Fairness Improvement of Communication Flows with No Coordination for Multi-Hop Wireless Network

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Abstract— **In multi-hop wireless networks, the number of hops from source node to destination node for each communication flow may be different, and it causes unfairness for the quality of services among communication flows. In this paper, we propose a fairness improvement method among communication flows for multi-hop wireless networks with no coordination, which means that all nodes in the network control their own transmission of packets without any exchange of control information about fairness improvement among their neighbor nodes. In our method, each node recognizes the surrounding transmission situation by overhearing packets from the neighbor nodes, and it controls its own packet queue and adjust the back-off time for packet transmission in MAC layer, to improve fairness among communication flows.**

Keywords—multi-hop wireless networks; fairness; back-off time

I. INTRODUCTION

Multi-Hop wireless network is one of the most promising techniques, which can be constructed by various types of devices with wireless communication function. It doesn't need any infrastructure such as fixed facilities and wired cables to connect with each other, and such wireless networks are much helpful for various situations such as temporal events and disaster situations. In such multi-hop wireless networks, however, the number of hops from source node to destination node for each communication flow may be different, and it may cause unfairness for the quality of services among communication flows. Therefore, developing the methods to improve the fairness among communication flows for multi-hop wireless networks is one of the most important research topics for practical use.

One of the reasons why unfairness among communication flows causes is by the same transmission opportunity among nodes. It means that it takes more time for a packet with more number of necessary hops to reach a destination node, and as a result, such flow can send less packets to the destination node. In contrast, a flow with less number of hops can send more packets to the destination node. Another reason is by management of packet queue. The drop-tail method is a simple one, in which the incoming packet is dropped if the packet queue is already full. In this method, however, the packet queue may be filled with the packets of the flow with high incoming rate to the queue, such as the source of the flow is just the node.

In this paper, we propose a fairness improvement method among communication flows for multi-hop wireless networks with no coordination, which means that all nodes in the network control their own transmission of packets without any exchange of control information about fairness improvement among their neighbor nodes. In our method, each node recognizes the surrounding transmission situation by overhearing packets from the neighbor nodes, and it controls its own packet queue and adjusts the back-off time for packet transmission in MAC layer with no coordination, to improve the fairness among communication flows.

The remainder of this paper is organized as follows. In Section 2, we explain some related works about fairness improvement for wireless networks and their problems. Section 3 describes our proposed method of fairness improvement based on packet queue management and adjustment of back-off time for multi-hop wireless networks. We evaluate our proposed method by network simulation and make a consideration in Section 4. The conclusion of this paper and future works are given in Section 5.

II. RELATED WORKS

There have been many proposed methods for improving fairness among communication flows in multi-hop wireless networks [1-6]. One of the approaches is by controlling packet queue of each node. E-QMMN [2] is one of packet queue management methods to improve fairness among communication flows. The authors of this method consider that the throughput of a communication flow with large hop count between source node and destination node tends to become lower. Therefore, each node checks the number of hops by calculating the packet arrival rate of each flow, and assigns more space of packet queue to the flow with more number of hops. However, only using queue management approach seems to be insufficient to improve fairness among communication flow, because in multi-hop wireless networks, the flow with more number of hops is necessary to forward a packet to a neighbor node repeatedly, and it causes additional delay to reach the destination node if the transmission opportunity in forwarding procedure at all nodes is the same. Additionally, therefore, adjusting transmission opportunity to forward packets with considering multi-hop flows is needed.

Other type of approaches to improve fairness among communication flow is to assign throughput of the flows among neighbor nodes. SECC [1] is a congestion control method with considering fairness among communication flows, in which each node checks the congestion status and exchanging control messages including desirable transmission rate of each flow if congestion causes. However, this type of approaches needs to exchange control messages and it takes more overhead to the communication channel and there may be no guarantee to receive such control messages at the neighbor nodes if the broadcast transmission is used to reduce the overhead of exchanging control messages.

Other approach is centralized one that the network information are collected and the resource allocation to each flow is calculated [5].

For TCP transmission flows, the authors of [4] proposed a method to improve fairness among communication flows by using IEEE802.11e TXOP function.

