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Position-Based Cluster Routing Protocol for Mobile Ad Hoc Networks

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Abstract: - Some of the proposed mobile ad hoc network routing algorithms require maintaining a global network state at each node. The global state is always an approximation of the current network state due to the non-negligible delay of propagating local state. The imprecision of global state information and the high storage and communication overhead make those algorithms do not scale well. In this paper, we propose a scalable loop-free cluster routing algorithm, which requires every node to maintain only its local state and uses physical location information to assist routing. In our protocol, the whole network is partitioned into several square clusters. In each cluster, we first use a cluster head selection algorithm to select a cluster head and then use a gateway selection algorithm to select gateways. After the construction of cluster heads and gateway nodes, it uses a distributed computation to collectively utilize the most up-to-date local state information to find multicast tree in a hop-by-hop basis. The performance of our algorithm was studied through extensive simulation. The simulation results reveal that our protocol has better performance than other algorithm.

Key-Words: - Mobile ad hoc network, Multicasting, QoS, GPS, Position-Based Routing Protocol

1 Introduction

Unlike conventional wireless networks, Mobile ad hoc network (MANET) is a network with no fixed routers, hosts, or base stations. Nodes in the network function as routers, which discover and maintain routes to other nodes. When a mobile host wants to communicate with another mobile host, appropriate routing information has to be setup at the source and some intermediate nodes.

Many future applications of computer network such as videoconferencing will involve multiple users that will rely on the ability of the network to provide multicast services. Thus, multicasting will likely be an essential part of MANET. One of the core issues that need to be addressed as part of providing such mechanisms is the issue of routing, which primarily refers to the determination of a set of paths to be used for carrying messages from the source to the destination nodes. Routing protocols used in conventional wired networks are not suited to the mobile environment due to the considerable overhead produced by periodic route update messages and their slow convergence to topological changes.

It has recently attracted a lot of attention in the design of multicast routing protocol for ad hoc mobile network [1-7]. The Reservation Based Multicast routing protocol [1] is a core based multicast protocol which is also responsible of admission control and resource reservation. The Adhoc Multicast Routing Protocol [2] is a shared tree protocol which allows dynamic core migration based on group membership and network configuration. The Lightweight Adaptive Multicast (LAM) algorithm [3] is a group shared tree protocol that suffers from disadvantages of traffic concentration and vulnerability of the core. The Core-Assisted Mesh Protocol [4] and ODMRP [5] are both mesh based. The AMRIS [6] is a share tree protocol that establishing a shared tree to deliver multicast data by the ID numbers. The Multicast Ad Hoc On Demand Distance Vector (MAODV) routing protocol [7]

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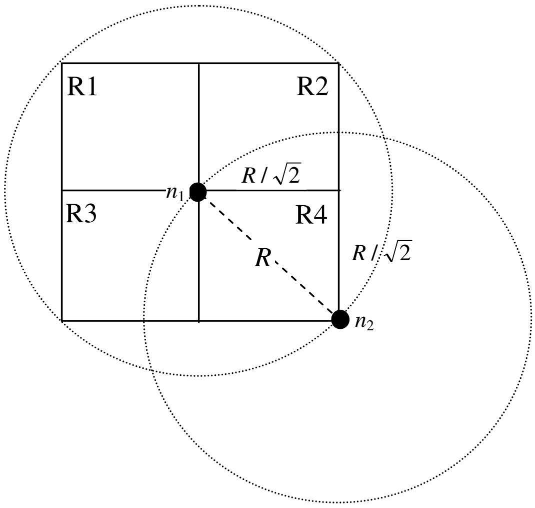

Figure 1 Let R and l represent the effective transmission radius of each mobile node and the side length of square regions respectively. When $l = R/\sqrt{2}$, the length of diagonal $\overline{n_1 n_2}$ will equal to R. Because the diagonal is the longest distance in the same region, this guarantees that each pair of nodes in the same region is within the effective transmission range.

