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An Adaptive Forwarding Cluster Routing Protocol for Large Scale Wireless Mobile Ad Hoc Networks

Li Wang, Ting Liu and Kai Liu
School of Electronics and Information Engineering
Beijing University of Aeronautics and Astronautics
Beijing 100191 China

***Abstract*-A novel routing protocol, namely adaptive forwarding cluster routing (AFCR) protocol, is proposed to improve the network scalability in a large scale Mobile Ad Hoc network (MANET). In the AFCR protocol, nodes are divided into several 1-hop clusters. Local routing information is exchanged between neighboring nodes to establish routes between cluster heads in adjacent clusters, which are further used to propagate routing information of nonadjacent clusters. Based on local routing information and cluster architecture, nodes adaptively forward data packets. Simulation results show that compared with the DSDV protocol, the proposed protocol can improve network performance in the present of a large number of mobile nodes and heavy traffic.**

Keywords: mobile ad hoc network, routing, scalability, clustering.

I. INTRODUCTION

A wireless mobile ad hoc network (MANET) is a self-organizing multi-hop wireless network without requiring any existing infrastructure, which is composed of a collection of mobile nodes equipped with wireless communication and networking abilities. In recent years, a great number of routing protocols have been developed to accommodate this specific network. The proposed protocols can be generally grouped into two different categories, i.e. flat routing protocols and hierarchical routing protocols.

Flat routing approaches adopt a flat addressing scheme. Each node participating in routing plays an equal role. The advantage of the flat routing is that there is no special node in the network, so the network throughput was shared in all nodes symmetrically. According to routing strategy, flat routing protocols are classified into proactive (or table-driven) and reactive (or on demand) [1]. Typical proactive approaches are DSDV [2] and OLSR [3] protocols, and typical reactive routing protocols are AODV [4] and DSR [5] protocols.

However, it has been proved that a flat structure exclusively based on proactive or reactive routing schemes cannot perform well in a large dynamic MANET. In other words, a flat structure encounters scalability problems with the increase of network size, especially in the present of node mobility at the same time [6]. One way to solve this problem and to produce scalable and efficient solutions is hierarchical routing. Cluster routing is a typical hierarchical routing. In cluster routing, mobile nodes in network are divided into different virtual groups according to some rules. By assigning a different status or function to nodes in each cluster, cluster routing can normal form a virtual backbone for inter-cluster routing, thus the generation and spreading of routing information can be restricted in a small set of nodes. So cluster routing makes it possible to guarantee basic levels of network performance, such as throughput and delay, in the presence of both mobility and a large number of mobile terminals. CGSR [7], CBRP [8] protocols are two typical cluster routing protocols for large scale MANET.

In this paper, a novel routing protocol, named adaptive forwarding cluster routing (AFCR) protocol, is presented to improve the network scalability in large scale MANET. In the AFCR protocol, nodes are divided into several 1-hop clusters. Local routing information is exchanged between neighboring nodes to establish routes between cluster heads in adjacent clusters, which are further used to propagate routing information of nonadjacent clusters. Based on local routing information and cluster architecture, nodes adaptively forward data packets. Simulation results show that compared with the DSDV protocol, the AFCR protocol has lower overhead as network size increases or traffic grows bigger.

The rest of this paper is organized as follows. Preliminaries are listed in Section II. Section III specifies the operation of clustering algorithm used in the AFCR protocol. Simulation results and discussions are presented in Section IV. At last, we conclude this paper.

II. PRELIMINARIES

Each node in the network has a unique ID and is equipped with a half-duplex transceiver, a data controller and a client terminal unit. That means, node can generate data, process wireless signals and avoid collisions with other nodes in shared wireless channels independently.

The transmission range of each node is fixed and identical. It is assumed that all links between nodes are bidirectional, i.e. if there is a communication link from node i to j, so is node j to i.

If two nodes can directly communicate with each other when they are within transmission range, they are 1-hop neighbors. If two nodes can only communicate with each other with the help of the relay of another node, they are 2-hop neighbors. In the same way, if two nodes need intermediate nodes to relay at least (n-1) times to

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exchange information between each other, they are n-hop neighbors.

III. AFCR PROTOCOL

A. Formation of Cluster

In the AFCR protocol, all the nodes in network are divided into 1-hop clusters. Each cluster has only one cluster head (CH) which can communicate with its cluster member (CM) directly. That means each CM is 1-hop far from its CH. The cluster architecture of the AFCR protocol is shown in Figure 1.