III. Fairness Improvement with No Coordination

In multi-hop wireless networks, there exists a problem about unfairness among communication flows with different hop counts exists. In this paper, we propose a method to improve this problem, in which each node manages its packet queue and adjusts back-off time with considering fairness. We will describe how to improve fairness among flows in the following subsections.

A. Adjusting Back-off Time

One of the ways to change the transmission opportunity is to adjust back-off time for IEEE802.11 MAC protocol. Back-off time is defined based on the number randomly selected from between 0 and *CW* (the value of Contention Window). This means that if *CW* is smaller, then the selected random number tends to become smaller, namely the back-off time is smaller and the node gets higher transmission opportunity. In contrast, if *CW* is larger, then the node gets lower transmission opportunity. Therefore, if each node can adjust the appropriate value of *CW* according to the current transmission situation, then the fairness among communication flow can be improved.

To adjust back-off time at each node, we consider three types of communication flow, incoming flow (InFlow), outgoing flow (OutFlow) and virtual flow (VirFlow), shown as Fig.1. Here, we assume that all nodes have a function of overhearing surrounding packet transmission, and the virtual flow means the flow whose packets are transmitted by the neighbor node and they can be overheard. Each node can adjust only the back-off time for outgoing flows, and the minimum number of contention window ($CW_{\min}$) is adjusted to the appropriate value to improve fairness in our proposed method.

To adjust $CW_{\min}$, we calculate two rate values with considering the balance of the throughput of each flow. The first rate value r_1 is based on the inter-node fairness, and calculated as follows:

$$r_1 = \frac{\theta_O}{((\theta_O + \theta_I + \theta_V)/2)},$$

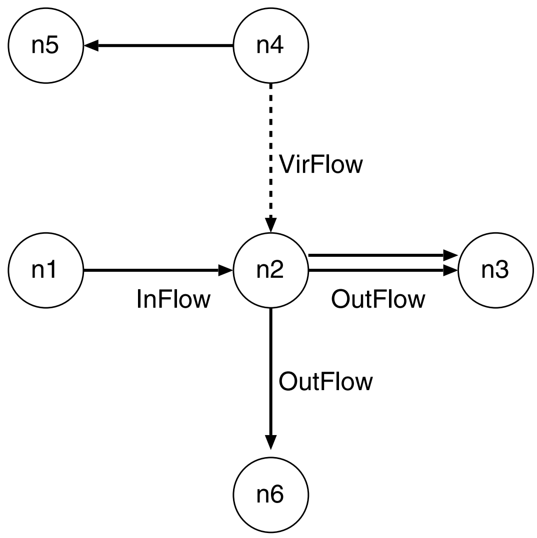


Fig. 1 Considerable flows for adjusting back-off time

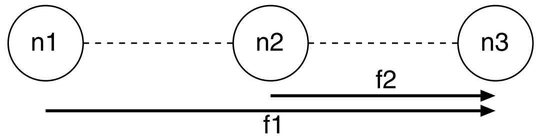


Fig. 2 Two flows with different hop counts

where θ_O, θ_I and θ_V represent the values of sum of the throughputs of OutFlow, InFlow and VirFlow, respectively.

The second rate value is based on the inter-ongoing fairness, and this value is calculated to the next hop of ongoing flows. In Fig.1, for example, node n_2 has two directions for ongoing flows, to node n_3 and to node n_6. These two groups of ongoing flows have different number of flows and transmission throughput. Therefore, the second rate value is calculated for each direction of ongoing flows. The second rate value r_{2i} for the next hop n_i is calculated as follows:

$$r_{2i} = \frac{\theta'_O / N_O}{\theta_i},$$

where θ'_O represents the sum of average throughput of OutFlow with the same next hop. N_O represents the number of next hops for OutFlow. θ_i represents the values of sum of throughput of OutFlow with the next hop n_i.

With using these two rate values, initial value CW_i of a new packet transmission for the flow with the next hop n_i is adjusted as follows:

$$CW_i = r_1 \times r_{2i} \times CW_{\min},$$

where $CW_{\min}$ represents the default minimum value of contention window.