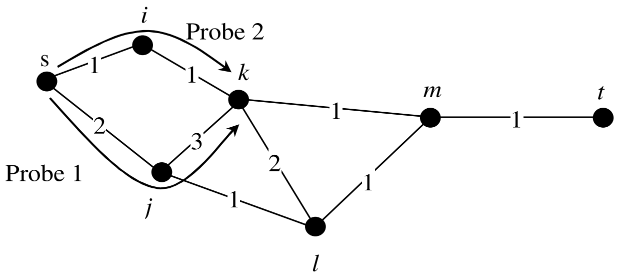

Figure 2 Assume Probe 1 arrived node k earlier than Probe 2. k's predecessor was first set to node j and record its accumulated cost = 5. Because Probe 2's accumulated cost = 2 is less than Probe 1's, after Probe 2 arrived at node k it changes k's predecessor to node i.

utilizing a destination sequence number strategy to prevent loops and to discard stale routes.

The availability of small, inexpensive low-power GPS receiver and techniques for calculating relative coordinates based on signal strengths make it possible to apply position-based routing algorithm in ad hoc mobile network [8]. There are some position-based routing protocols were proposed recently [8-12].

In this paper, we propose a scalable and loop-free distributed cluster routing protocol, which requires every node to maintain only its local state and uses physical location information provided by positioning devices [13, 14] in route discovery and route maintenance. In our protocol, the whole network is partitioned into several square zones called clusters. In each cluster, we first use a cluster head selection algorithm to select a cluster head and then use a gateway selection algorithm to select gateways of neighbor cluster heads. After the construction of cluster heads and gateway nodes, it uses a distributed computation to collectively utilize the most up-to-date local state information to find multicast tree in a hop-by-hop basis. Our clustered routing algorithm used only source, destination, cluster heads and gateway nodes to search routes, so that the route probing packets can be reduced significantly. Our algorithm can be applied to solve both unicast and multicast routing problem. The performance of our algorithm was studied through extensive simulation. The simulation results reveal that it has much better performance than MAODV.

The rest of the paper is organized as follows. Our protocol is described in Section 2. Section 3 presents the simulation model and the simulation results. Finally, we give a conclusion in Section 4.

2 The LACMQR Routing Protocol

In this section, we describe our distributed routing protocol for mobile ad hoc network, called Location-Aware Cluster Multicast QoS Routing protocol (LACMQR).

Let R and l represent the effective transmission radius of each mobile node and the side length of square regions. In our protocol, we set l to be $R/\sqrt{2}$ that guarantees each pair of nodes in the same region always within the effective transmission range, see figure 1. We divided the entire network into $l \times l$ square clusters by the assistance of the physical location information of every mobile node get from positioning device, e.g., global positioning system (GPS).

After the clusters have been constructed, a cluster head selection algorithm is first used to determinate a cluster head of each cluster. Next, a gateway selection algorithm is exploited to select the gateway node between adjacent clusters. A gateway node is responsible for relaying packets when the adjacent cluster heads are out of the effective transmission radius. Our cluster head selection algorithm always chooses a node nearest to the center of a cluster as the cluster head. A node of this kind has longer distance to the side of cluster; it will take more time to roam out of this region so that it will keep a longer route lifetime. When the distance of two adjacent cluster heads is longer than the effective transmission radius,

