Fair Scheduling for Throughput Improvement in Wireless Mesh Networks

Nguyen H. Tran, Choong Seon Hong
Department of Computer Engineering, Kyung Hee University
Giheung, Yongin, Gyeonggi, 449-701 Korea
Email: nguyenth@networking.khu.ac.kr, cshong@khu.ac.kr

Abstract. Throughput improvement problem in wireless mesh network can be alleviated by equipped mesh router with multiple radios tuned into orthogonal channels. However, some links on the same channel also can be activated concurrently if the Signal-to-Noise and Interference Ratio (SNIR) at their receiver endpoints is not lower than the threshold. We propose a greedy algorithm to investigate the problem of how to schedule a set of feasible transmission under physical interference model by using the spatial time-division multiple-access (STDMA) scheme. We also consider the fairness in scheduling to prevent some border nodes from starvation. We evaluate our algorithms through extensive simulation and the results show that our algorithms can achieve better aggregate throughput and fairness performance than 802.11 standard.

Keywords: Wireless mesh networks, scheduling, fairness

I. INTRODUCTION

Recently, several works have focused on many typical problems of Wireless Mesh Networks (WMNs) like channel assignment, routing, scheduling [1, 2, 5,]. One of the important factors to improve the network capacity is spatial reuse, the total number of concurrent transmissions that can be accommodated in the network. Consequently, spatial reuse TDMA which was introduced in [4] is an access scheme that provides the concurrent transmissions as long as they do not interfere too much with each other. Another popular MAC protocol that attracts most of the recent work is CSMA/CA proposed in IEEE 802.11 standard. Since its conservative mechanism with carrier sensing and collision avoidance characteristics, high traffic demand can not be satisfied, especially with WMNs. There are two main interference models in literature: *protocol* and *physical* interference models, which were first proposed in [6]. The behavior of protocol interference model is similar the characteristic of CSMA/CA. We see that the characteristic of physical model is suitable with spatial re[1]use TDMA access scheme. Moreover, the majority of traffic is transferred to and from gateways, traffic flows will likely aggregate at the mesh routers close to the gateways. There is probably the starvation of the mesh client of border mesh routers. So, fairness must also be considered significantly. In this paper, we propose a heuristic scheduling algorithm using STDMA access scheme under the physical interference model to reach the objective of throughput improvement with fairness in WMNs. Simulation results show that the performance of our algorithm is significantly better than 802.11 CSMA/CA both in throughput improvement and fairness.

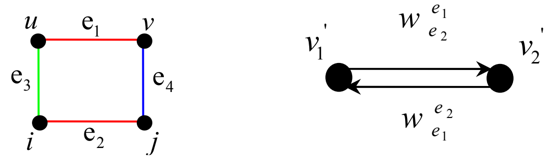
II. SYSTEM MODEL, ASSUMPTIONS, AND DEFINITIONS

A. Network Model

We consider the backbone of WMN modeled by a *network graph* $G(V,E)$, where V is the set of nodes (mesh routers) and E is the set of links. We assume that time is slotted, denote by t, and that the packet length is normalized in order to be transmittable in a unit time slot. We denote $Q_e(t)$ the number of packets waiting to be transmitted on link e by the end of time slot t, also known as queue length of e. In each period, the priority of a link will be based on its queue length at the end of previous period. Each node in the system is equipped with one or more wireless interface cards, referred to as radios in this paper. We assume there are K orthogonal channels are available in the network.

B. Interference Model

1) Physical Interference Model: Denoting RSS_j^i is the signal strength of node j when node i transmits to node j, and ISS_j^k is interfered signal strength from another node k also transmitting. Packets along the link (i,j) are correctly received if and only if:



(a) Network (b) Weighted interference graph

Fig. 1. Network graph and weighted interference graph

$$\frac{RSS_j^i}{N+\sum_{k\in V_s} ISS_j^k} \geq \alpha \qquad (1)$$

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where N is the white noise, V_S is the subset of nodes in V that are transmitting concurrently, and α is the threshold. The set of links that interfere with each other can be represented by using *interference graph* [2].

