Energy Aware Load Balancing Clustering in Mobile Ad Hoc Networks

Ratish Agarwal, Roopam Gupta, and Mahesh Motwani

Abstract—A mobile ad hoc network is a decentralized type of network formed by collection of autonomous mobile nodes connected by wireless links. Constraints such as limited bandwidth, energy scarcity, mobility, non-deterministic topology and physically insecure environment make ad hoc routing a challenging area of research. In a large ad hoc network, clustering is a solution to limit the amount of routing information that propagates inside the network. In a cluster one node works as a clusterhead and coordinates all the activities such as routing. In this paper authors proposed a novel energy aware load balancing Clustering “LS-WCA”. If a clusterhead becomes overloaded due to migration of nodes in its vicinity than cluster division is executed to form a new cluster. The clusterhead of the parent cluster bears the responsibility of appointment of a new clusterhead. The appointment is based on the weight of the node and its distance from the parent clusterhead. The performance of the proposed work is compared with WCA using various parameters by simulating it on network simulator.

Keywords— Cluster, load-balancing, mobility, clusterhead.

I. INTRODUCTION

MANET has various potential applications. Some typical examples include emergency search-rescue operations, meeting events, conferences, and battlefield communication between moving vehicles and soldiers. With the abilities to meet the new demand of mobile computation, the MANET has a very bright future.

Cluster-based routing is a solution to address nodes heterogeneity, and to limit the amount of routing information that propagates inside the network. The idea behind clustering is to group the network nodes into a number of overlapping clusters. 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. Inside the cluster one node that coordinates the cluster activities is clusterhead (CH). Inside the cluster, there are ordinary nodes also that have direct access only to this one clusterhead, and gateways. Gateways are nodes that can hear two or more clusterheads. By replacing the nodes with clusters, existing routing protocols can be directly applied to the network. Only gateways and clusterheads participate in the propagation of routing control/update messages. In dense networks this significantly reduces the routing overhead, thus solving scalability problems for routing algorithms in large ad hoc networks.

Combined metrics based clustering or weighted clustering algorithm [1,2] takes a number of metrics into account for cluster configuration, including node degree, residual energy capacity, moving speed, and so on. One advantage of this clustering scheme is that it can flexibly adjust the weighting factors for each metric to adjust to different scenarios.

In clustered ad hoc networks, Clusterheads bear extra responsibility of routing packets for others. If a clusterhead has too many neighbors it may become bottleneck, since it has to perform routing related works of all of its members [3].

There may exist some situations where some regions of the network become overcrowded (for example location near the speaker in a conference) and the clusterheads lying in such regions may be overloaded due to movement of some nodes with in this area. The performance of the network may degrade due to congestion and buffer flow at the clusterheads. Authors proposed a new technique for load sharing to relieve the clusterheads from overload.

II. LITERATURE REVIEW

A number of clustering algorithms for mobile ad hoc networks have been proposed in the literature. In Lowest ID cluster algorithm (LIC) [4] a node with the minimum id is chosen as a clusterhead. Drawback of lowest ID algorithm is that certain nodes are prone to power drainage [5] due to serving as clusterheads for longer periods of time.

In Highest connectivity clustering algorithm (HCC) [4] the degree of a node is computed based on its distance from others. The node with maximum number of neighbors (i.e., maximum degree) is chosen as a clusterhead. This system has a low rate of clusterhead change but the throughput is low. As the number of nodes in a cluster is increased, the throughput drops. K-CONID [6] combines two clustering algorithms: the Lowest-ID and the Highest-degree heuristics. In order to select clusterheads connectivity is considered as a first criterion and lower ID as a secondary criterion. In HCC clustering scheme, one cluster head can be exhausted when it serves too many mobile hosts. It is not desirable and the CH becomes a bottleneck. So a new approach [7] is given in which when a CH's Hello message shows its dominated nodes' number exceeds a threshold (the maximum number one CH can manage), no new node will participate in this cluster. Adaptive multihop clustering [8] sets upper and lower bounds (U and L)
on the number of cluster members within a cluster that a clusterhead 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. 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.