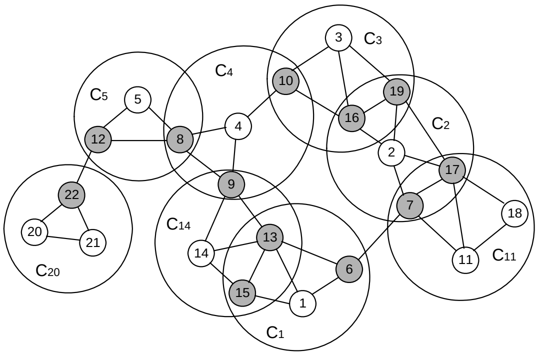

Figure 1. Cluster architecture of the AFCR protocol

In order to form the cluster architecture, we adopt an improved lowest ID clustering algorithm. The clustering steps are as follows:

At first, all the nodes in the network broadcast their own control packet in any order, so that each node knows its 1-hop neighbors and forms a neighbor table. Then each node sets a clustering timer and starts to perform the following clustering strategies:

(1) If a node has the smallest ID comparing to its neighbors, it becomes a new CH and declares it to form a new cluster and cancels its clustering timer. Otherwise it keeps listening until the timer expires.

(2) If a node received a message from one of its neighbors which declares to become a new CH, it joins the new cluster. In the meantime, it broadcasts this information to notify its other 1-hop neighboring nodes immediately and cancels its clustering timer. Otherwise it keeps listening until the timer expires.

(3) If a node finds that all of its 1-hop neighboring nodes with lower ID than its ID have already joined other clusters, it declares to form a new cluster and cancels its clustering timer. Otherwise it keeps listening until the timer expires.

(4) If the clustering timer of a node expired, in order to decide whether it joins a cluster or forms a new cluster, it resets the clustering timer and sends a cluster inquiry packet to the nodes from which it did not receive any packet and whose ID is smaller than its. This inquiry packer must be responded. If it received the packets from these nodes, it executes the three steps described above.

(5) If it did not receive some response packets to the cluster inquiry packets, it execute step (4) again. And if the timer expired again, it declares to form a new cluster, and broadcast this information to its 1-hop neighbors.

These clustering strategies above can avoid the long time waiting of a node because of not receiving any message from its neighbor due to packet collisions or transmission errors during the clustering phase. As a result, 1-hop cluster architecture can be quickly formed.

B. Route Discovery

In a cluster routing protocol, in order to reduce the size of routing table, routes to all nodes in a cluster is replaced by the route to its CH. Therefore, the main purpose of route discovery in a cluster routing protocol is to discover routes to each CH.

Destination sequenced distance vector (DSDV) routing protocol is a typical proactive routing protocol for MANET, which is based on the Distributed Bellman-Ford algorithm. It is easy to implement and can provide loop-free routes at all time. In the AFCR protocol, we use the DSDV protocol as a basis to establish shortest-path loop-free routes to CHs.

In order to avoid the impact of CH change, and enhance the robustness of the entire network and forward data packets adaptively, the AFCR protocol adopts a distributed way to store routing information, that is, all nodes in the network establish route to each CH independently according to received routing messages. However, in order to decrease the growth rate of routing overhead with the increase of network scale and traffic load, especially in the present of both large scale of network size and heavy traffic, the AFCR protocol uses the following routing discovery scheme:

1) Adjacent cluster Routing

As described previously, nodes in AFCR protocol are divided into several 1-hop clusters, which means that each node in the network is a CH or can communicate with a CH directly. So it is easy to make the conclusion that the distance between two CHs in adjacent is 3 hops at most (C20-C5 in Figure 1). Therefore, each node only needs to broadcast its own route information about CHs which is not bigger than 2 hops to establish routes between CHs in adjacent clusters. By this way, all nodes in the network know routes to their neighboring CHs within 3-hop.

2) Nonadjacent Cluster Routing

As routes between CHs in adjacent clusters have been established through local routing information exchange among neighboring nodes, we make full use of these routes to spread routing information of the nonadjacent clusters.

In the AFCR protocol, routing information of the nonadjacent clusters is always initiated to send by CHs. In order to limit the number of nodes which participate in the forwarding of routing information for nonadjacent clusters, CH specifies the node which is the next hop of the route to its neighboring CH to forward these messages. The node continues to forward the routing information to the neighboring CH or the next hop to the neighboring CH.

Generally, routes are established through the following two steps: firstly, routes between CHs in adjacent clusters are established through local routing information exchange among neighboring nodes; secondly, these "backbone routes" are further used to propagate routing information of nonadjacent clusters. With this way, nodes in the AFCR protocol reduce redundant transmission of routing information, and limit the size of routing packets and the number of nodes involved in the route discovery procedure. This will greatly reduce the growth rate of routing overhead and improve network performance in the present of a large number of mobile nodes or heavy traffic.

