An Ad-hoc Routing Protocol with Minimum Contention Time and Load Balancing

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Abstract— In spite of using IEEE 802.11 as medium access control (MAC), most of the ad-hoc routing protocols do not consider contention time that occurs in the medium reservation procedure. Large, contention times can be more critical than hop counts in determining the end-to-end delay. In ad-hoc networks, traffic concentration on some mobile nodes leads to long queuing delays, low packet delivery ratios, and inefficient power consumption. In this paper, we propose an ad-hoc routing protocol with Minimum Contention Time and Load Balancing (MCL). MCL has two main characteristics. Firstly, MCL selects a route with minimum contention among many possible routes between source and destination in the route selection procedure; secondly, intermediate nodes do not reply to RREQs in the route discovery procedure. These characteristics reduce contention time in medium reservation procedure and distribute traffic throughout the network. We have compared the proposed MCL and the Ad-hoc On-demand Distance Vector (AODV) routing protocol. Simulation results show that MCL outperforms AODV in terms of packet delivery ratio, average end-to-end delay, and normalized routing overhead. In situation where several mobile nodes send data to a fixed node such as an access point or a server, our proposed routing protocol MCL delivers a high performance gain as a result of load balancing.

I. INTRODUCTION

A mobile ad-hoc network (MANET) is a collection of mobile nodes which are formed temporarily without any aid of an established infrastructure. In MANET, the network topology changes frequently due to unpredictable movement of the mobile nodes. In order to deliver data packets in such a dynamic environment, we need efficient routing protocols that are different from the ones used in fixed networks.

Many routing protocols have been proposed for MANET. Most of them use IEEE 802.11 [1] as the underlying MAC protocol. In IEEE 802.11, each node contends with its neighbors and also the neighbors of its neighbors in the medium contention procedure (we will explain the reason in Section 2). Since the range of possible medium contention of a mobile node is wide, medium contention times can affect the end-to-end delay considerably.

In [5], K. Wu and J. Harms introduced the importance of the load balancing in ad-hoc networks. Due to power and bandwidth limitations, ad-hoc routing protocols should consider load balancing. If a large amount of data traffic flows through a few nodes, the nodes are heavily loaded and will power down faster than other remaining nodes. This will reduce the connectivity of the network and can lead to a network partition. Furthermore, heavily loaded nodes have a long queuing delay and a low packet delivery ratio. Therefore, load balancing is very important in the ad-hoc routing protocol design.

Although many routing protocols have been proposed for MANET, none of them have considered the medium contention time and the load balancing simultaneously. In [2], S.T. Sheu and J. Chen proposed the Delay-Oriented Shortest Path Routing (DOSPR) protocol, which utilizes medium contention time information as the main route selection criterion. Although DOSPR assumed IEEE 802.11 as the MAC protocol, it limited the range of contention of a mobile node to its neighbors only. But, in reality, the range of contention of a node covers not only its neighbors but also the neighbors of its neighbors (we will explain the reason in Section 2). DOSPR did not consider load balancing and employed a table-driven approach rather than an on-demand one. Many routing protocols for load balancing have been proposed in the literature. The protocols define the traffic load of each node as the total number of routes passing through the node and its neighbors [3] and also the number of packets queued in the interface of the node [4]. In [5], Load-Sensitive Routing (LSR) protocol uses the load information in a node and its neighbors as the main route selection criterion. But none of them have considered the contention time that occurs in the medium reservation procedure.

In this paper, we propose an ad-hoc routing protocol with Minimum Contention time and Load Balancing (MCL). MCL uses the medium contention information as the main route selection metric. The medium contention information of a node reflects both the medium contention time and traffic load associated with the node. By using the medium contention information in the route selection procedure, MCL reduces the end-to-end delay and distributes traffic evenly throughout the network. In the MCL route discovery procedure, an intermediate node does not reply to a RREQ, even though it has a path to the destination. Why? MCL does not use this
route cache mechanism in order to prevent traffic from concentrating on a few nodes. It also reduces the routing overhead. Following this Introduction, the proposed MCL routing protocol is explained in detail in Section 2. In Section 3, we describe the simulation environment to evaluate the performance of the MCL routing protocol. The simulation results are given in Section 4. Finally, we make a conclusion in Section 5.