Mobility-based d-hop clustering algorithm [9] 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. Local stability is computed in order to select some nodes as clusterheads. A node may become a clusterhead if it is found to be the most stable node among its neighborhood. In Mobility Based Metric for Clustering [10] a timer is used to reduce the clusterhead change rate by avoiding re-clustering for incidental contacts of two passing clusterheads. Mobility-based Frame Work for Adaptive Clustering [11] partition a number of mobile nodes into multi-hop clusters based on (a, t) criteria. The (a, t) criteria indicate that every mobile node in a cluster has a path to every other node that will be available over some time period ‘t’ with a probability ‘a’ regardless of the hop distance between them.

In LCC [12] 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 clusterheads. Re-clustering is event-driven and invoked if two clusterheads move into the reach range of each other and when a mobile node cannot access any clusterhead. Adaptive clustering for mobile wireless network [13] ensures small communication overhead for building clusters because each mobile node broadcasts only one message for the cluster construction.

3-hop between adjacent clusterheads (3-hBAC) [14] algorithm introduce a new node status, “clusterguest”. When a mobile node finds out that it cannot serve as a clusterhead or join a cluster as a clustermember, but some neighbor is a clustermember of some cluster, it joins the corresponding cluster as a clusterguest.

A clustering protocol that does not use dedicated control packets or signals for clustering specific decision is Passive Clustering [15]. In this scheme, when a potential clusterhead with “initial” state has something to send, such as a flood search, it declares itself as a clusterhead by piggybacking its state in the packet. Load balancing clustering (LBC) [3] provide a nearby balance of load on the elected clusterheads. Once a node is elected a clusterhead it is desirable for it to stay as a clusterhead up to some maximum specified amount of time, or budget. Initially, mobile nodes with the highest IDs in their local area win the clusterhead role. LBC limits the maximum time units that a node can serve as a clusterhead continuously, so when a clusterhead exhausts its duration budget, becomes a non-clusterhead node. Power-aware connected dominant set [16] is an energy-efficient clustering scheme which decreases the size of a dominating set (DS) without impairing its function. Clustering for energy conservation [17] assumes two node types: master and slave. The purpose of this scheme is to minimize the transmission energy consumption summed by all master-slave pairs and to serve as many slaves as possible in order to operate the network with longer lifetime and better performance.

Weighted clustering algorithm (WCA) [1] selects 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. 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.

In WCA high mobility of nodes leads to high frequency of reaffiliation which increase the network overhead. Higher reaffiliation frequency leads to more recalculations of the cluster assignment resulting in increase in communication overhead. Entropy based clustering [18] overcomes the drawback of WCA and forms a more stable network. It uses an entropy-based model for evaluating the route stability in ad hoc networks and electing clusterhead. Entropy presents uncertainty and is a measure of the disorder in a system. So it is a better indicator of the stability and mobility of the ad hoc network.

Vote-based clustering algorithm [7] is based on two factors, neighbors' number and remaining battery time of every mobile host (MH) Each MH has a unique identifier (ID) number, which is a positive integer. The clustering approach presented in WBACA [19] is based on the availability of position information via a Global Positioning System (GPS). The WBACA considers following parameters of a node for clusterhead selection: transmission power, transmission rate, mobility, battery power and degree. In Connectivity, energy & mobility driven weighted clustering algorithm (CEMCA) [20] the election of the cluster head is based on the combination of several significant metrics such as: the lowest node mobility, the highest node degree, the highest battery energy and the best transmission range.

An optimal energy-efficient clustering method in wireless sensor networks using multi-objective genetic algorithm [21] is a multi-objective genetic algorithm (GA) whose goal is to obtain clustering schemes in which the network lifetime is optimized for different delay values. A load balancing energy efficient clustering algorithm [22] in this paper, the author proposed a dynamic energy-efficient clustering algorithm that prolongs the network lifetime by electing cluster-heads taking into consideration, in addition to other parameters such as mobility, their residual energies and making them dynamically monitor their energy consumption to either diminish the number of their cluster-members or relinquish their roles.

