algorithm again to create new clusters, it consumes a lot of resources, and many algorithms try to avoid it.
- **Cluster Stability:** Cluster stability is an indicator of how little the change in the topology occurs in the cluster, the more change in the topology, the less stable a cluster is, less stable clusters usually suffers from reaffiliation and

reclustering, both of which consume resources, this is why clustering algorithms prefer stable clusters.

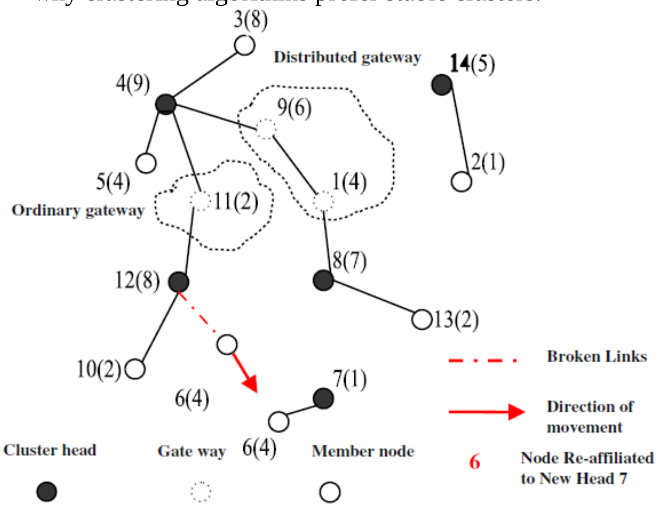

Figure 1: Cluster Components [5]

4. Weight Based Clustering Algorithms

Weight-Based Clustering Algorithms use a combination of metrics to decide which node in a cluster is selected as a clusterhead, so that it selects the best fitting node depending on these metrics. The general formula of weight based clustering algorithms is [6]:

$W=w1*v1 + w2*v2 + w3*v3 + \ldots.etc.$ (1)

Where w is weight and v is a normalized variable

This allows the algorithm to change to importance of each parameter depending on the network and the application.

Clustering algorithms usually have two phases, cluster formation and cluster maintenance.

4.1 Cluster Formation Phase

This phase starts when network nodes are started, nodes usually start finding their neighbors and creating clusters according to a predefined algorithm. Clustering algorithms are used to define the criteria for selecting a clusterhead, when a node is up, it follow the algorithm steps to find its neighbors, sometimes do some calculations, and then elect clusterheads and create clusters by attaching to them, a usual procedure for the cluster formation phase in weight based algorithm is [6]:

a) For every node, find the node's neighbors.
b) For every node, get required information from the node itself and from its neighbors.
c) For every node, calculate the weight according to the algorithm
d) Any group of neighbors selects the lowest weight node as their clusterhead and attach to it.
e) Repeat the steps until all nodes belong to clusters, either as clusterheads or as cluster members.

After the first clustering operation complete, the cluster formation phase ends, and all the next modifications to the cluster happen in the maintenance phase [6].

Cluster formation usually differs between algorithms by the clusterhead selection criteria, some algorithms only use IDs to select clusterheads, some use mobility, other use multiple weighted parameters to select the nodes that best fit the role of a clusterhead.

4.2 Cluster Maintenance Phase

After cluster formation, a new phase starts, the maintenance phase, this phase is needed because of the changing topology of the network (MANET nodes are freely moving).

The problem is that network's auto organization and management is that it is costly, e.g. cluster formation process that chooses a manager node for every cluster (the clusterhead) and ensures every node is a member of a cluster, requires lots of control messages and setup time, which needs resources (bandwidth and time), so reducing the management overhead is very important.

Most clustering algorithms try to make the clusters as stable as possible so that reclustering is rarely required, some choose weights or weight factors inversely proportional with the mobility of the node to get the most stable clusters, and some sets the most connected node as a clusterhead.

The usual cases for cluster maintenance are [6]:

a) A node moves away from its clusterhead, and into an area covered by another clusterhead.
b) A node moves away from its clusterhead, but to an area not covered by another clusterhead.
c) A clusterhead moves away from its cluster members, and into an area covered by another clusterhead.
d) A clusterhead moves away from its cluster members, but to an area not covered by another clusterhead.

Most algorithms just reaffiliate the node that moves away into another cluster with the new cluster's clusterhead. Some algorithms do the reclustering procedure when a node moves into an area not covered by clusterheads, other algorithms try to mitigate this by different methods.

