Hybrid Routing Protocol Based on the Clustering Structure for MANETs

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Abstract
A mobile ad hoc network (MANET) is a multi-hop wireless network established by a collection of mobile nodes that communicate with each other in the absence of a fixed infrastructure. In MANET, most of the routing protocols that do not use Global Positioning System (GPS) make use of flooding, usually with some optimizations for routing process. Despite the optimizations in routing protocols that use flooding, many routing messages are propagated unnecessarily. In this paper, we propose a novel hybrid routing protocol based on the clustering structure. In route discovery, the source forwards the route request packet (RREQ) to the destination based on the cluster-based routing protocol (CBRP). But the route reply packet (RREP) does not trace back to the source through the route that RREQ has traversed. Instead, the route between the source and destination is established by broadcasting the RREP only via the nodes in the clusters that the RREQ has ever passed previously. The route constructed in this way can avoid the clusterheads always being in the transmission route and collapsing due to overloading.

In comparison with the cluster-based routing protocol, the proposed protocol can distribute the communication workload from the clusterheads to member nodes. Simulation results demonstrate that the performance of the proposed protocol is better than that of CGSR and CBRP.

Keywords: Mobile Ad Hoc Network (MANET), clustering, hybrid, routing protocol

1. Introduction
A mobile ad hoc network (MANET) is a multi-hop wireless network established by a collection of mobile nodes that communicate with each other in the absence of a fixed infrastructure. Due to considerations such as radio power limitation, channel utilization, and power-saving concerns, a mobile node may not be able to communicate with each other directly. Rather, the packets sent by the source node rely on the relay of intermediate nodes to reach the destination node in a multi-hop fashion. The nodes in such a network may roam around at their will, causing the network topology unpredictable change. Hence, the design of a MANET routing protocol is more complicated than that of wired networks. In the recent past, a variety of MANET routing protocols has been proposed. Most of the routing protocols that do not use GPS (Global Positioning System) make use of flooding, usually with some optimizations [4]. Despite the optimizations in routing protocols that use flooding, many routing messages are propagated unnecessarily.

Organizing nodes into a hierarchical structure can reduce routing messages flooding throughout the network and improve the routing efficiency. In the cluster-based network architecture, nodes organize themselves into several disjoint or overlapping entities called clusters. Each cluster elects one node as the clusterhead (CH). The clusterhead of each cluster is responsible for maintaining the cluster membership information, resource managements of the cluster, and routing process etc. They are selected usually by the selection algorithm such as the lowest-ID [3], the highest connectivity [3], Least Clusterhead Change (LCC) [2], and the Weighted Clustering Algorithm (WCA) [1]. Cluster structures are usually employed to increase the scalability and improve the performance for a large wireless network.
Based on the routing information update mechanism, wireless ad hoc routing protocols can be classified into three categories: proactive/table-driven, reactive/on-demand, and hybrid. In a proactive routing protocol, every node maintains the network topology information in the form of tables. This approach incurs significant overhead because the table should be updated frequently in order to maintain consistent and accurate network state information. A reactive routing protocol is activated only when a path is required by a source to communicate with the destination. In comparison with a proactive routing protocol, this approach costs lower for maintaining routing tables, but causes prohibitive flooding traffic in route discovery. Hybrid routing protocols are developed for a better trade-off between proactive and reactive routing.

In this paper, we employ reactive routing instead of using DV(Distance Vector)-routing table for data transmission. Neighbor nodes exchange their neighbor information to select the clusterhead for forwarding the RREQ. When a clusterhead receives a RREQ, it forwards the RREQ to the neighboring clusterhead by a gateway. When a destination receives the RREQ, it feeds the RREP back to the source. The RREP is forwarded only by the nodes in the clusters whose clusterheads had ever forwarded the RREQ previously. Therefore, RREQs and RREPs are forwarded only by a portion, but not all, of the nodes in the network. In this work, each source-destination connection might utilize different routes for transmission and the clusterheads do not must be in the connection. Thus, the heavy communication workload of the clusterheads in the cluster-based routing protocol (CBRP) can be relieved.

The remainder of this paper is organized as follows. Section II discusses the related work. Section III presents the proposed protocol. Section IV presents simulation results of the proposed protocol. Conclusions are given in Section V.

2. Related Work

The Cluster head Gateway Switch Routing (CGSR) protocol [2] is a table-driven protocol extended from the Dynamic Destination-Sequenced Distance-Vector (DSDV) routing protocol [10]. CGSR organizes nodes into clusters and selects clusterheads by using the LCC algorithm. Each node maintains two tables, a cluster member table which contains the clusterhead for each destination and a DV(Distance Vector)-routing table which keeps the next hop for reaching every destination cluster. In communication, the source sends the packet to its clusterhead. The clusterhead then relays the packet to the gateway node that connects this clusterhead and the next clusterhead along the route to the destination. This process proceeds until packets reach the destination. The disadvantages of CGSR are increase in path length and instability in the network when the rate of change of clusterheads is high.