III. PROPOSED METHODOLOGY

In weighed cluster algorithm [1] the selection of clusterhead is performed after considering a number of performance parameters including degree difference, distance with neighbors, mobility of nodes and remaining battery power. The proposed work “Load Sharing in Weighted Clustering Algorithm (LS-WCA)” follow the clusterhead selection procedure given in WCA.
3.1 Clusterhead selection

The parameters considered for clusterhead selection are described below.

3.1.1 Degree Difference

In cluster-based structure a performance parameter for load balancing is degree difference \((\Delta_v)\) [1], for each node \(v\) which is defined as the difference of ideal node degree \((\delta)\) and actual degree (connectivity) of that node. Degree of node \((dv)\) is the number of neighbors of node \(v\) that are in the transmission range. Ideal degree is the number of neighbors that a clusterhead can handle effectively.

\[
\text{Degree difference}(\Delta_v) = |d_v - \delta|
\]

3.1.2 Energy Consumption

Clusterhead has to perform extra task for routing and forwarding the packets, so it is more prone to energy drainage. More power is needed for communicating long distant neighbors. In mobile ad hoc network nodes communicate with each other through the wireless channel, the Friis transmission equation is as follows

\[
\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2
\]

Or

\[
P_t \propto R^2
\]

Where, \(P_t\) is transmitted power and \(P_r\) is power at the receiving antenna, \(G_t\) and \(G_r\) are the antenna gains, \(\lambda\) is the wavelength used and \(R\) is the distance between the nodes. Energy-consumption of a node is directly proportional to the distance of that node with its neighbors.

Sum of distance to all neighbors \((Sdv)\) is found as

\[
Sdv = \frac{1}{d_v} \sum_k \sqrt{(x_v - x_k)^2 + (y_v - y_k)^2}
\]

where \((x_v, y_v)\) and \((x_k, y_k)\) are the coordinates of the node \(v\) and node \(k\) respectively. Summation is done for all neighbors \(k\) of node \(v\). The parameter “Sum of distances” is used for energy consumption at the time of clusterhead selection [1].

3.1.3 Mobility

Mobility or stability is an important factor in deciding the clusterheads. In order to avoid frequent clusterhead changes, it is desirable to elect a clusterhead that does not move very quickly. When the clusterhead moves fast, the nodes may be detached from the clusterhead and as a result, a reaffiliation occurs. Reaffilation can increase computation and processing, which is not a desirable feature [1]. The running average of the speed for every node till current time \(T\) gives a measure of mobility and is denoted by \(Mv\) as

\[
Mv = \frac{1}{T} \sum_{t=1}^{T} \sqrt{(x_t - x_{t-1})^2 + (y_t - y_{t-1})^2}
\]

Where \((x_t, y_t)\) and \((x_{t-1}, y_{t-1})\) are the coordinates of the node \(v\) at time \(t\) and \((t - 1)\) respectively.

3.1.4 Power

A clusterhead consumes more battery than an ordinary node because it has extra responsibilities. It can estimate the remaining battery power by the amount of time spent by the node as a clusterhead. The parameter \(Pv\) is the cumulative time of a node being a clusterhead. \(Pv\) is used to measure how much battery power has been consumed by the node [1]. Higher the value of \(Pv\) lower the remaining battery power.

All four parameters \((\Delta_v, Sdv, Mv,\text{ and } Pv)\) explained above can be used as a performance matrix for selection of a node as a clusterhead. Weight of these parameters can change according to requirement.

Weighing factors are chosen in such a way that

\[
W_1 + W_2 + W_3 + W_4 = 1
\]

Combined weight of a node \(W_v\) is calculated as follows

\[
W_v = W_1 \Delta_v + W_2 Sdv + W_3 M_v + W_4 P_v
\]

Each node calculates its weight and broadcasts it periodically in a hello packet to all nodes in its transmission range. When a node receives the weights of its 1-hop neighbors, it inserts them in the possible CH set, which includes all potential cluster-heads.

