

A List-Based Medium Access Control Algorithm in IEEE 802.11 Wireless Mesh Networks

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Abstract — The Head-Of-Line (HOL) blocking problem is one of major reasons for degradation of the performance in wireless mesh networks (WMNs). Since IEEE 802.11 MAC handles packets as the First-In, First-Out (FIFO) policy, devices having frames to transmit may stay in back-off stage for a long time due to a HOL-blocked packet. To resolve the HOL blocking problem, we propose a novel scheduling algorithm called as List-Based Medium Access Control (LBMAC). Our LBMAC algorithm improves the network performance by alleviating the HOL blocking problem and reducing the excessive back-off time. We design the LBMAC based on CSMA/CA algorithm so as to easily incorporate with IEEE 802.11 standards. Performance evaluation shows that our algorithm achieves better performance than IEEE 802.11 MAC protocol.

Keywords— Head-of-line, RTS/CTS, Back-off Time, Packet Scheduling, 802.11 MAC

I. INTRODUCTION

Recently, wireless communications have become a popular way to access network due to good mobility and easy implementation. As the transmission rate of the wireless network has increased, access points can be used as multi-hop mesh routers. In addition, because it has advantages of a cheapness and expansion to construct networks using wireless technologies in a specific area, many researches have been performed on wireless mesh networks (WMNs). In the WMNs, nodes may have to forward multiple data flows because they used to have several neighbor nodes and end users. Since only one transmission is allowed at a time in a co-channel circumstance, all nodes need to contend to occupy a channel frequently. Thus, there can be many collisions as the number of node increases. These contention and collisions impose bad influences to the network performance. IEEE 802.11 MAC standards adopt several schemes to overcome this throughput degradation. First, Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme mitigates collisions by a channel contention. Second, Request-To-Send (RTS) and Clear-To-Send (CTS) frame are adopted to solve a hidden node

problem, which occurs when a node out of carrier sense range intends to send a packet to the node receiving another packet because the sender doesn't know that transmission. These schemes help wireless network have less degradation of the network throughput. Since IEEE 802.11 MAC uses FIFO queue scheduling, the blocked head-of-line (HOL) packet in the queue prevents other packets from being transmitted. That is, packets to be forwarded to a neighbor node with a good channel state cannot be delivered because of the HOL packet destined to a neighbor node with a bad channel state. The HOL blocking problem is one of the major problems to degrade the performance of the wireless network. When the network becomes highly loaded, the HOL blocking problem will be more serious.

Many researches are performed to solve HOL blocking problem. P. Bhagwat *et al.* in [1] proposed the Channel State Dependent Packet Scheduling (CSDPS) scheme to deal with the HOL problem in the wireless LANs. CSDPS controls the transmission and retransmission of a lost packet using channel-state diversity. Fragouli *et al.* used RTS/CTS to check channel state and retransmission number of RTS to estimate the channel condition. In addition, they combined Class-Based Queuing (CBQ) scheme in CSDPS to solve the problem of unfair bandwidth sharing and the HOL problem [2]. They insisted that if we can probe the exact channel state, the HOL problem can be alleviated by modifying MAC scheduling with measured channel state. However, since probing a channel is very costly, we need to find out an appreciate way to increase the RTS success rate with minimum change. In this paper, we propose a new MAC algorithm which can increase the RTS success rate. The proposed MAC algorithm can improve the performance of WMNs by giving a chance for transmission of back-logged packets without waiting for transmitting the HOL packet completely. The performance evaluation shows that our algorithm can achieve better performance.

The rest of the paper is organized as follows. Section II presents the related works, and section III explains details of proposed scheme. Simulation results and analysis are provided and discussed in section IV. Finally, conclusions are given in section V.

II. HOL BLOCKING PROBLEM IN WIRELESS MESH NETWORKS

IEEE 802.11 Distributed Coordination Function (DCF) employs the RTS/CTS scheme to resolve a hidden node problem [3]. It also contributes to shortening collision duration. As shown in Figure 1, a node sends a short RTS frame to probe the state of channel before sending a data frame. The receiver replies with a CTS frame to let the sender know that it is ready to receive. After exchanging RTS/CTS frames, the sender starts to transmit a data frame. The other nodes in a carrier sense range of the sender and receiver set Network Allocation Vector (NAV) to freeze during packet transmission. With the RTS/CTS scheme, wireless nodes can reduce their unnecessary collisions and alleviate the hidden node problem. But the HOL blocking problem by FIFO packet scheduling still exists.