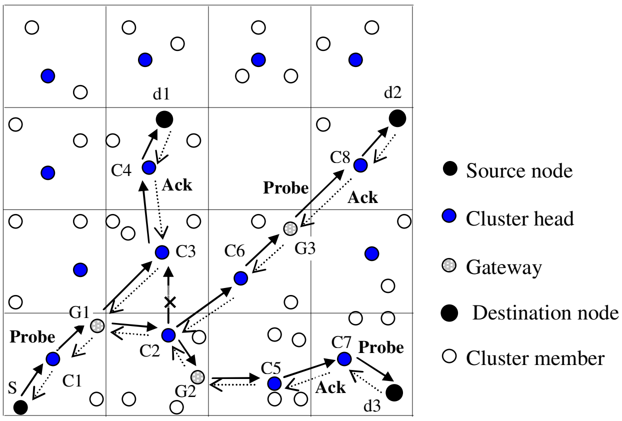

Figure 3 The procedure of route discovery in the distributed cluster multicast routing. When source node S needs to transmit packet, it forward a Probe packet to its cluster head C1. C1 will check the destination address to see if any destination node in this cluster; if so, it will forward the probe packet to it otherwise it will forward the probe packet to gateway node. The gateway will forward this probe packet to neighbor cluster head. The process will repeat until the route is found or route discovery procedure is failed. When the destination node received a PROBE packet, it will reply an Ack packet along the reverse path to source node.

the gateway selection algorithm will choose an intermediate node that has least distance to those two cluster heads as a gateway node. On the other hand, it will not need to run the gateway selection algorithm for choosing a gateway.

The procedure of route discovery is modified from a distributed multi-constraint QoS multicast routing protocol that we proposed for wired network earlier [15]. This proposed protocol is based on a best predecessor replacement policy. It works as follows, when a node receives a probe packet, it will compare the accumulated metric (e.g. accumulated delay, cost) of the current probe packet with the previous probe packets'. If the accumulated metric of the new probe is better than the previous probes', the node changes its predecessor to the node that the new probe packet comes from and forwards this probe packet immediately. Owing to every node select the best predecessor the path found by this algorithm is optimal. See an example depicted in figure 2. We assume that the number on each edge represents the cost of each link and Probe 1 arrived at node k earlier than Probe 2. When Probe 1 arrives at node k, it sets k's predecessor to node j and records its accumulated cost as 5. After Probe 2 arrives at node k, it compares Probe 2's accumulated cost with Probe 1's. Because Probe 2's accumulated cost = 2 is less than Probe 1's, it changes the predecessor of k to i and updates the accumulated cost of k to 2. By this replacement strategy, the path $s \rightarrow i \rightarrow k$ is selected to replace the path $s \rightarrow j \rightarrow k$. Probes are contended in a hop-by-hop basis using this best predecessor replacement strategy until an optimal path is found.

In MAODV routing protocol, all network nodes must participate in the route discovery process. Every node received a probing packet will replicates and forward it to all neighbor nodes. The probing traffic is proportion to the number of network nodes n that will cause tremendous probing packets and is not suitable for large scale network. In our protocol, the route discovery process is responsible by the source node, destination nodes, cluster heads and gateway nodes not by all network nodes. In our protocol, the probing traffic is proportion to the number of clusters that will reduce the probing traffic significantly and is suitable for large scale network. If the number of source and destination nodes are n_s and n_d respectively and the whole network is partitioned into r row and l column. The maximum number of nodes participate in the route discovery process n_r is less than $5rl+ n_s + n_d$. The larger number of network nodes n, the more efficiency our protocol will show.

The procedure of route discovery is as follows: When a source node needs to transmit packets and there is not a valid route, it will initiate a path search procedure to find a new route. It sends a route probe packet PROBE to its cluster head, see figure 3 as an example. If the destination is in the same cluster, the cluster head will forward this probe packet to the destination node directly. On the other hand, the cluster head will forward this probe packet to its gateway nodes. After receiving the probe packet, the gateway nodes forward the PROBE packet to the proper neighbor cluster head immediately, and so on, until either the destination or an intermediate node with a valid route to the destination is reached. When the PROBE reaches the destination or an intermediate node with a valid route to the destination, the destination or intermediate node will select an optimal route based on the best predecessor replacement policy and reply an acknowledgement packet ACK to its predecessor which then forwards the acknowledgement packet to its predecessor along the reverse direction, and so on, until the source node is reached. Once the source node has received the ACK packet, the route is established.