3.2 Cluster formation with load balancing

At the system initiation each node is assumed to be holding a status “undecided”. Periodic broadcast of hello message enables a node to gather useful information about its neighborhood. Based upon the information obtained from the hello messages each node computes the combined weight value. This information is further exchanged by neighbors and nodes store this neighborhood information including combined weight in neighbor tables. If a node determines that it has the lowest value of combined weight among its neighbors, it changes its status as “CH” and sends “join_cluster” messages to its neighbors. Each neighboring node receiving this join request check its own status and if it is still “undecided”, it respond with “accept_join” and become a member of that clusterhead and change its status as “member”. This process runs in parallel and continued until all the nodes of the network either become clusterheads or members.

In ad hoc environment there may exist some situations where some regions of the network become overcrowded (for example location near the speaker in a conference) and the clusterheads lying in this regions may be overloaded due to movement of some nodes with in this area. A clusterhead is called overloaded if it is serving more than a predefined number of threshold members. The overloaded clusterheads can adversely affect the performance of the network.

Authors have addressed this issue by splitting the cluster in two parts. Fig. 1 show two clusters \(C1\) and \(C2\). It is assumed that the threshold number is six and clusterhead of \(C1\) has eight members which are greater than threshold and thus it is overloaded and cluster division is needed.
The clusterhead of the parent cluster can appoint another member node as the clusterhead of the second (disjointed) cluster C3. The selection of the new clusterhead is performed as follows.

In LS-WCA technique, authors have used two factors to calculate fitness of the nodes for the appointment as new cluster head. First factor is its distance from the parent clusterhead and the second factor is its weight value. The clusterhead of C1 calculates a factor for fitness of all members and the node with best fitness (maximum fitness factor) is appointed as a new clusterhead of disjoined cluster. The fitness factor \( F_x \) for all member nodes \( x \) calculated at clusterhead node \( n \) is given by

\[
F_x = \alpha \ast (1 - W_x) + \beta \ast D_{nx}
\]

Where \( W_x \) is the weight of node \( x \) and \( D_{nx} \) is the normalized distance between node \( n \) and node \( x \). \( \alpha \) and \( \beta \) are weight factors (importance factors) assigned to \( W_x \) and \( D_{nx} \). The values of \( \alpha \) and \( \beta \) are adaptively set according to the situations.

Now, for the cluster formation of this new disjoined cluster all the members of the parent cluster find out distance to newly appointed clusterhead. Nodes join the new cluster if they are closer to the newly appointed clusterhead as compared to their original parent clusterhead. Otherwise they stay under the affiliation of parent cluster.

3.3 Routing in cluster based structure

It is assumed that the graph of nodes is a connected graph that means all nodes are connected with the probability of almost one. Any node of the network can establish connection to any other node of the network. If a node A wants to establish a connection to node B, then it has to first find the route to be. The routing process depends whether the node B is in the same cluster as node A or in another cluster.

3.3.1 Inter_cluster routing

If the sender \( A \) and receiver \( B \) are not in the same cluster then node \( A \) sends a route request message containing node \( B \) as a destination to its clusterhead. \( A \)’s clusterhead propagates the message to its neighboring clusterheads.

3.3.2 Intra_cluster routing

If the destination node \( B \) is in the same cluster as source node \( A \), then the clusterhead of this cluster directly sends a positive acknowledgement to node \( A \) that, it has a direct route to node \( B \).

IV. SIMULATION AND PERFORMANCE ANALYSIS

Proposed work has been implemented in NS-2 simulator version 2.34 on Ubuntu 10.10 platform. During the simulation, the source and the destination nodes are randomly chosen among all the nodes in the network. For each data point in the results, 10 simulations were performed and the average value was computed.