II. MCL ROUTING PROTOCOL

A. Background


In the Ad-hoc On-demand Distance Vector (AODV) routing protocol, if a source node does not have a route to a destination, it will initiate a route discovery procedure by broadcasting a route request packet (RREQ). When a node receives a RREQ, if it is the first time for the node to receive the RREQ, it will setup a reverse path to the source and rebroadcast the RREQ. Otherwise, the node will simply discard the RREQ. Once the RREQ reaches the destination node, the destination will reply with a route reply packet (RREP) to the source through the established reverse path. When a node receives a RREP, this node will setup a forward path to the destination node and relay the RREP to the next node in the reverse path. Once the source receives the RREP, the source and all traversed nodes have a route to the destination. Now the source can start transmitting data packets to the destination.

AODV uses a route cache mechanism: if an intermediate node has a route to the destination, it can reply to the RREQ. AODV has a route maintenance procedure: when a link breaks, a route error packet (RERR) is sent back toward the source node. A RERR contains unreachable destination information. Any node that receives the RERR will remove the route cache entry for the corresponding destination.

A.2. Classification of Neighbor Nodes

In the MCL routing protocol, we classify neighbor nodes into four types: tx-neighbor, rx-neighbor, tx/rx-neighbor, and null-neighbor. An example is shown in Fig.1, where node A has all four types of neighbors. A solid line between a pair of nodes indicates that there is at least one data packet to transmit between the two nodes, with an arrow showing the direction of the pending data transmission. A dotted line indicates that there is no data waiting for transmission between the pair of nodes. Notice that a neighbor’s type will change dynamically in time.

- **tx-neighbor** is a neighbor (e.g., node B in Fig. 1) which has a data packet to send to me (node A).
- **rx-neighbor** is a neighbor (node C) which I have a data packet to send to.
- **tx/rx-neighbor** is a neighbor (node D) that is tx-neighbor and rx-neighbor.
- **null-neighbor** is a neighbor (node E) which has no data packet to send to or receive from me.

A.3. Contention Nodes

Contention nodes of a node are nodes that prevent the node from obtaining the shared communication medium when the node tries to reserve the medium to transmit a data packet. In this paper, we use IEEE 802.11 as the MAC protocol and define contention nodes in the term of the virtual carrier sensing of IEEE 802.11. An example is shown in Fig.2, where node A has all four neighbors and seven neighbors of its neighbors. A solid line between a pair of nodes indicates that there is at least one data packet to transmit between the two nodes, with an arrow showing the direction of the pending data transmission. A dotted line indicates that there is no data waiting for transmission between the pair of nodes. Notice that contention nodes of a node will change dynamically in time.

The contention nodes of a node are as follows:

- Contention nodes of a node are its neighbors which have rx-neighbor. In Fig.2, when node A tries to reserve a shared medium to transmit data packets, if one of node A’s neighbors (nodes B, C, D) which have rx-neighbor reserves a medium to send data packets to its rx-neighbor by using RTS/CTS faster than node A, node A modifies its own NAV field on the base of the duration field of RTS that one of node A’s neighbors which have rx-neighbor broadcasts and defers sending data packets.

- Contention nodes of a node are tx-neighbors of its neighbors. In Fig.2, when node A tries to reserve a shared medium to transmit data packets, if one of tx-neighbors (nodes F, H, K, L) of node A’s neighbors reserves the medium to send data packets to its rx-neighbor, namely a neighbor of node A, by using RTS/CTS faster than node A, node A modifies its own NAV field on the base of the duration field of CTS that one of its neighbors broadcasts and defers sending data packets.

For example, contention nodes of node A in Fig. 2 are its neighbors (nodes B, C, D) that have rx-neighbor and tx-neighbors (nodes F, H, K, L) of its neighbors. Therefore, node A has the contention nodes of 7.

