Mobility-Aware and Load Balancing Based Clustering Algorithm for Energy Conservation in MANET

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Abstract Mobile ad hoc network (MANET) is one of wireless communication network architecture that has received a lot of attention. MANET is characterized by dynamic network topology and limited energy. With mobility-aware and load balancing based clustering algorithm (MLCA), this paper proposes a new topology management strategy to conserve energy. Performance simulation results show that the proposed MLCA strategy can balance the traffic load inside the whole network, so as to prolong the network lifetime, mainly, at the same time, achieve higher throughput ratio and network stability.

Key words communication network; MANET; energy conservation; topology management

Mobile ad hoc network (MANET) is a collection of wireless mobile nodes forming a temporary communication network without the aid of any established infrastructure or centralized administration[1]. The wide range of potential applications has led to a recent rise in research and development activities.

Efficient energy conservation plays an important role in the protocol design of each layer in MANET because mobile host in such networks are usually battery-operated[2]. This paper only focuses on the hierarchical topology management. In this framework, a subset of the network nodes is selected to serve as the network backbone over which essential network control functions are supported. Hierarchical topology management is often called clustering, and consists of selecting a set of cluster-heads in a way that every node is associated with a cluster-head, and cluster-heads are connected with one another directly by means of gateways. Once election completed, the ordinary node can turn off their radio to conserve energy.

1 Related Work
The key step of hierarchical topology management is cluster-head election. Several algorithms have been proposed to choose cluster-heads in MANET. Let’s summarize below these algorithms.

1.1 Max-Degree Algorithm
The Max-Degree Algorithm is a commonly used algorithm in which nodes with higher degree are more likely to become cluster-heads[3]. The neighbors of a cluster-head become members of that cluster and can no longer participate in the election process. Experiments demonstrate that the system has a low rate of cluster-head changes, but that the network topology changes this approach can result in a high turnover of cluster-heads.

1.2 Lowest-ID Algorithm
Several approaches utilize the node identifiers to elect the cluster-head with one or multiple hops[4]. This kind of algorithm assigns a unique ID to each node and chooses the node with the minimum ID as a cluster-head. The drawback of this kind of algorithm is its bias towards those nodes with smaller identifier.

1.3 Node-Weight Algorithm
Basagni et al. introduces two algorithms, named distributed clustering algorithms (DCA) and distributed mobility adaptive clustering (DMAC)[5]. A node is chose to be cluster-head if its node-weight is higher than any of its neighbor’s node-weight. Both DCA and DMAC are executed at each node with the sole knowledge of the identity of the one-hop neighbors.

None of the above three kind of algorithms leads to an optimal election of cluster-heads since each deals with only a subset of parameters which can possibly impose constraints on the system. Each of these algorithms is suitable for a specific application rather
than for arbitrary wireless mobile networks. More important, these algorithms do not request the normal nodes to turn off his radio in order to conserve energy.

2 Mobility-Aware and Load Balancing Based Clustering Algorithm

2.1 Network Assumptions

This work assumes that MANET comprises a group of mobile nodes communicating through a common broadcast channel. Each node has one unique identifier, and all transmissions are omni-directional with the same transmission range. In addition, a reliable neighbor protocol is assumed to enable the quick update neighbor information at each node.

2.2 Basis for Cluster-Head Election Algorithm

To decide how well suited a node is for being a cluster-head, we take into account its dynamic priority (DP), relative mobility and remaining battery power. The following features are considered in our clustering algorithm:

1) The cluster-head election procedure is not periodic and is invoked as rarely as possible. This reduces system updates and hence computation and communication costs.

2) In order to avoid frequent cluster-head changes, we should elect a cluster-head that does not move very quickly.

3) Given that cluster-heads provide the backbone for a number of network control function, their energy consumption is more pronounced than that of ordinary nodes. Low-energy nodes must try to avoid serving as cluster-heads to save energy.

4) To balance the load of serving as cluster-heads, every node should take the responsibility of serving as a cluster-head for some period of time.

2.3 Cluster-Head Election Procedure

Based on the preceding discussion. We propose an algorithm called mobility-aware and load balancing based clustering algorithm (MLCA) that effectively combines each of the above system parameters with certain weighing factors chosen according to the system needs. The procedure consists of seven steps as described below:

1) Step 1: Each node broadcasts a discovery message that contains its node ID, DP, and remaining power. At the same time creates the one-hop neighbors set $N_i, \forall i \in V$.