4.1 Simulation parameters

Summary of the simulation parameters [23,24] taken during the simulation is presented in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulator</td>
<td>NS 2.34</td>
</tr>
<tr>
<td>MAC Type</td>
<td>802.11</td>
</tr>
<tr>
<td>Simulation Area</td>
<td>1000 m X 800 m</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>100 sec</td>
</tr>
<tr>
<td>Number of Nodes</td>
<td>25, 50, 75, 100</td>
</tr>
<tr>
<td>Channel Type</td>
<td>Wireless</td>
</tr>
<tr>
<td>Antenna</td>
<td>Omni-Antenna</td>
</tr>
<tr>
<td>Radio Propagation</td>
<td>Two Ray Ground</td>
</tr>
<tr>
<td>Traffic Type</td>
<td>CBR(UDP) and FTP(TCP)</td>
</tr>
<tr>
<td>Data Payload</td>
<td>512 bytes/packet</td>
</tr>
<tr>
<td>Packet Interval</td>
<td>1, 0.2, 0.1 and 0.066 sec</td>
</tr>
<tr>
<td>Transmission Range</td>
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</tr>
<tr>
<td>Movement Model</td>
<td>Random waypoint</td>
</tr>
<tr>
<td>Maximum Speed</td>
<td>10m/s</td>
</tr>
</tbody>
</table>

4.2 Simulation Results & Observations

In the following subsections, the results and observations of the proposed LS-WCA protocol along with WCA have been presented.

Packet delivery fraction (PDF) is defined as the ratio of total packets transmitted to total packets received at the destination. In WCA some of the packets may drop due to congestion and buffer overflow at the clusterheads, this results in the drop of PDF whereas LS-WCA performed load balancing and this improves PDF as shown in fig. 2.
Throughput gives the effective utilization of the channel and is measured in kbps. The results shown in figure 3 show that the proposed work shows better throughput than the WCA. In WCA, packets have to wait for their turn because some of the clusterheads may be overloaded and congested. Our work uniformly distributes the load on the selected clusterheads and thus good throughput is maintained.

End to end delay includes all possible delay that may be caused by: buffering during route discovery, queuing at the interface queue, retransmission delay at the MAC layer, propagation and transfer time. It is defined as the time taken for a data packet to be transmitted across a MANET from source to destination. The E2E delay metric is given by:

$$E2E \text{ delay} = Tr - Ts$$

Where, $Tr$ is the time that a packet is received and $Ts$ the time that this packet was injected into the network.

As the traffic in the network increases, the clusterheads have to bear the increased load of routing the packets form source to destination. If clusterheads are serving a large no. of members than, it may become congested, this results larger end to end delay of routed packets. WCA does not limit the member of a clusterhead and thus, as the packet interval is decreased, more packets are transmitted by the source nodes in the unit time and this results in the more E2E delay. In LS-WCA a threshold is set on no. of members, so clusterheads are not overloaded. The E2E delay in proposed LS-WCA is less than that of WCA as shown by experimental results shown in fig. 4.

Average number of neighbors of each clusterhead is $\mu$ and $\mu = (N-k)/k$

Load balancing factor ($LBF$) can be used to measure how well balanced the clusters are [1]. For a network with $N$ number of nodes, cluster-based structure is formed by $k$ number of clusters and each cluster has $x_k$ number of members.

$$LBF = \frac{k}{\sum_{i=1}^{k} (x_i-\mu)^2}$$

A higher value of $LBF$ signifies a better load distribution and it tends to infinity for a perfectly balanced system. WCA does not have any limit on the number of members of clusterheads and thus there is non-uniform distribution of the load on the clusterheads. Proposed work distributes the load uniformly and an improved load balancing factor is achieved as showed in figure 5.

V. CONCLUSIONS

"Ad hoc network" is a topic of interest because there is no prior investment for fixed infrastructures, it can be easily deployed in a short time, and end users can access and manipulate data anytime and anywhere. This research paper presented energy aware and load balancing technique of clustering (LS-WCA) for mobile ad hoc networks.

Though clustering provides a good technique to reduce the control overhead in scalable ad hoc networks but there is always a chance of bottleneck formation at the selected clusterheads. This bottleneck can degrade the performance of
the network. Our proposed technique LS-WCA subdivide the overloaded cluster in two clusters and the head of the disjoined cluster is chosen by considering the power consumption during communication and weight values of the nodes. Since more power is needed to communicate at large distance, the farthest away node with suitable weight is assigned as the new clusterhead. Uniform distribution of the load on the selected clusterheads can improve the performance in terms of PDF, throughput, E2E delay and Load balancing.

REFERENCES


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