2) Interference graph: In an interference graph, a node v' represents for the edge e in network graph and the directed edge between two nodes has a weight. This weight is the ratio of maximum permissible noise and interference level at the receiver of link contributed by other concurrent transmissions. Consider an example in Figure 1, the communications between node u and v, i and j are on the same channel (the same red color). We can construct the interference graph based on the network graph as Figure 1(b). The weight value $w_{e_2}^{e_1}$ represents for the interference contributed by e_1 to e_2 is:

$$w_{e_2}^{e_1} = \frac{\max(ISS_j^v, ISS_j^u)}{\frac{RSS_j^i}{\alpha} - N} \tag{2}$$

C. Conditions

We find the conditions to determine whether a certain set of concurrent transmissions on the same channel is feasible. 1) A necessary condition: The set $E_M = \{e_1, ..., e_k\} \subseteq E$ is feasible only if none of its edges is incident with each other on the same node. 2) A sufficient condition: Every receiver of all links in E_M must have $SINR \geq \alpha$. So, we can state the following corollary:

COROLLARY 1. *A set $E_M \subseteq E$ of concurrent transmission on the same channel in a given network graph $G(V, E)$ is feasible under physical interference model if every vertex of the corresponding interference graph $G'(V', E')$ satisfies:*

$$\sum_{v_k' \in V_M' - \{v'\}} w_e^{e_k} \leq 1 \tag{3}$$

Proof: From Eq. (1) and (2), we can easily derive the result.

III. FAIR SCHEDULING ALGORITHM

In this section, we present a greedy algorithm to construct a feasible schedule for a set of transmissions under physical interference model. Instead of considering for the whole network, proposed algorithm just investigates in a subgraph. The reason is to improve the fairness characteristic. If we consider the feasible schedule for whole network, the links close to gateways have higher priority will take over the right to be scheduled first. It leads to some links at the border of system may not have a chance to transmit the data. When setting feasible schedule for a subgraph in each period, the number of high priority links has been reduced, so the border links can transmit with higher probability. Consequently, we decide to choose Minimum Spanning Tree (MST) as the subgraph of the network graph $G(V, E)$ in our algorithm because MST has all characteristics appropriate for the purpose of our algorithm. First, MST is a spanning subgraph that contains all vertices of $G(V, E)$ so it gives an equal chance for all links incident with all nodes to be considered in each period of the schedule. Second, MST of a graph defines the cheapest subset of edges that keeps the graph in one connected component. So each link in a MST will have the higher priority than the others incident on the same node with it. It satisfies the condition that links with higher priority will be considered to be scheduled first. Finally, it can be computed quickly and easily, e.g. Kruskal's minimum spanning tree algorithm [7] can have the running time $O(|E| \log |V|)$. It's an important factor to reduce time complexity of our algorithm. Figure 2 is an example of MST (the bold lines) constructed from a WMN. There are total 7 links operating on channel 1 contend to be scheduled for whole network while in this MST, there are just 4 links. So with the priority criterion, links of border nodes will have higher chance to be in a schedule.

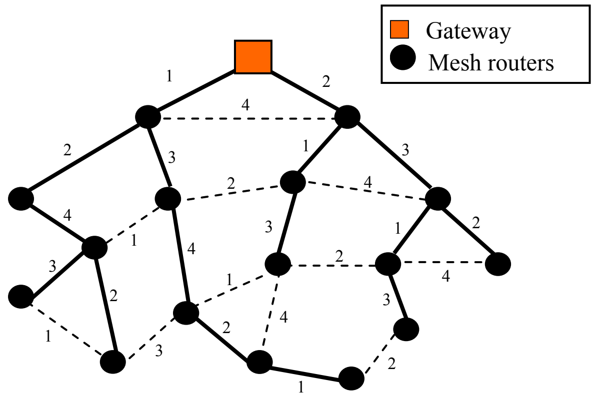

Fig. 2. A Minimum Spanning Tree of WMNs.

The fair scheduling algorithm is as follows.

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1. Construct MST from network graph
forall $k = 1..K$ orthogonal channels in the MST
    2. Order the set of links on the same channel $k$ according to the decrease of queue lengths.
    3. Find the maximal feasible set $E_M^k$. Beginning with the highest queue length link, transform next ordering links into vertices of the interference graph until there is a link making the interference graph unsatisfied with corollary 1.
    4. Schedule each link in $E_M^k$ from slot 0 to slot $Q_e(t)$.
endfor
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Finally, we have aperiodic time slotted schedules in which the set of feasible transmission satisfies corollary 1 in every slot. The length of a period depends on the link which has the maximum queue length in set E_M^k, $T = \max_{e \in E_M^k} Q_e(t)$ with $k = 1..K$. And the algorithm schedules each edge e of E_M^k in $Q_e(t)$ time slots.