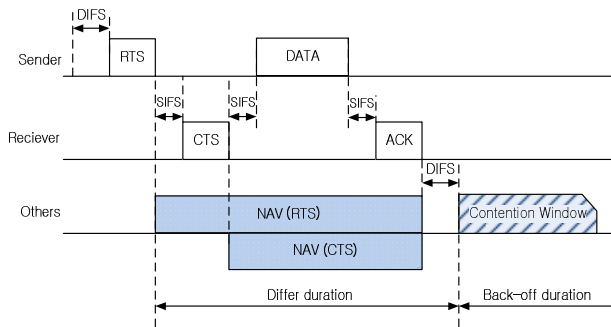


Figure 1. Timeline of RTS/CTS/ACK frames

The details of HOL blocking problem are as follows. As shown in Figure 2, node *A* is in a transmission range of node *O*, and in a carrier sense range of node *X*. When node *X* is transmitting a data frame to node *Y*, node *O* cannot send data frames to node *A* since node *A* senses that the channel is busy due to the transmission of flow *XY*. Since flow *XY* is independent of flow *OB*, both of flow *XY* and flow *OB* can be transmitted simultaneously. However, if node *O* has packets destined to both nodes *A* and *B*, the packet destined to node *A* would be delayed by flow *XY*. Therefore, the head-of-line packet in queue destined to node *A* prevents packets destined to node *B* from transmitting. In this manner, FIFO scheduling makes the packets destined to the nodes with good channel state may suffer a large delay.

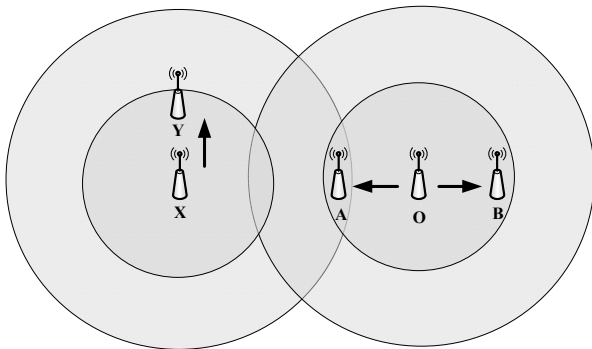


Figure 2. An Example of HOL Blocking Problem

The RTS frame is a short unicast frame composed of a few fields including one receiver address and one duration field. Some papers proposed MAC scheduling schemes using a Multicast-RTS (MRTS) concept in WMNs. As Figure 3 shows, MRTS frame has additional Receiver Address (RA) and duration fields of queued packets while the RTS packet has only one receiver address and duration field. Zhang *et al.* in [4] proposed adaptive Channel-State-Based (CSB) scheduling scheme to solve the HOL blocking problem. They used the MRTS frame to measure the channel conditions of multiple receivers simultaneously, and introduced the diversity weight based on the correlation of channel states of receivers to adjust adaptively the receiver list length in MRTS frames in dynamic network conditions. They showed that Variable-Length CSB (VL-CSB) scheme achieved better throughput than the fixed-length one in dynamic traffic situations. Wang *et al.* in [5] also used the MRTS to propose the Opportunistic packet Scheduling and Medium Access control (OSMA) protocol to exploit high quality channel condition under certain fairness constraints. They explored the multiuser diversity, and used the MRTS and prioritized CTS frame to alleviate HOL blocking problem. Miao Zhao *et al.* in [6] introduced the MRTS concept as well to propose a MAC protocol called Contention-Based Prioritized Opportunistic (CBPO) medium access control protocol. This protocol takes advantage of multiuser diversity, rate adaptation, which utilizes the multi-rate capability offered by IEEE 802.11, and black-burst (BB) contention to access the shared medium in a distributed manner.

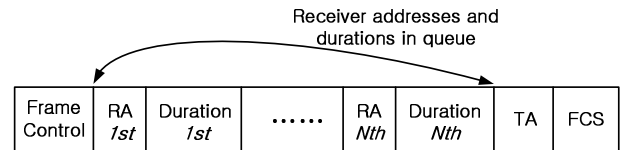


Figure 3. Format of Multicast RTS Frame

However, RTS/CTS scheme is adopted to decrease the waste time for completing the transmission of a collided packet using a very short RTS frame instead of a long actual data frame. However, the RTS frames become longer in MRTS scheme with additional address and duration fields. And CTS frames also become longer because it needs to add a new address field of a source node. Hence, our proposed algorithm uses the original RTS/CTS scheme without changing the length of the RTS frame.