Cluster-based Routing Protocol (CBRP) [5] is an on-demand routing protocol. Source routing is employed in route discovery to construct a fixed route for data transmission. Each node in the network maintains a neighbor table which contains the information of each neighbor node. The clusterhead has a member table that contains the information of the members of its cluster. Besides, it also maintains a cluster adjacency table that contains the cluster ID of each neighbor clusters and the gateway through which the neighbor cluster can be reached. The route request packet (RREQ) is flooded only to the clusterheads. When gateway nodes receive the RREQs, they forward them to the next clusterhead instead of broadcasting them. When the destination receives the RREQ, it feed the RREP back to the source through the path that the RREQ has traced. Since the clusterhead must forward data packets for all its members which causes high load in the clusterhead, the clusterheads will incur traffic congestion and die out quickly because of power exhaustion.

3. Protocol Description

Notations and Definitions:

TTL: Time-to-live. The TTL is used to limit a packet relayed in a restricted hop count.

RREQ: Route Request Packet. A RREQ contains the source ID, the destination ID, and the cluster ID list to record which clusterhead have forwarded the RREQ.

RREP: Route Reply Packet. A RREP contains the source ID, the destination ID, the cluster ID that listed in the RREQ, and the list of intermediate node ID from the destination to the source.

Overview of the proposed protocol

The proposed hybrid routing protocol based on the clustering structure is developed for a better trade-off between table-driven and on-demand routing by integrating the merits of these two routing protocol. This work organizes nodes into clusters according to the LCC algorithm. As the CBRP, nodes are classified into four states, and each node maintains a neighbor table and a cluster adjacency table. In the routing process the routing control packets, RREQ and RREP are employed as in on-demand routing. The source sends the RREQ to its clusterhead. When the clusterhead receives the RREQ it checks if the destination is in the cluster. If not, it will forward the RREQ to the neighboring clusterhead through the gateway node. When the destination receives the RREQ, it replies an RREP to the source. Only the nodes in the clusters whose clusterheads helped forwarding the RREQ will forward the RREP. Hence, the flooding traffic in route discovery can be reduced. In comparison with CBRP, instead of using fixed route this work chooses a source-destination path for each communication, in
which the RREP arrives at the source in the earliest.

3.1 Clustering formation

Node states

Nodes in a network are classified into four states, they are normal node, clusterhead, gateway, and member. The node state will change based on the LCC algorithm.

- Normal node: A normal node is the node that does not belong to any cluster.
- Clusterhead: A cluster head is elected from neighboring nodes which has the lowest ID. A clusterhead change occurs only in two conditions: one is when two clusterheads come into one cluster leading to a situation where someone has to give up its clusterhead position according to the lowest ID; the other is when one of the nodes is out of range of all clusterheads.
- Gateway node: Any node that can be used to communicate with an adjacent cluster is called a gateway node.
- Member node: All nodes within a cluster except the clusterhead are called members of this cluster.

Each node contains a neighbor table and a cluster adjacency table. When a node receives hello messages from neighbors, it updates its tables to maintain the latest information. The neighbor table maintains the clusterhead ID and the node state for each neighbor node. The cluster adjacency table maintains the neighboring cluster and the gateway to that cluster.

3.2 Routing

Route discovery

The routing process is triggered when a source wants to route to the destination by sending out the RREQ. When a node receives a RREQ, it does the following:

IF the node is the destination
stop forwarding the RREQ, and reply the RREP back to the source
ELSE IF the node is a clusterhead and never received the RREQ before
IF the destination is in the neighbor table
send the RREQ to the destination
ELSE IF the destination is not in the neighbor table
fill its node ID in the cluster ID list of RREQ then forward the RREQ to the neighboring clusterhead
ELSE
discard the RREQ
END IF
ELSE IF the node is a gateway
forward the RREQ to the clusterheads in cluster adjacency table
ELSE

discard the RREQ
END IF

After the destination receives the RREQ, it copies the cluster ID list from the RREQ to the RREP. The destination then tries to route the RREP to the source. When a node receives the RREP, it does the following:

IF the node belongs to a cluster of the cluster ID list in the RREP
forward the RREP
ELSE IF the node is the source
stop forwarding the RREP
ELSE
discard the RREP
END IF

Route maintenance

The source-destination transmission might break down due to the node mobility. Thus, the route maintenance mechanism helps repair the transmission. When an upstream node detects that the link to downstream node is failure, it sends the RREQ within TTL=2 to the neighboring clusterhead for searching the downstream node. The clusterhead checks its neighbor table and sends the RREQ to the downstream node. When a downstream node receives the RREQ, it replies the RREP to the upstream node that sends the RREQ. The RREP will be forwarded in the restricted cluster(s) for local repair. When the upstream node receives the RREP, the source-destination route is repaired. Otherwise, the upstream node will send a route error message to the source to trigger the routing process.