B. Queue Management for Fairness

Now, we assume two communication flows f_1 and f_2 with different hop counts shown as Fig.2, where flow f_1 from node n_1 needs two hops to reach the destination node n_3, and flow f_2 from n_2 needs only on hops to the destination n_3. The packets of both flows are temporally stored in the packet queue at node n_2. In this case, the generated packets for f_2 are directly inserted to the packet queue of node n_2, and it is clear that the packet queue is easily filled with packets of f_2, if the transmission rate of f_2 is high, and the most packet of f_1 will be dropped at n_2, even if the transmission opportunity of flow f_1 increases. Therefore, we need to consider not only adjusting back-off time, but also another point of view, management of packet queue.

In this paper, we employ a simple queue management algorithm as follows:

- If a node receives a packet and its packet queue is not full, then the received packet is inserted to the packet queue.
- If a node receives a packet and it's packet queue is already full, then the node counts the number of packets of each flow in the packet queue including the received packet, and the last inserted packet of the flow with maximum number of the packets in the packet queue is dropped, and the received packet is inserted if it is not dropped.

IV. Performance Evaluation

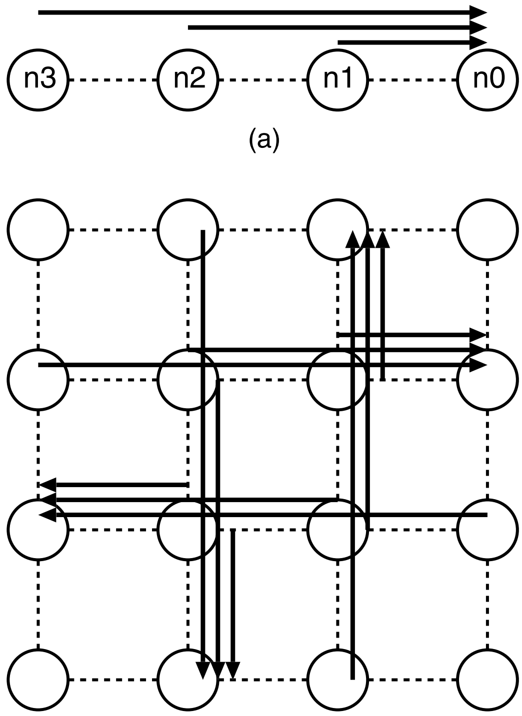
To evaluate our proposed method, we made network simulation based on The Network Simulator ns-2[7]. In this simulation, we use two network topologies shown as Fig.3. Simulation parameters are shown as Table 1. The simulation results are the averages of 100 times of different generation patterns of random numbers.

TABLE I. SIMULATION PARAMETERS

Parameter	Values
Distance between nodes	200m
Transmission range	250m
Propagation model	TwoRayGround
MAC protocol	IEEE802.11b
Routing protocol	DSDV
Transport protocol	UDP
Application protocol	CBR
Packet size	1000bytes
Transmission rate	100-1000kbps
Simulation time	500sec

We compared the performance of our proposed method with normal IEEE802.11b and E-QMMN method, at the values of fairness index among communication flows and total link throughput. Fairness index F among communication flows is calculated as follows:

$$F = \frac{(\sum_{i=1}^{n} g_i)^2}{n \sum_{i=1}^{n} g_i^2},$$



(b)

Fig. 3 Network topologies

where n and g_i represent the number of communication flows and the throughput of flow i, respectively. Total link throughput represents the sum of throughput values of all links. The sum of goodput of all flows may be not appropriate in this case, because a flow with less number of hops can obtain higher goodput and the sum of goodput tends to become higher in unfair situation. Therefore, we measured the total link throughput, to check if our proposed method decreases the transmission opportunity for achieving fairness among communication flows.

A. Results in Chain Topology

Figure 4 shows the graph of fairness index of three communication flows with different number of hops on the chain topology shown as Fig.3 (a). The horizontal axis means the transmission rate of each flow. From this graph, our proposed method had better performance than the other methods. We consider that the reason of this result is that the communication flow with more number of hops had more transmission opportunity by the function of adjusting back-off time which our proposed method has. Additionally, it seems that queue management of each node also played a role of keeping the balance of communication rate among communication flows.