2) Step 2: Compute the aggregate relative mobility $M_i$ for every node $i$ as Eqs.(1) and (2).

$$M_i = \sum_{j \in N_i} |M_i^{\text{old}}(j)| \quad \forall j \in N_i$$  \hspace{1cm} (1)

$$M_i^{\text{old}}(j) = 10 \log_{10} \frac{p_{\text{new}}^{\text{old}}(j)}{p_{\text{old}}^{\text{new}}}$$  \hspace{1cm} (2)

where $p_{\text{new}}^{\text{new}}(j)$ and $p_{\text{old}}^{\text{old}}(j)$ represent the values of receive power at node $i$ from node $j$ at two successive time overhead.

3) Step 3: Compute the remaining energy as

$$B_i = \frac{F_i}{R_i(t)}$$  \hspace{1cm} (3)

where $F_i$ is the full battery capacity of node $i$, and $R_i$ is the remaining battery capacity of node $i$ at time $t$.

4) Step 4: Compute the DP as below process.

if node is clusterhead then $DP_{\text{new}} = 1$
else if $DP_{\text{old}} = 1$ then $DP_{\text{new}} = 1$
else $DP_{\text{new}} = \text{int}(0.5 \times DP_{\text{old}})$
else $DP_{\text{new}} = DP_{\text{old}} + 1$

Then compute the load balance parameter $D_i$ for each node $i$ as Eqs.(4).

$$D_i = 1 - \frac{DP_i}{\text{Max}}$$  \hspace{1cm} (4)

where Max is a constant and equal to the number of nodes in our simulation.

5) Step 5: Calculate the combined weight $W_i$ for each node $i$, where

$$W_i = 10 \log_{10} \left( \frac{1}{M_i} \right) \frac{1}{(1 - B_i)} \log(10D_i)$$  \hspace{1cm} (5)

6) Step 6: Choose that node with the smallest $W_i$ as the cluster-head. All the neighbors of the chosen cluster-head are no longer allowed to participate in the election procedure.

7) Step 7: Repeat Steps 2)~6) for the remaining nodes not yet selected as a cluster-head or assigned to a cluster.

2.4 Gateway Node Selection Strategy

After cluster-head election, MLCA begin to elect the gateway nodes to connect all clusters to ensure overall network connectivity. In graph theory, the selected cluster-head are equivalent to a approximately minimal dominating set (MDS), and the selected gateway and cluster-heads forms the connected dominating set (CDS).
Among the gateway nodes, those nodes that can hear multiple cluster-heads are primary gateway nodes and those that can hear a combination of cluster-head and primary gateway are secondary gateway nodes.

Gateway selection is determined by several rules. First, primary gateway nodes have higher priority than secondary gateway nodes since at least two secondary gateway nodes, instead of just one primary gateway node, are needed to connect adjacent clusters. Second, gateway nodes with more cluster-head have higher priority. Third, gateway nodes with longer lifetimes have higher priority in order to balance node energy.

2.5 Update Policy

There are two main kinds of update conditions, named as cluster-head re-election and normal node re-affiliation.

2.5.1 Cluster-Head Re-Election Policy

After the selection of cluster-heads, the remaining redundant nodes are powered off to conserve energy. When a node’s radio is powered off, its forwarding role can be replaced by cluster-head through use 802.11 power saving mode [6].

In order to maintain the stability and avoid oscillation of the routing path, MLCA strategy tries to prolong the cluster duty cycle. On the other hand, we must re-form the cluster before the cluster-head runs out of energy or leaves its cluster region.

So whenever a cluster is formed, each node in this cluster sets a common wake-up timer that will wake it up in time \( T_s \), which is set to some fraction of the estimated node lifetime and mobility prediction of the cluster-head, which is defined as Eq.(6).

\[
T_s = \min\left(\frac{R_s}{32}, \frac{R}{4S}\right)
\]

where \( S \) is the cluster-head’s current speed and \( R \) is its radio transmission range.