Figure 1 sketches an example of the proposed protocol. When the source(S) wants to search the destination(D), it forwards the RREQ to clusterhead(a). Since the destination is not in the cluster, clusterhead(a) forwards the RREQ to the gateway node in the neighbor table, gateway(i) and gateway(h). When gateway(i) and gateway(h) receives the RREQ, they forward the RREQ to the clusterhead(b) and clusterhead(f), respectively. clusterhead(b) and clusterhead(f) check their neighbor tables and find that destination(D) is not in their clusters. They in turn forward the RREQ to gateway(l), gateway(k) and gateway(m). The forward process is repeated until a clusterhead finds the destination is in its neighbor table. A clusterhead discards the duplicated RREQ that it has received; for instance, CH(e) discards the RREQ sent by gateway(m), and CH(c) discards the RREQ sent by gateway(g). When the RREQ forwarded to CH(c), the clusterhead finds that the destination(D) is in the cluster. As this time, CH(c) sends the RREQ directly to the destination. When destination(D) receives the RREQ, it responds the RREP back to the source. When a node receives the RREP, it forwards the RREP if the node belongs to the clusters listed in the RREQ; otherwise it discards the RREP. Duplicated
RREP will be discarded also when the source receives the RREP, the route to the destination, (S)-(i)-(k)-(q)-(D), is established.

![Diagram of hybrid routing protocol](image)

**Figure 1. Example of hybrid routing protocol based on the clustering structure**

4. Performance Evaluation

The ns-2 simulator [12] is utilized to evaluate the performance of proposed protocol. The simulations deployed 120 nodes randomly in the region of 2000m × 500m. Each node was with a radius transmission range of 250m with maximum moving speed of 10m/s. The IEEE 802.11b standard was applied as the medium access control (MAC) layer protocol with a channel capacity of 2Mbps. Each simulation lasted 180 seconds. The traffic was set as the continuous-bit-rate (CBR) type. Each packet was 256 bytes. Each connection generated 4 packets per second. The simulation parameters are summarized in Table 1.

<table>
<thead>
<tr>
<th>Network area</th>
<th>2000m × 500m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of nodes</td>
<td>120</td>
</tr>
<tr>
<td>Maximum moving speed</td>
<td>10 m/s</td>
</tr>
<tr>
<td>Transmission range</td>
<td>250m</td>
</tr>
<tr>
<td>Pause time</td>
<td>30s</td>
</tr>
<tr>
<td>Number of connections</td>
<td>10, 20, 30, 40, 50</td>
</tr>
<tr>
<td>Simulation time</td>
<td>180 seconds</td>
</tr>
</tbody>
</table>

**Table 1. Simulation parameters**

Each connection of the proposed protocol and the comparing routing protocols utilizes single path for data transmission. The performance of proposed protocol is evaluated using the following two metrics.

1. **Packet delivery ratio**: The number of received data packets divided by the number of generated data packets. This metric reveals the connectivity of network.

2. **Average end to end delay**: This is the average time that each data packet takes to move from a source to a destination. This metric measures the network traffic condition.

![Graph of packet delivery ratio vs. number of connections](image)

**Figure 2. Packet delivery ratio vs. number of connections**

Figure 2 shows the influence of connections on packet delivery ratio. The result of CGSR is commonly lower than other two protocols due to the update rate of routing table cannot catch up the change of network. The CBRP forwards CBR packets through the fixed route that constructed by the clusterhead for inter-cluster transmission, thus the variation of the clusterhead will affect the data transmission. Hence, the proposed protocol improves this defect via constructing an on-demand route for each connection. As shown in the figure 3, the proposed protocol has the better packet delivery ratio.

![Graph of average end to end delay vs. number of connections](image)

**Figure 3. Average end to end delay vs. number of connections**

Figure 3 shows the results of average end-to-end delay time versus the number of connections. As simulation results demonstrated, CGSR performed the worst because of its low scalability. The average end-to-end delay time of CBRP increases as the number of connections due to the bandwidth constraint. Packets are relayed through the fixed route in CBRP, so the average delay time increases when the route capacity is insufficient. The result of the proposed protocol is better due to the proposed protocol reduces the condition of bottleneck happened at the clusterhead when the traffic load increases.
5. Conclusions

In this paper, we propose a hybrid cluster-based routing protocol for mobile ad hoc networks. The number of forwarded RREQs are reduced because they are not flooded blindly to every node. The route between source and destination is built by rebroadcasting the RREP back to the source, via the nodes in the clusters that the RREQ passed through, when the destination receives RREQ. Unlike CBRP, the route is established reactively and not necessary composed of only clusterheads. Hence the workload of clusterhead is effectively relieved. Simulation results demonstrate that the proposed protocol has better packet delivery ratio and average end to end delay than CGSR and CBRP.

References


