Scheduling Management in Wireless Mesh Networks*

Nguyen H. Tran and Choong Seon Hong

Department of Computer Engineering, Kyung Hee University
Giheung, Yongin, Gyeonggi, 449-701 Korea
nguyenth@networking.khu.ac.kr, cshong@khu.ac.kr

Abstract. We propose a greedy algorithm to investigate the problem of how to schedule of a set of feasible transmissions under physical interference model. We also consider the fairness in scheduling to prevent some border nodes from starvation. We evaluate our algorithm through extensive simulation and the results show that our algorithm can achieve better aggregate throughput and fairness performance than 802.11 standard.

1 Introduction

Recently, several works have focused on many typical problems of Wireless Mesh Networks (WMNs) like channel assignment, routing, scheduling [1], [2]. In literature, there are two main interference models in literature: *protocol* and *physical* interference models. 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 reuse TDMA access scheme. Moreover, since the majority of traffic is transferred to and from management nodes, traffic flows will likely aggregate at the mesh routers close to the management nodes, which connect to the Internet. 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.

2 System Models

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. Each node is equipped with one or more wireless interface cards, referred to as radios in this paper. We assume there are K orthogonal channels available in the network without any inter-channel interference. We assume the packet length is normalized in order to be

* This research was supported by the MIC, Korea, under the ITRC support program supervised by the IITA (IITA-2006-(C1090-0602-0002)).

S. Ata and C.S. Hong (Eds.): APNOMS 2007, LNCS 4773, pp. 507–510, 2007.

transmittable in a unit time slot t. 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.

Physical Interference Mode: Denoting $RSS_j^{\,i}$ as the signal strength of node j received when node i transmits to node j, and $ISS_j^{\,k}$ as interfered signal strength received by j from another node k which is also transmitting, packets along the link (i, j) are correctly received if and only if:

$$\frac{RSS_j^{\,i}}{N + \sum_{k \in V_c} ISS_j^{\,k}} \geq \alpha \tag{1}$$

where N is the white noise, V_C is the subset of nodes in V that are transmitting concurrently, and the threshold α is the constant.

Interference graph: In an interference graph [3], a node v' represents for the edge e in network graph and the directed edge between two nodes has a weight. The weight value $w_{e_2}^{e_1}$ represents for the interference contributed by e_1 to e_2 is:

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

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 if every vertex of the corresponding interference graph* $G'(V', E')$ *satisfies:*

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

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

3 Scheduling Algorithm

In this section, we present a greedy algorithm to construct a feasible schedule for a set of transmissions by investigating WMN in a subgraph for fairness characteristic. When setting 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. Second, MST of a graph defines the cheapest subset of edges that keeps the graph in one connected component. Finally, it can be computed quickly and easily, e.g. Kruskal's minimum spanning tree algorithm [5] can have the running time $O(|E|\log|V|)$. It's an important factor to reduce time complexity of our algorithm. The fair scheduling algorithm is as follows.

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

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.

4 Performance Evaluation and Conclusion

We evaluate the performance of our scheduling algorithm by comparing with the algorithm of Alicherry, et al. [2], which uses CSMA/CA whose behavior is similar to protocol interference model. We have implemented our algorithm in ns-2 (ver2.28). 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 [5] to construct the MST from the network for our algorithms.

Throughput Improvements Evaluation: 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 1, 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 algorithm is respectively 45%, 36%, 30% and 25%.

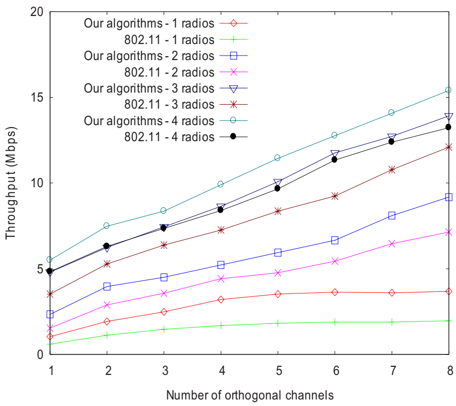

Fig. 1. Throughput Improvement Evaluation

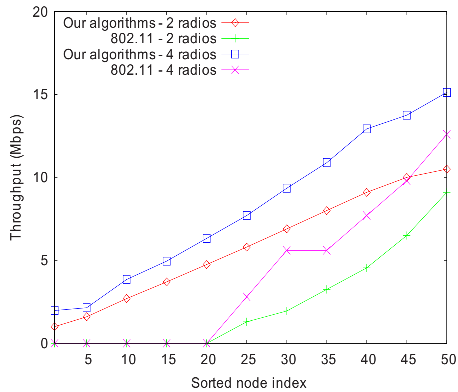

Fig. 2. Fairness Evaluation

Fairness Evaluation: To evaluate the fairness of our algorithm and Alicherry's algorithm using 802.11, we compare the aggregate throughput of nodes starting from the border of network towards the nodes which are near the management node. 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 2, 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.

References

1. Ben Salem, N., Hubaux, J.P.: A Fair Scheduling for Wireless Mesh Networks. In: WiMesh, IEEE Computer Society Press, Los Alamitos (2005)
2. Alicherry, M., Bathia, R., Li, L.: Joint Channel Assignment and Routing for Throughput Optimization in Multi-Radio Wireless Mesh Networks. In: Proc. ACM Mobicom, pp. 58–72 (2005)
3. Jain, K., Padhye, J., Padmanabhan, V., Qiu, L.: Impact of Interference on Multi-Hop Wireless Network Performance. In: Proc. ACM Mobicom, pp. 66–80 (2003)
4. Nelson, R., Kleinrock, L.: Spatial-TDMA: A Collison-free Multihop Channel Access Protocol. IEEE Trans. on Communication 33, 934–944 (1985)
5. Cormen, T.H., Leiserson, C.E., Riverest, R.L., Stein, C.: Introduction to Algorithms, 2nd edn. MIT Press, Cambridge (2001)