Theorem 1 If the number of source and destination nodes is n_s and n_d respectively and the whole network is partitioned into r row and l column. The maximum number of nodes participate in the route discovery process n_r is less than $5rl+ n_s+ n_d$.

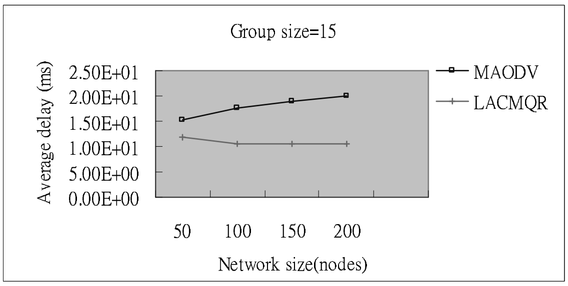

Figure 4 Average delay of MAODV and LACMQR for different network size and group size=15.

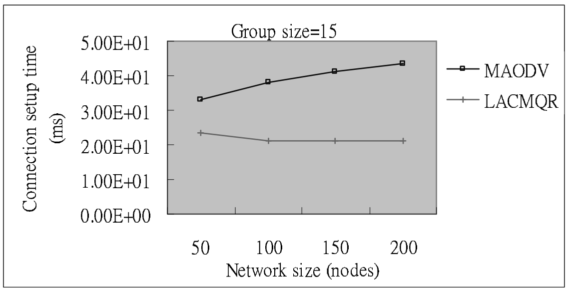

Figure 5 Connection setup time of MAODV and LACMQR for different network size and group size=15.

Proof:

n_r = #gateway nodes + #cluster head nodes + $n_s + n_d$
<= $\{[3 + 4(l\text{-}2) + 2](r - 1) + (l - 1)\} + rl + n_s + n_d$
$< 4rl + rl + n_s + n_d = 5rl + n_s + n_d$ #

Theorem 2 If the path of a connection is existed, it must be loop-free.

Proof: If the path of the connection has a loop, there must be a node k on the path received and forwarded the same PROBE packet twice. If a PROBE packet passed node k twice, its accumulated metric will greater or equal to the previous probes' and it will be discard. That contradicts to the above assumption. #

Theorem 3 The path $P= s \rightarrow n_1 \rightarrow n_2 \rightarrow \cdots \rightarrow n_k \rightarrow t$ established by the algorithm is optimal.

Proof: If the path $P = s \rightarrow n_1 \rightarrow n_2 \rightarrow \cdots \rightarrow n_k \rightarrow t$ is not optimal, there must exist an optimal path $P' = s \rightarrow n_1 \rightarrow n_2 \rightarrow \cdots \rightarrow n'_k \rightarrow t$ such that $Am(s \rightarrow n'_k) + Am(n'_k \rightarrow t)$ is minimal. $Am(x \rightarrow y)$ represents the accumulated metric of node x to node y. According to our proposed algorithm, node n'_k will be select to as the new predecessor of node t. That contradicts to the fact that t's predecessor is node n_k. #

3 Simulation Results

We developed a simulator to evaluate the performance of our protocol and MAODV. The average delay, connection setup time, and average probe overhead are studied by simulation. The network was placed in a rectangle of size 1600 × 1000 m^2, simulates actual mobile ad hoc networks. The side length of the square region l is 200 meters. The entire network is divided into 40 square regions. The network size is in the range of [50, 100, 150, 200] nodes that were generated randomly. The data rate of each mobile node is 11Mbps.

The simulator uses two types of traffic sources, i.e., voice source and video source. An on-off model is used for voice sources, more detailed description of the model can be found in [16]. A 10-state model is used for video sources [17]. Both of them are variable bit rate sources suitable for multimedia applications. The peak rate, average to peak ratio, and mean burst size are 10Mbps, 0.5, and 3 respectively.