C. Cluster and Route Maintenance

In MANET, network topology changes in an unpredictable manner due to node mobility and unreliable wireless link. So it is essential for a cluster routing to adjust adaptively and effectively according to topology changes.

In cluster routing protocol, topological change corresponds to both route change and cluster membership change. So the work of cluster and route maintenance mainly is composed by two different parts: cluster maintenance and route maintenance:

1) Cluster Maintenance:

Cluster maintaining work is mainly done by the CH. The main points are the follows:

Management of CMs: The purpose of CMs management is to refresh the cluster membership between CHs and their CMs. It mainly deals with two cases of CM: join/quit a cluster. In the AFCR protocol, when a node joined a cluster, it broadcasts this information immediately to notify the CH that it joins. This is the only way that a CH adds a new CM to its cluster member table. Contrarily, there are two ways for CM to quit from a cluster: proactively and reactively. When a CM finds that its former CH is no longer its neighbor, it broadcasts a message to inform its neighbors and starts to cluster immediately. If a CH cannot contact with one of its CM any more, it deletes the node from its cluster member table and notify other nodes this message.

Management of CHs: The purpose of CHs management is to deal with death and re-selection of CHs, i.e., to decide whether give up or keep the status of CH. In order to maintain the stabilization of cluster architecture and cover all nodes with the least amount of CHs, CHs would be modified only in the following two conditions: one is when a CH has no cluster member any more, it gives up its status of CH; the other is when a node loses its connections with all of CHs, it then will build a new cluster.

2) Route Maintenance: as the AFCR protocol uses the DSDV protocol as a basis to establish shortest-path loop-free routes to CHs, we adopt a new route reconstruction strategy which is detailed in paper [9] to maintain the routes to CHs when topology changes, i.e., when route becomes invalid due to link breakage, a novel message exchange scheme for invalid route information dissemination and existing route information reuse is proposed to rapidly reconstruct invalid route in local area. To make it simple, we call the improved DSDV protocol rapid-route-reconstruction DSDV (RRR-DSDV) protocol.

D. Adaptive Data Forwarding

In the AFCR protocol, node stores routing information independently. That means each node in the network has a neighbor table, a CM table which stores the cluster membership, and a routing table which stores routes to each CH. So it is easy for the AFCR protocol to forward data packets adaptively based on local routing information and clustering architecture. When there are data packets to send or forward, node will first search the destination node in its neighbor table. If the destination node is one of its neighboring nodes, it sends the data packets to the destination node directly. Otherwise, it will search the destination node in its CM table to find the CH that the destination node belongs to. If the CH node does exist, it checks its routing table. If route to the CH exists, it sends data packets to the next hop according to the routing table. If there is no information about the destination node in the three tables, it will buffer the in-coming data packets and wait for the building of the route. The data forwarding flow chart of the AFCR protocol is described in Figure 2.

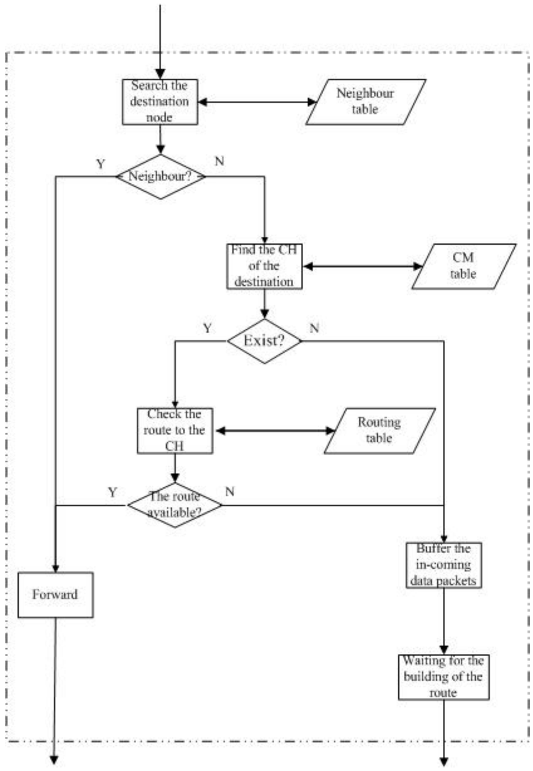

Figure 2. Data forwarding flow chart of the AFCR protocol

As nodes in the AFCR protocol adaptively forward data packets based on local routing information and cluster architecture, we could see that the more close to the destination node, the more precise route the node will select. Meanwhile, the 1-hop neighboring nodes will communicate with each other regardless of cluster membership, and this will greatly reduce the routing overhead generated by CHs.