2.5.2 Normal Node Re-affiliation Policy

Besides a common wake-up timer \( T_s \), each node \( j \) also sets a hypo-wake-up timer \( T_h(j) \), which is defined as Eq.(7).

\[
T_h(j) = \begin{cases} 
T_s & \text{if } S(j) \leq S \\
\frac{T_s}{1 + \int \frac{S(j)}{S}} & \text{if } 7S \geq S(j) > S \\
\frac{T_s}{6} & \text{if } S(j) > 7S 
\end{cases}
\]

where \( S(j) \) is the current speed of node \( j \). Eq.(7) implies that the more fast mobility node the more fast frequency wake-up. When node wake up, it must compare the cluster-head ID in his cache and the currently information to decide whether re-affiliation or not.

3 Simulation and Evaluation

Because it is difficult to capture the detail of MLCA performance in an analytical model, we implemented MLCA in the wireless extension NS-2.26 and use dynamic source routing (DSR) to route packets[7].

3.1 Simulation Model

We used a network with constant nodes in a rectangular region of size 1000×1000 m². 40 connections are established at random using constant bit rate (CBR) traffic. The average duration of each connection is the time that finishes sending 200 packets. RF value is maintained at 281.8 mW. Nodes follow random waypoint mobility model. Nodes pause and then move to a randomly chosen location at a fixed speed 5 m/s. We consider seven kinds of pause times from 0 to 60 s.

In most scenarios, we use 50 nodes in the constant area. And we vary node density by increasing the number of node from 100 to 600.

Concerning energy consumption, only packets relayed or transmitted consume a fixed amount of energy from the battery as given by Eq.(8).

\[
E(\text{packet}) = \frac{m \times \text{packet\_size}}{\text{Bandwidth}}
\]

where \( m \) is 1.33 W for transmitting packets and 0.97 W for receiving packets that correspond to 2400 MHz, 2 Mbps WaveLAN implementation of IEEE 802.11, \( \text{packet\_size} \) is 512 Bytes and is sent at 4 packets/s. The nodes initial battery capacity is randomly assigned by a normal Gauss distribution with mean 20.0 joules and variance \( (v) \) ranging from 0 to 2.0.

3.2 Network Lifetime

We define the metric lifetime of network as the duration from the beginning of the simulation to the first time a node runs out of energy. We use this metric with different node initial energy variances to measure the load balance and conservation energy performance of our proposed MLCA strategy.

As shown in Fig.1, DSR with MLCA strategy achieve about 50% lifetimes \((l)\) longer than pure DSR, because the MLCA strategy can conserve the lower
power node. The lower remaining power node can avoid being cluster-head and turn off his radio.

On the other hand, Max Degree strategy and Lowest ID strategy don’t request the normal nodes to turn off his radio in order to conserve energy, so the lifetime of networks shorten.

3.3 Network Connectivity

It is easy to conserve energy if one does not care about connectivity. It is thus important to evaluate the network connectivity produced by our protocols. We define throughput ratio \( r \) as the ratio of the number of packets received to the total number of packets sent. Under varying mobile node pause time, this metric truly reflects the effect of our protocol on network capacity as well as on connectivity.

![Network Connectivity Graph](image)

As shown in Fig.2, DSR routing protocol with MLCA get more throughput ratio than pure DSR. But more important, the advantage is more obvious when the topology variation speed up. This indicates that the MLCA strategy can adapt to mobility.

3.4 Network Stability

The mean time for which once a node is elected as a cluster-head, it stays as a cluster-head. This statistic is a measure of stability. The longer the cluster-head duration is, the more stable the network is. Under varying node density, this metric can reflect the effect of MLCA strategy on network stability.

![Network Stability Graph](image)

Fig.3 shows the cluster-head durations for the max degree strategy, Lowest ID strategy and MLCA strategy. Under varying the number of node in the system, the cluster-head election algorithm in MLCA makes a noticeable difference in the cluster-head. It proves that the cluster-head in MLCA strategy is the best candidature according to whether the mobility or remaining power.

4 Conclusions

With introducing mobility-aware and load balancing strategy into cluster-head election and update, this paper proposes a new topology management strategy MLCA to conserve energy and improve network capacity. The key contribution of this work consists of converting the static attributed of a node, such as node identifier, into a dynamic control mechanism that incorporates the three key factors for topology management in MANET—the remaining power, relative mobility, and load balancing.

Performance simulation results shows that the proposed MLCA strategy can prolong the network lifetime, and achieve higher throughput ratio and network stability.

References


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