IV. PERFORMANCE EVALUATION

In this section, through simulation, we evaluate the performance of our scheduling algorithm by comparing with IEEE 802.11 CSMA/CA whose behavior is similar to protocol interference model. We present two sets of simulation results. The first set evaluates throughput improvement and the second set evaluates the fairness. We have implemented our algorithm in ns-2 (ver2.28). In particular, we have modified in ns-2 such that the interference perceived at a receiver is the collective aggregate interference from all the concurrent transmissions. There's a complete 802.11 MAC model in ns-2. We use two-ray propagation model. In case of 802.11, each node has the transmission range of 150 m, carrier sense range of 300 m. The simulations are carried out for a $800 \times 800\, m^2$ area in which 50 nodes are placed randomly. We use the default transmission rates 11 Mbps to reflect realistic 802.11b data rates. We also use constant bit rate (CBR) over UDP and use Adhoc On-demand Distance Vector (AODV) as the base routing protocol. We choose Kruskal's algorithm [7] to construct the MST from the network for our algorithms

A. Throughput Improvements Evaluation

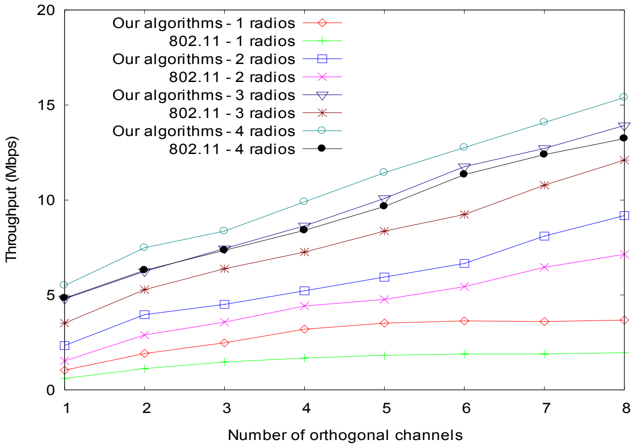

Fig. 3. Throughput Improvement Evaluation

We compare our algorithms and 802.11 based on the effect number of channels and number of radios. We vary the number of orthogonal channels available from 1 to 8 and the number of radios is from 1 to 4 respectively. From Figure 3, we see that our algorithm can exploit effectively the increasing number of channels with different number of radios. For example, as the number of channels goes from 1 to 8, the network throughput goes from 1.3 Mbps to 4.6 Mbps, from 2.9 Mbps to 11.7 Mbps, from 5.8 Mbps to 16.86 Mbps and from 6.75 Mbps to 18.9 Mbps in case of 1, 2, 3 and 4 radios respectively. Compared with 802.11, we can see the average increase of our algorithms is respectively 45%, 36%, 30% and 25%.

B. Fairness Evaluation

To evaluate the fairness of our algorithm and 802.11, we compare the aggregate throughput of nodes starting from the border of network towards the nodes which are near the gateway. Therefore, the nodes are sorted with the order of increasing queue length. We also vary number of radios (2 and 4 radios) to show their effects on fairness evaluation. We choose the fixed number of orthogonal channels in the network $K = 8$. From Figure 4, it can be observed that the border nodes throughput of our algorithm is higher than that of 802.11. The number of nodes which are starved in case of 802.11 is significant (nearly 20 nodes). With our algorithm, the fairness has been improved much when the border nodes still can transmit the data.

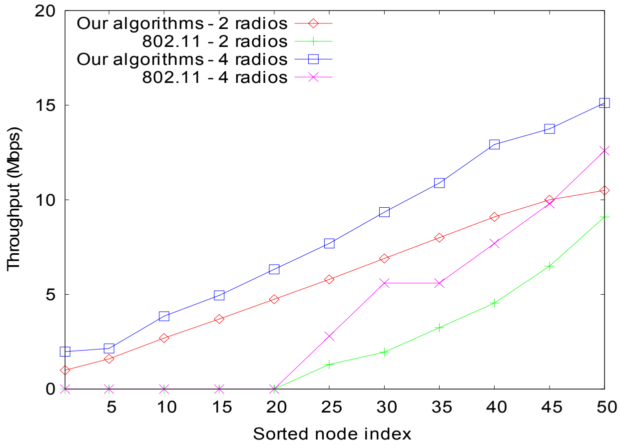

Fig. 4. Fairness Evaluation

V. CONCLUSION

In this paper, we have investigated how to schedule links fairly in WMNs by using STDMA access scheme under physical interference model. Our algorithm not only improves system throughput but also guarantees the fairness for all nodes in the system, which are proven through extensive simulations.

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