Figure 5 shows the graph of total link throughput in this scenario on the chain topology shown as Fig.3 (a). We can see that the results of three methods are almost the same, and this means that our proposed method can improve the fairness among communication flows with different number of hops without total network performance in this topology.

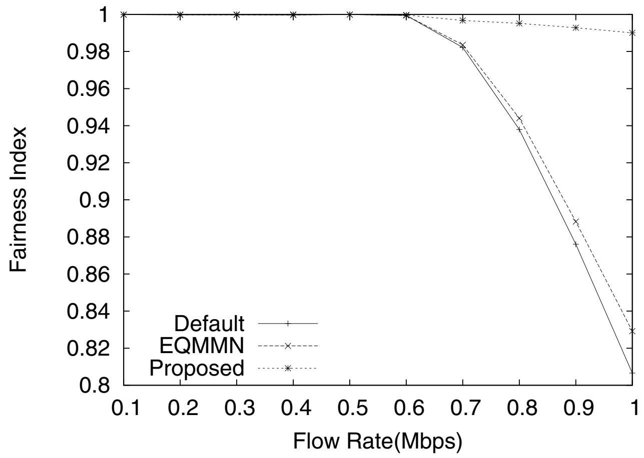


Fig. 4 Fairness index in chain topology

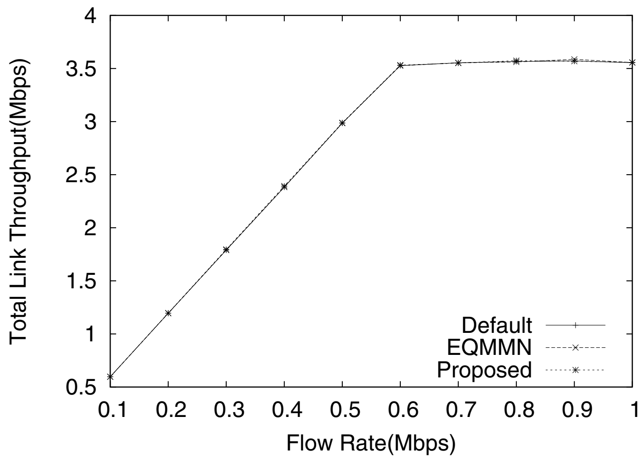


Fig. 5 Total link throughput in chain topology

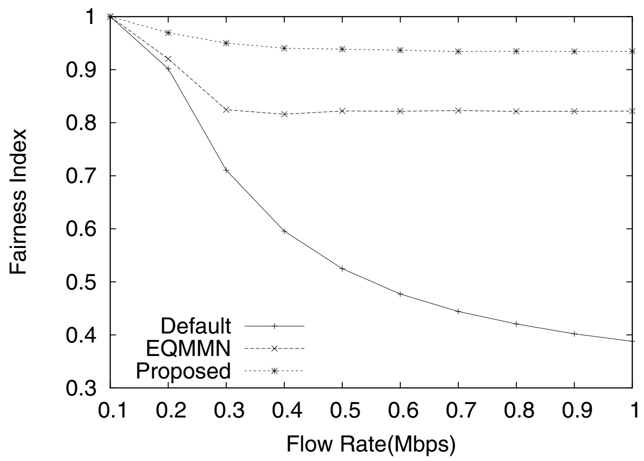


Fig. 6 Fairness index in mesh topology

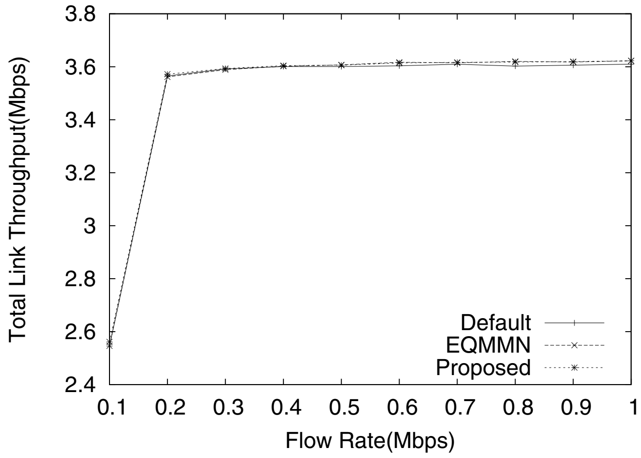


Fig. 7 Total link throughput in mesh topology

B. Results in Mesh Topology

Figure 6 shows the graph of fairness index of twelve crossing communication flows with different number of hops on the mesh topology shown as Fig.3 (b). The horizontal axis means the transmission rate of each flow. From this graph, our proposed method also had better performance than the other methods at this scenario. Our proposed method adjusts back-off time at each node with considering surrounding transmission condition, and also controls packet queue with considering the balance of communication rate among communication flows. This result proves the good effect of our method.

Figure 7 shows the graph of total link throughput in this scenario on the chain topology shown as Fig.3 (b). As well as the result of the chain topology, the results of three methods are almost the same. This means that our proposed method can also improve the fairness among communication flows with different hop count without total network performance in more complex topology.

Next, we show the simulation results using the same mesh topology shown in Fig.3 (b), but the source node and the destination node of each flow are randomly chosen. It may be much difficult to improve the fairness among communication flows in such scenario, because there are some overlapping patterns of communication flows where the fairness can't be improved. Anyway, we tried it to check the performance of our proposed method, with comparing to the other methods.

Figure 8 and 9 show the graph of fairness index among communication flows and the total link throughput with varying the number of communication flows, respectively. The transmission rate of all communication flows is fixed to 200kbps. From these graphs, our proposed method also had better performance than the other methods at this scenario. Our proposed method is effective at various types of network situation. However, the effect of our proposed method in this situation is smaller than the previous results, and we need to refine our method to enhance fairness among communication flows in such network situation.