IV. PERFORMANCE EVALUATION

A. Simulation Environment

We performed simulations using the NS2 simulator [10], its version is 2.29. Simulations were based on the network formed by N_{node} nodes, distributing in a rectangular (1000m×1000m) flat area. The IEEE 802.11 MAC protocol was used as the MAC layer protocol. The transmission range of each node is 250m. Each simulation was run for 300 seconds.

Random-Waypoint was selected as the mobility model. In this model, each node begins the simulation by remaining stationary for *pause-time* seconds. It then selects a random destination in the 1000m×1000m space and moves to that destination at a speed distributed uniformly between 0 and maximum speed. Upon reaching the destination, the node pauses again for *pause-time*, selects another destination, and proceeds there as previously described, repeating this behavior for the duration of the simulation. We fix maximum speed at 3 m/s and the *pause-time* at 0 second, which means constant movement for each node in the network.

Traffic sources were Constant Bit Rate (CBR). The size of CBR packet was 512 bytes. There are N_{source} source nodes to send data packets with the sending rate of 1 packet per second. The start times of all the communication connections are uniformly distributed between 0 and 5 seconds.

B. Different Network Scale

Figure 3, 4 and 5 show performance comparison between the AFCR protocol with the DSDV and RRR-DSDV protocols on different network scale. N_{source} is fixed at 20.

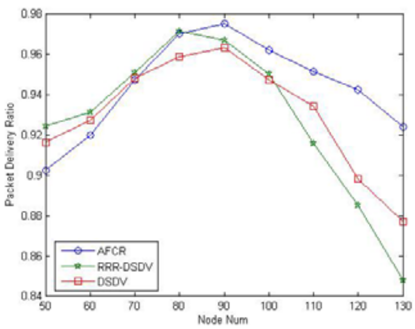

Figure 3. Packet delivery ratio on different network scale

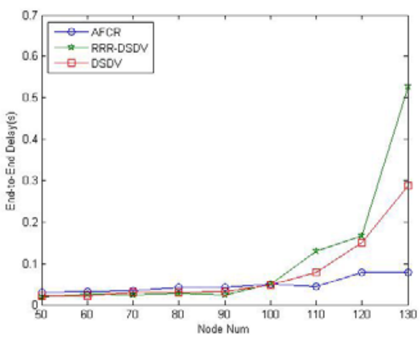

Figure 4. Average end-to-end delay on different network scale

Figure 3 shows the packet delivery ratio of the three routing protocols on different network scale. From it we can see that with the increase of the network scale, the packet delivery of the three protocols increases at first and then decreases. When the network scale is small (the node number is smaller than 100), the delivery ratio of the three protocols is almost the same, and with the increase of the network scale, the AFCR protocol has a higher packet delivery ratio, and the decrease rate is smaller than the other two.

Figure 4 shows the average end-to-end delay of the three protocols on different network scale, from which we can see that with the increase of the network scale, the average end-to-end delay of them increases and is almost the same when the node number is smaller than 100, and when the node number keeps on increasing, the increase of the average end-to-end delay of the AFCR protocol is not obviously, but that of the other two protocols is increasing rapidly.

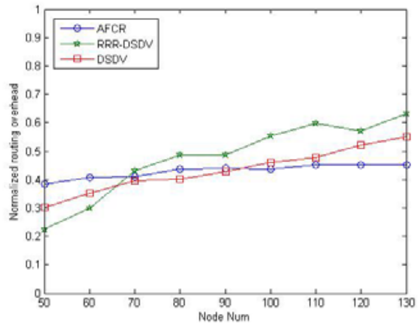

Figure 5. Routing overhead on different network scale

Figure 5 shows the normalize routing overhead (that is, the average routing packet number sent by each node per second) of the three protocols on different network scale, from which we can see that with the increase of the network scale, the routing overhead of the AFCR protocol trends to be stabilization, but that of the other protocols is increased obviously. When the network scale is small, the routing overhead of the RRR-DSDV protocol is the least, but after the node number increased to 100, the routing overhead of the AFCR protocol performs better than that of the other two protocols.