5. Some Weight-Based Clustering Algorithms

Clustering in Mobile Ad Hoc Networks is very complicated topic with active research, because of the benefits it brings over flat MANETs, and because of the plethora of parameters that can be changed and tuned to different goals, some algorithms emphasize energy consumption, and others are more concerned with the overall network bandwidth, some aim to minimize delay. Here, some of the recent research in designing clustering algorithms for MANETs is presented:

- **Stefano Basagni, 1999 [7]** proposed two of the earliest weight based clustering algorithms, DCA (Distributed Clustering Algorithm) and DMAC (Distributed and Mobility-Adaptive Clustering), with parameters depending on node mobility. The algorithms only use local topology information (one-hop neighbors) at each node, while making each ordinary node have direct access to at least one clusterhead. This guarantees fast inter-cluster and intra-cluster communication between any pair of nodes. DCA is suitable for static or quasi-static networks, while DMAC improves on DCA by adapting to node mobility in MANETs.

- **Mainak Chatterjee, et al., 2002 [6]** proposed WCA (Weighted Clustering Algorithm), it uses multiple weighted parameters to keep the topology as stable as possible. Clusterheads form a dominant set in the network, they decide the topology, and they are also responsible for the topology stability. System parameters taken into account in this algorithm are: ideal degree (most suitable degree for the pre-defined network application), transmission power, node mobility and node's battery power. The algorithm works on-demand and only executed when required to maintain the stability of the nodes, this lowers the maintenance costs of the network. Simulation results show that the WCA performs better than other existing algorithms (Highest-Degree, Lowest-ID, and Node-Weight heuristics). WCA is also tunable (by changing parameter weights) to different MANET types and applications.
- **Sanjay Kumar Dhurandher and G. V. Singh, 2005 [8]**, proposed Weight Based Adaptive Clustering Algorithm (WBACA) for MANETs. WBACA takes into account the transmission power, transmission rate, mobility, battery power and the degree of a node for forming clusters. Simulation results show that WBACA has better performance than Lowest-ID and WCA algorithms; it also improves the stability of the clustered topology by reducing the number of clusters formed and the number of reaffiliations under different scenarios.
- **Likun Zou, et al., 2008 [9]**, proposed a new algorithm to decrease the network overhead by solving high frequency of reaffiliations in WCA, which is caused by the high mobility of nodes. The proposed Improved Weight-based Clustering Algorithm (IWCA) can enhance the stability of the network by taking the relative mobility of node and its neighbors into consideration. Simulation results indicate that IWCA has improved performance over the original WCA by reducing reaffiliation count.
- **Mohamed Aissaa and Abdelfettah Belghith, 2014 [10]** propose a new scheme for clustering MANETs, called FWCA (Fast Weighted Clustered Algorithm), with the parameters: Energy Consumption, Stability Factor, Relative Dissemination Degree, Remaining Battery Energy. They conclude it performs as well as the best known algorithms (like WCA).
- **Vijayanand Kumar and Rajesh Kumar Yadav, 2016 [11]**, used a dynamic weight adjustments to change WCA weights, allowing them to improve the network lifetime, while using the same WCA parameters.
- **Jianmin Du, et al., 2017 [12]** propose a weighted clustering algorithm based on node stability (SA-WCA) that can obtain the mutual node movement only based on the transmitting and received power of nodes, saving GPS positioning energy. It depends on the remaining energy of the node, the node degree, and node stability.

The above algorithms are summarized in Table 1:

Table 1: Weight Based Clustering Algorithms

Algorithm	Weight Parameters	Notes
DMAC	Mobility	
WCA	degree-difference, sum of the distances, average speed, cumulative time as a clusterhead	Widely used as a reference algorithm to compare with
WBACA	transmission power, transmission rate, mobility, battery power, degree	
IWCA	degree-difference, average relative distances, cumulative time as a clusterhead, relative mobility	
FWCA	Energy Consumption, Stability Factor, Relative Dissemination Degree, Remaining Battery Energy	
WCA w/ Weight Correction	degree-difference, sum of the distances, average speed, cumulative time as a clusterhead	Same as WCA but with dynamic weight adjustments
SA-WCA	remaining energy of the node, the node degree, and node stability	

6. Summary

Weight-Based Clustering Algorithms can improve the network stability by selecting suitable clusterheads and do reclustering only when it's required. These algorithms usually use parameters that affect the stability or longevity of the network, e.g. mobility and remaining battery power. They also take into account the number of neighboring nodes and the transmission characteristics of each node. Weight-based clustering algorithms are good fit for most applications due to their flexibility and because they make better-informed decisions by taking multiple node parameters into account.

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