III. LIST-BASED MEDIUM ACCESS CONTROL

IEEE 802.11 MAC adopts the CSMA/CA scheme and exponential back-off algorithm to avoid collisions. Node probes the channel state before transmitting and starts to transmit a data frame if the channel is idle, otherwise it doubles a Contention Window (CW) and defers for specific time equal to slot times of a random number in $[0, CW-1]$. Hence, CW increases exponentially as the failure of transmission is repeated. Repeated attempt of transmission to neighbor nodes

with bad channel state is inefficient, because it makes a node stay in back-off stage for a long time and results in the degradation of the network throughput. Although it's not an actual data transmission, the same result is provided when a sender attempts to send to the node has set NAV. Therefore, if the network is highly loaded, frequent contention makes a node spend a lot of time in back-off time and degrade the performance. Especially, the HOL blocking problem in IEEE 802.11 MAC using FIFO scheduling makes this degradation be more serious.

In this paper, we solve the HOL blocking problem by reducing the increase rate of back-off time. Since the major effect of HOL blocking problem is an excessive increase of back-off time by repeating a packet transmission through the congested channel, the proposed List-Based Medium Access Control (LBMAC) algorithm can improve the network performance by scheduling packets based on an address list and reducing whole back-off time. Details are as follows.

A. Address-list

Since FIFO scheduling in IEEE 802.11 MAC deals with packets one by one with incoming sequence, the blocked HOL packet makes the others wait in queue. To overcome this problem, our proposed LBMAC algorithm uses the list-based packet scheduling. As shown in Figure 4, an address list is created by next hops of queued packets. The rank of each address element is simply decided by queued sequence of packets. All elements must be unique and cannot be duplicated. Then, the sender tries to transmit a packet which has the next hop of the first address list. If it fails to transmit, it continues to send a packet which has the next hop of the second address list one after another until it succeeds to transmit. The address list will be updated whenever it transmits a packet successfully or gets a new incoming packet. Many scheduling algorithms such as Round Robin (RR) and Earliest Timestamp First (ETF) have been proposed [7]. We can also use a prioritizing scheme to decide the rank of the list in other researches [4-6], but we will focus on alleviating the HOL blocking problem with simple RR scheduling based on the address list in this paper. We leave this issue for the future research and expect the fairness and QoS can be further enhanced by more complex scheduling algorithms.

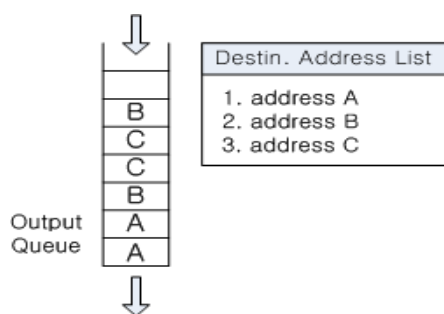


Figure 4. Address List Example

B. Selective Incremental Back-off Algorithm

In exponential back-off algorithm in IEEE 802.11 MAC, the CW is doubled whenever a node fails to transmit each frame. If a node has packets destined to various neighbor nodes, it may spend too much time on retransmitting the HOL packet destined to the node in a bad channel state. Considering the maximum number of RTS retransmission is seven, it will take quite long time to complete a transmission if a packet is to be transmitted in a highly loaded channel condition. More importantly, all other back-logged packets in queue have to wait for the same long time when this node stays in a back-off stage. The whole network throughput may go down frequently.

To reduce this wasteful back-off time, our LBMAC introduces Selective Incremental Back-off (SIB) algorithm. In the SIB algorithm, the CW is doubled only if list sequence expires. That is, only if all attempts to transmit packets of all lists in the address list are failed, the CW increases. When a node fails to send a RTS frame, the LBMAC algorithm does back-off without doubling CW and tries to send a packet of the next list. After attempts continued to fail till the last list, it concludes that all neighbor links are busy, and CW is doubled and the address list is initialized. Consequently, the LBMAC algorithm can improve the performance by scheduling packets with good channel condition earlier. Figure 5 shows the timeline of the RTS/CTS frames in the LBMAC algorithm.

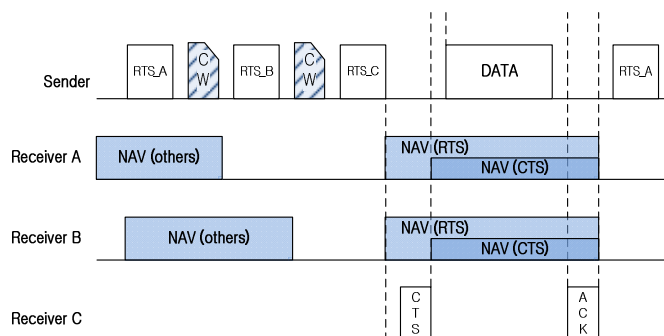


Figure 5. Timeline of the LBMAC Algorithm

In comparison with IEEE 802.11 MAC, our LBMAC algorithm can dramatically reduce the whole back-off time. The ratio of reduction depends on the length of address list, and it can improve the network performance more especially in a highly loaded wireless network with many flows.