The reason is that in large scale network, the DSDV and RRR-DSDV protocols are flat routing protocols, each node stored the routing information to all nodes in the network, when the network topology changed, more control message is needed to maintain the change of the routing information, and this would consume more limited bandwidth and then increase the collisions in the network, so the packet delivery ratio decreased obviously, the average end-to-end delay and the routing overhead increased rapidly. But in the AFCR protocol, based on the cluster architecture it could lighten the effect of the topology change through the limitation of the routing table size. With the increase of the network scale, the AFCR protocol performs better in the packet delivery ratio, the average end-to-end delay and the routing overhead.

C. Different Traffic Load

Figure 6, 7 and 8 show performance comparison between the AFCR protocol with the DSDV and RRR-DSDV protocols on different traffic load. N_{node} is fixed at 100.

Figure 6 shows the packet delivery ratio of the three protocols on different traffic load, from which we can see that with the increase of the traffic load, the packet delivery of them decreased, but the AFCR protocol decreased slower. And the packet delivery ratio of the AFCR protocol is bigger than the other two protocols in different traffic load.

Figure 7 shows the average end-to-end delay of the three protocols on different traffic load, from which we can see that, with the increase of the traffic load, the average end-to-end delay of them increased, but when the traffic load is heavier (that is, the source node is increased more than 25), the increase speed of the average end-to-end delay of the AFCR protocol is much slower than that of the other two protocols.

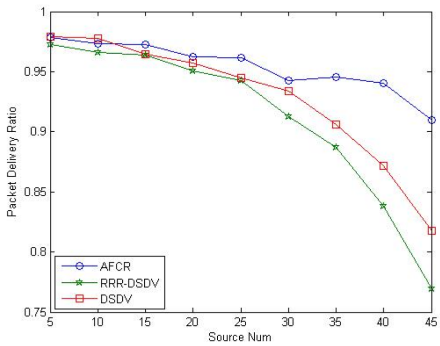

Figure 6. Packet delivery ratio on different traffic load

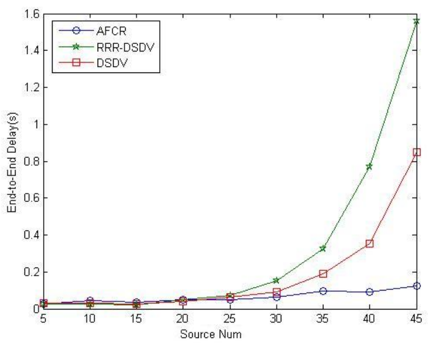

Figure 7. Average end-to-end delay on different traffic load

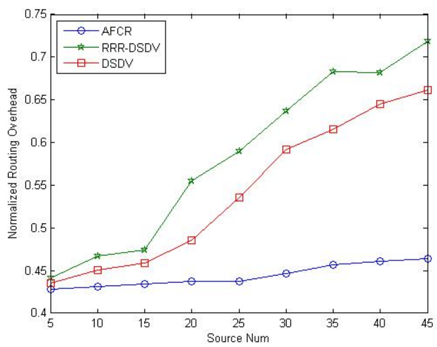

Figure 8. Normalize routing overhead on different traffic load

Figure 8 shows the normalize routing overhead of the three protocols on different traffic load, from which we can see that with the increase of the traffic load, the AFCR protocol could effectively control the increase rate of the normalize routing overhead; on the contrary, that of the other two protocols increased rapidly with the increase of the traffic load.

The reason is that the AFCR protocol adopts a series of measures, which described in last section, to reduce the routing overhead, so the increase of the traffic load would not cause the collisions seriously, and then reduce the loss of the routing information packet. Then the node would obtain the correct routing information on time because of the reduction of the routing information packets. So the AFCR protocol improved the performance of the packet delivery ratio and the average end-to-end delay compared with the other two protocols. In routing overhead, all of the three protocols belonged to the proactive routing protocol, the node maintains the routing information proactively, and the data traffic load do not affect this process, however, the AFCR protocol would reduce the network collisions, and then reduced the update packets because of the link state over time, so the routing overhead of the AFCR protocol does not change obviously.

V. CONCLUSIONS

In this paper, a novel routing protocol, named adaptive forwarding cluster routing protocol, is presented to improve the scalability and to reduce the increasing speed of the routing overhead of the large scale wireless mobile ad hoc network. In this protocol, nodes maintain cluster architecture and link neighboring clusters by exchanging local routing information with each other. On the other hand, they adaptively forward data packets based on local routing information and cluster architecture. Finally, simulation results show that the proposed protocol can effectively decrease the growth rate of routing overhead and end-to-end delay, and the reduction rate of packet delivery ratio in the case of large network size and heavy traffic load.

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