The number of contention nodes of a node is connected with both the medium contention time with the node and the traffic load around the node. The number of contention nodes of a node is proportional to the contention time to spend to obtain the shared medium. That is also proportional to the.
number of nodes to send data packets around the node. And, the number of nodes to send data packets around a node is proportional to the traffic load around the node. Therefore, if a routing protocol uses the number of contention nodes as a route selection criterion, it can find a route with short contention time and get the effect of load balancing. So, MCL use the contention nodes information as the route selection metric.

B. Overview of MCL

B.1. Route Discovery

Like AODV, MCL is the on-demand routing protocol. The route discovery procedure in MCL is similar to that in AODV. So, we will explain only the difference between AODV and MCL in the route discovery procedure.

In MCL, if a source does not have a route to a destination, it will initiate a route discovery procedure by broadcasting a RREQ. This RREQ contains the number of the source’s contention nodes. Nodes within the transmission range of the source receive the RREQ and setup a reverse path to the source. If an intermediate node receives the RREQ, it inserts the total number of contention nodes included in the received RREQ and its own contention nodes in the RREQ and rebroadcast the RREQ.

Once the destination node receives the RREQ, it will reply with a RREP to the source through the established reverse path. This RREP contains the number of the destination’s contention nodes. If the destination node receives the same RREQ with the smaller contention nodes than the previously received RREQ, it will reply with a new RREP to the source again.

If an intermediate node receives the RREP, it will setup a forward path to the destination. The intermediate node inserts the total number of contention nodes included in the received RREP and its own contention nodes in the RREP and relays the RREP to the next node in the reverse path.

Once the source receives the RREP, it makes the destination’s route table entry and starts sending data packets to the destination. If the source receives the same RREP with the smaller contention nodes than the previously received RREP, it will update the destination’s route table entry.

B.2. Route Maintenance

Data packets are transmitted through the primary route unless the route breaks down. A node uses the link layer feedback signal from the MAC protocol to detect a link breakdown. When a node detects a link breakdown, it performs a local repair: instead of a source, the node to detect a link breakdown initiates a route discovery procedure for a unreachable destination. If the local repair succeeds, data packets will be delivered through a new route. Otherwise, the node that detects the link breakdown sends a RERR toward the source. If the source that receives the RERR wants to communicate with the destination, it will initiate a route discovery by broadcasting a RREQ.

III. SIMULATION MODEL

Computer simulation is done using a simulation model based on ns-2.1b9 to evaluate the performance of MCL. We compare the performance of MCL with that of the AODV, which allows an intermediate node to reply to a source with a RREP and does not consider medium contention time and load balancing. The distributed coordination function (DCF) of IEEE 802.11 is used as the MAC protocol. DCF uses Request-to-Send (RTS) and Clear-to-Send (CTS) control packets to reduce packet collisions resulting from the hidden node problem. For the radio model, we use the Lucent’s WaveLAN parameters in our simulation. WaveLAN have the transmission range of 250m and the channel capacity of 2Mb/s. In both MCL and AODV, RREQ and RERR are treated as broadcast packets and RREP and data packets are as unicast packets. Both protocols use the link layer feedback signal from the MAC protocol to detect a link breakdown. They do not transmit hello messages periodically [7].

The Traffic and Mobility Models

Traffic sources are constant bit rate (CBR). The size of a data packet is 512 bytes. The packet rate is 2 packets/s. In our simulation, 50 mobile nodes move in a 1500m * 300m rectangular area. Simulation time is set to 900s. The random waypoint model is used as the mobility model of mobile nodes. The mobile nodes move with speeds uniformly selected between the minimum and the maximum. In our simulation, the minimum speed is 0 m/s and the maximum speed is 20 m/s.

Two scenarios are used in the simulation:

(i) General ad-hoc network

(ii) Multi-hop access network.

In the case of (i), the sources and destinations are randomly selected with uniform probability. We vary the pause time from 0 to 900s to investigate the performance variance in different mobility conditions.

In the case of (ii), an AP is located in (750, 150) for a 900s simulation time. The sources are randomly selected with uniform probability, but the destinations are selected in the way that α percentages of the selected destinations become the AP.
We vary the AP traffic ratio ($\alpha$) from 0% to 100% to investigate the performance variance in different traffic loads on the AP. The duration of the pause time of mobile nodes is 300s.