Figure 4 shows the results of running MAODV and LACMQR on random generated network, group size = 15, for different network size. The QoS constraint concerned here is transmission delay. The average delay of the multicast tree established by LACMQR is less than the average delay of the multicast tree constructed by MAODV. This result is the same as we expected. Because the best predecessor replacement policy of LACMQR always tries to find a route with minimum delay among all routes, the average delay of the route constructed by LACMQR must less than the route found by MAODV. When the network size less than 100 nodes, the average delay of LACMQR is greater than that of the larger network size and decreases when the network grows. This is resulted from the sparse density of nodes in each region. When the network node's density is sparse there will have little chance to get a good route. When the network size greater than 100 nodes, the average delay of LACMQR increase slowly when the network grows. In MAODV, the average delay increases rapidly when the network grows. The simulation result reveals that LACMQR always find a path better than MAODV.

The connection setup time for each connection request of running LACMQR and MAODV on networks generated randomly, group size = 15, for different network size is illustrated in figure 5. In this figure, we can find that LACMQR requires less connection setup time than MAODV for the same connection request. It means that LACMQR can search for a path faster than MAODV. That is very important for real time applications. In MAODV, the connection setup time increase rapidly when the

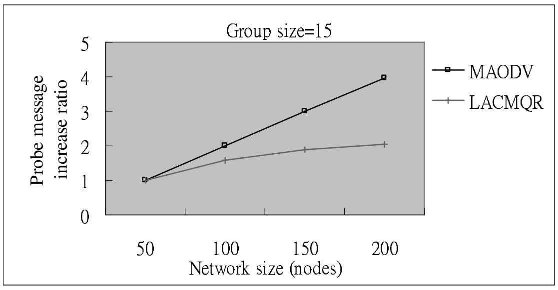

Figure 6 The Probe message increase ratio of MAODV and LACMQR for different network size and group size=15.

network size rises. In LACMQR, when the network size less than 100 nodes the connection setup time decreases when the network grows. The reason is mentioned above. While the network size greater than 100 nodes, the connection setup time is slightly increases when the network rises. It revealed that when the density of nodes is enough the connection setup time is approximate to a constant. Because in the LACMQR algorithm only source node, cluster head, gateway and destination node are participate in the route discovery process not all the network nodes, it reduces the connection setup time significantly. The connection setup time of LACMQR is related to the number of total regions in the network not the number of nodes in the network. This characteristic makes the LACMQR to be a scalable algorithm.

Figure 6 depicts the probe message overhead increase ratio of LACMQR and MAODV in different network size. The y-axis represents the increase ratio of probe message overhead. It is evident that MAODV has higher overhead than LACMQR. In MAODV, every node will join the route discovery procedure that duplicate the PROBE packet and forward it to all neighbor nodes. The probing traffic is increased tremendously as the network size grows. In LACMQR algorithm only source node, cluster head, gateway and destination node are participate in the route discovery process. The amount of probing traffic is related to the number of total clusters in the network so the probe message overhead is lower. The probe message increased ratio of network size 100, 150, 200 is never greater than 2. It means that LACMQR is a scalable routing protocol.

4 Conclusion

In this paper, we proposed a scalable and loop-free distributed cluster multicast routing algorithm, we call it LACMQR. Unlike those algorithms that need to maintain a global network state at each node by the distance vector or link state algorithm, our proposed algorithm requires every node to maintain only its local state that saves the storage and communication overhead significantly. We divided the entire network into a number of square regions called zones or clusters. LACMQR uses a distributed computation to collectively utilize the most up-to-date local state information to construct multicast tree in a hop-by-hop basis. Our route discovery protocol is responsible by the source node, destination nodes, cluster heads and gateway nodes not all the network nodes that will reduce the probing traffic significantly. The performance of our algorithm was studied through extensive simulation. From the simulation results, it evident that the average delay, connection setup time and probe message overhead of LACMQR is much better than MAODV.

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