IV. SIMULATION RESULTS

In this section, we evaluate the performance of our LBMAC scheme and compare it with the IEEE 802.11 standards. We show that the LBMAC has better throughput and lower delay time than IEEE 802.11 MAC protocol. We consider the scenario in Figure 2 with five nodes and three data flows (OA, OB and XY). All packets have a fixed size of 1023 bytes. Node O generates 1000 packets per second to both node A and B. Then, the queue in node O is backlogged all the time. The distance from node X, O to nodes Y, A, B is 200 meters. Node X is 400 meters far away from node A. The carrier sense range

and transmission range are set to 500 meters and 250 meters respectively. We investigate the performance of node O using LBMAC algorithm varying the flow rate from node X to node Y . Each simulation is performed for 300 seconds.

Figure 6 shows the throughput comparison of 802.11 MAC and LBMAC. In 802.11 MAC, throughputs of flow OA and OB are reduced simultaneously as the rate of flow XY grows although flow OB is independent of flow XY . Since the packets destined to node A from node O cause the HOL blocking problem on node O , the flow OB is also affected. However, since the proposed LBMAC uses more effective MAC algorithm, it can alleviate the HOL blocking problem and improve the performance of wireless network as in Figure 6. We can observe that throughputs of flow OA and OB are improved. Especially, the throughput of flow OB grows dramatically. Since the LBMAC helps the packets destined to node B have more chances to be transmitted alleviating the HOL blocking problem. Also we find out that the whole network throughput is better since the selective incremental back-off algorithm reduces the excessive back-off time.

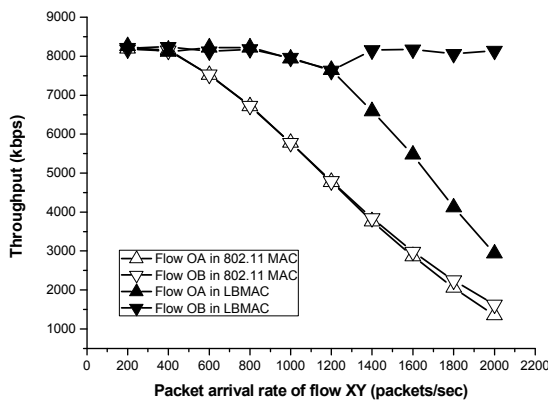


Figure 6. Throughput Comparison

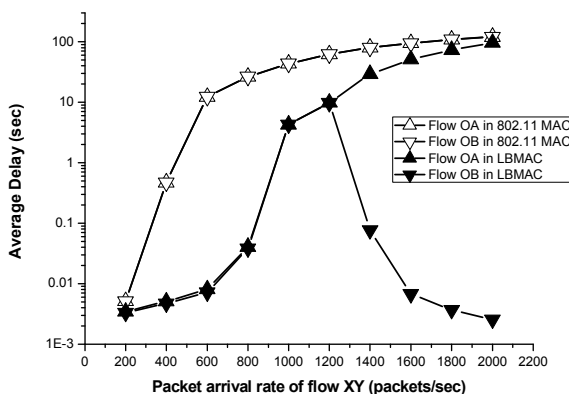


Figure 7. Average Delay Comparison

Figure 7 compares average delays of conventional and proposed LBMAC algorithm. In IEEE 802.11 MAC scheduling, delays of flows from node O to nodes A and B increase as the rate of flow XY increases. The reason is the same with the former result for throughput. Since FIFO scheduling in IEEE 802.11 MAC has the HOL blocking problem, all packets in queue are influenced by HOL blocked packets. On the other hand, the LBMAC algorithm gives better performance since the LBMAC can solve the HOL blocking problem and reduce whole back-off time with a selective incremental back-off technique. Especially as the rate of flow XY exceeds a specific value, the delay of packets destined to node B on node O further decreases. The reason is that severe competition between flow OA and XY makes packets of flow OA drop easily, and thus, the flow OB has higher probability to transmit.

V. CONCLUSIONS

In this paper, we propose LBMAC algorithm using a list-based packet scheduling and a selective incremental back-off algorithm. The LBMAC can improve the performance of wireless networks by alleviating the HOL blocking problem and reducing whole back-off time. Simulation results show that our LBMAC algorithm have better performance than IEEE 802.11 MAC standards. The simulation is performed in an environment with single hop flow. It remains for further work to extend to a lot of mesh points with multi-hop flows.

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