**Performance Metrics**

Three performance metrics are evaluated in our simulation:

- **Packet delivery ratio** – The packet delivery ratio is the ratio of the total number of data packets received by destinations over the total number of data packets transmitted by sources.

- **Average end-to-end delay** – The average end-to-end delay is the average of delays for all received data packet from the sources to destinations.

- **Normalized routing overhead** – The normalized routing overhead is defined as the total number of routing control packets (RREQ, RREP, and RERR) normalized by the total number of received data packets.

**IV. SIMULATION RESULTS**

**A. Packet Delivery Ratio**

The packet delivery ratios of MCL and AODV in the general ad-hoc network scenario and the multi-hop access network are shown in Figs. 3 and 4, respectively. In the two scenarios, the packet delivery ratio of MCL is usually better than that of AODV regardless of the degree of mobility (Fig. 3) or traffic load on AP (Fig. 4). The reason is that MCL node selects a fresh route in the route discovery procedure by using no route cache mechanism and transmits data packets to destination through the fresh route. The use of a fresh route reduces the probability of route breakdown. Therefore, MCL will drop smaller amount of packets than AODV, which uses the route cache mechanism. Another reason is that MCL distributes traffic evenly throughout the network by using the contention nodes information as the route selection metric and no route cache mechanism. This will reduce the packet drop rate due to buffer overflow in the heavily loaded node. Especially, in the multi-hop access network scenario that most traffic concentrates on an AP, MCL shows much better performance in the term of the packet delivery ratio than AODV as a result of load balancing. We can verify the advantage of load balancing at higher AP traffic ratio in Fig. 4.

**B. Average End-to-End Delay**

The average end-to-end delays of MCL and AODV are shown in Figs. 5 and 6 in the general ad-hoc network scenario and the multi-hop access network, respectively. In the two scenarios, the average end-to-end delay of MCL is usually better than that of AODV regardless of the degree of mobility (Fig. 5) or traffic load on AP (Fig. 6). The reason is that MCL uses the total number of the contention nodes for a route as route selection criterion. Because MCL transmits data packets over a route with minimum contention, it has lower contention time than AODV, which does not consider contention time that occurs in the medium reservation procedure. This will reduce packet delay. Another reason is that, due to load balancing, MCL has lower queuing delay than AODV, which does not consider load balancing. This will also reduce packet delay. Especially, in the multi-hop access network scenario that most traffic concentrates on an AP, MCL shows much better performance in the term of the average end-to-end delay than...
AODV as a result of load balancing. We can verify the advantage of load balancing in Fig. 6.

C. Normalized Routing Overhead

In Figs. 7 and 8, we show the normalized routing overhead of MCL and AODV in the general ad-hoc network scenario and multi-hop access network, respectively. In the two scenarios, the normalized routing overhead of MCL is better than that of AODV regardless of the degree of mobility (Fig. 7) or traffic load on AP (Fig. 8). The reason is that MCL reduces routing overhead that occurs in route discovery by improving the packet delivery ratio. Because AODV uses the route cache mechanism, the number of its RREP is more than that of MCL and the number of its RREQ is less than that of MCL. But, AODV has much more RREP than MCL, whereas MCL has a little more RREQ than AODV. This is another reason why AODV is poorer than MCL in the term of the normalized routing overhead. In the multi-hop access network scenario that most traffic concentrate on an AP, if a mobile node initiates a route discovery for the AP, because most of mobile nodes within the ad-hoc network may have a route to the AP, many intermediate nodes will reply with a RREP. By RREP storm, the normalized routing overhead of AODV is much more than that of MCL in the multi-hop access network scenario. We can verify RREP storm in Figs. 9 and 10.

V. CONCLUSION

In this paper, we propose an ad-hoc routing protocol with Minimum Contention Time and Load Balancing called MCL. The MCL routing protocol considers medium contention time and load balancing in the route selection procedure. Simulation results show that, compared with AODV, MCL yields better performance in terms of the packet delivery ratio, the average end-to-end delay, and the normalized routing overhead.

REFERENCES