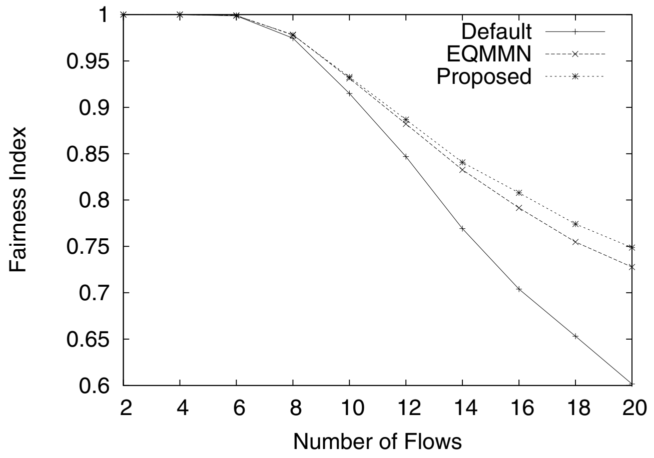


Fig. 8 Fairness index in mesh topology with random flows

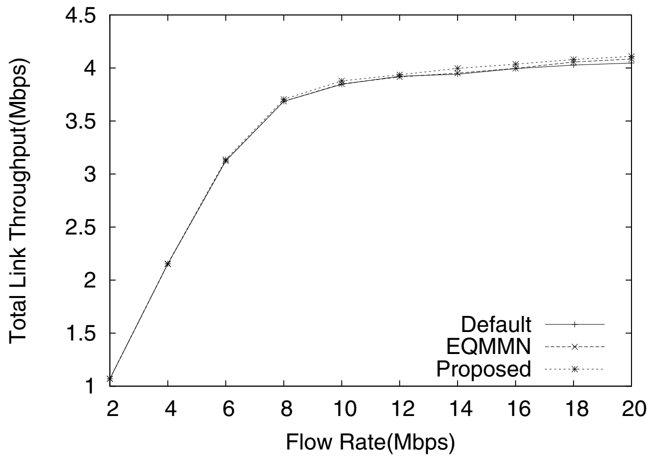


Fig. 9 Total link throughput in mesh topology with random flows

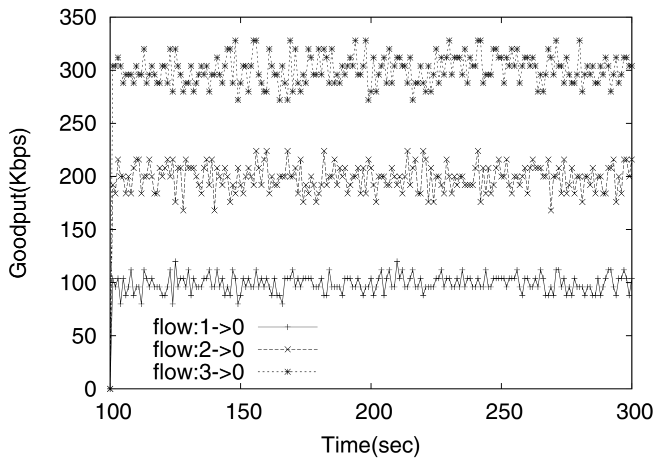


Fig. 10 Goodput of each flow in light load case

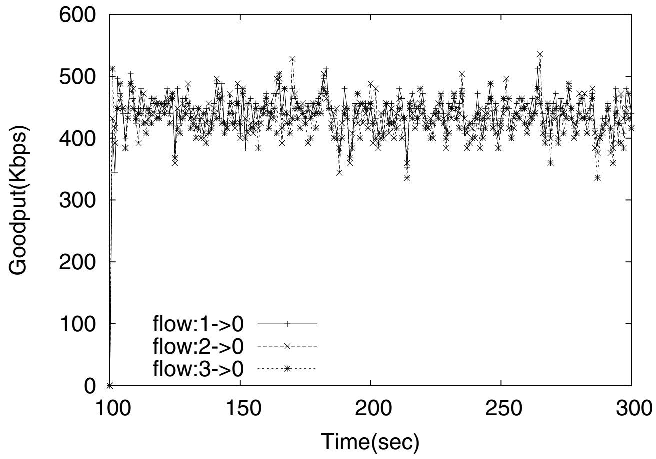


Fig. 11 Goodput of each flow in heavy load case

C. Results of flows with different transmission rates

In the above simulation results, all of the flows in a simulation has the same transmission rate. We also check the performance of our proposed method in the case that the flows in a simulation has different transmission rates. Here, we use the chain topology shown as Fig.3 (a). At first, we show the simulation result in lighter network load, where the transmission rates of flows (n3->n0, n2->n0 and n1->n0) are 300kbps, 200kbps and 100kbps, respectively. Figure 10 shows the transition of goodput of each flow. We can easily understand that each flow could obtain the desirable communication performance in this case, and our proposed method have the function of giving the necessary communication rate to each flow when the network load is not heavy.

Next, we show the simulation result in higher network load, where the transmission rate of flows are 1500kbps, 1000kbps and 500kbps, respectively. Figure 11 shows the transition of goodput of each flow. This graph means that three flows got the same communication rate in this case, and we can confirm that our proposed method enables that all flows fairly have the same communication rate in the heavy network load.

V. Conclusions

In this paper, we propose a fairness improvement method among communication flows for multi-hop wireless networks in distributed manner, which means that all nodes in the network control their own transmission of packets without any exchange of control information among their neighbor nodes. In our method, each node recognizes the surrounding transmission situation by overhearing packets, and it controls its own packet queue and adjust the back-off time for packet transmission in MAC layer autonomously. The simulation results showed better performance of our method than the traditional methods.

We have some future works, such as another method of adjusting back-off time to enhance the fairness among communication flows and the network performance. Also, we need to investigate the network performance with using our proposed method in various types of network situations such as including flows with different transmission rate and using different transport and application protocols. Actually, we simply tested our proposed method in the case of using TCP as the transport protocol. The obtained results were not satisfactory, though the fairness among communication flows was a little improved, compared with the other methods. The reason may be that the current version of our proposed method can't adapt the congestion control function which TCP has. We need to consider how to improve our proposed method, to accomplish the fairness among TCP flows.

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