# Towards High-Throughput and Fair Multicast in Wireless Mesh Networks

Dimitrios Koutsonikolas, Saumitra M. Das, Sabyasachi Roy, Y. Charlie Hu
*School of Electrical and Computer Engineering*
*Purdue University, West Lafayette, IN 47907*
{dkoutson, smdas, roy0, ychu}@purdue.edu

## I. Introduction

Wireless mesh networks (WMNs) have been proposed as an efficient solution for ubiquitous last-mile broadband access. In order to become a viable last-mile technology, WMNs must compete with existing broadband technologies, such as cable and DSL. In particular, WMNs have to meet two performance criteria: to provide **high throughput** in order to meet the ever-growing demand of network applications, and to guarantee **fairness** among different clients who usually pay the same flat rate for their subscriptions.

Multicast is a fundamental routing service in multihop mesh networks. It provides an efficient means of supporting collaborative applications such as video conferencing, online games, webcast and distance learning, among a group of users. In spite of its significance, there has been little work on providing high-throughput and fair multicast in WMNs. For example, all routing algorithms proposed for multicast in wireless networks use minimum hopcount as the routing metric, as opposed to unicast routing. Moreover, there is no experimental work on providing fairness among multicast members in a multihop wireless network.

This thesis aims to fill this gap. We study *how to increase throughput and provide fairness among multicast members in a typical WMN environment with interference and fading present.*

We will tackle the problem in three steps:

- First, we study the design of link quality-based metrics for high-throughput multicast in WMNs.
- Second, we will develop a MAC layer solution for improving fairness and throughput for multicast in WMNs. We have proposed *Interference Aware Fair Scheduler* (IAFS), a TDMA-based MAC layer solution which aims to reduce the unfairness caused due to interference among multicast members of a WMN, while exploiting spatial reuse for high throughput.
- The final step of this thesis is to implement an architecture that will achieve a high-throughput, fair service for multicast clients in WMNs, by combining our work both at the routing and at the MAC layer.

## II. Published and Submitted Work

### A. High-Throughput Multicast Routing Metrics

The first step in the proposed thesis work is to design high-throughput link quality-based metrics for multicast in WMNs. We have completed this step with the results published [1]. To our best knowledge, this is the first study on high-throughput routing metrics for multicast in WMNs.

In designing high-throughput metrics for multicast, one potential approach is to simply adopt the existing unicast routing metrics. However, multicast routing is inherently different from unicast routing in the way the link layer handles data packets. In particular, while unicast routing protocols use unicast to send data packets at the link layer, most multicast routing protocols use broadcast at the link layer for disseminating data packets. The fundamental difference between link layer broadcast and link layer unicast is that the former has no RTS/CTS and no link layer acknowledgments. This difference has two immediate implications on multicast routing: (1) the link quality that matters is *unidirectional*; and (2) each node has only *one chance* to properly transmit a data packet at the link layer since there are no retransmissions.

Our study consists of two steps. First, we showed how to adapt routing metrics initially proposed for unicast for use in multicast routing protocols, based on the above differences between multicast and unicast. We adapted five routing metrics, namely ETT [2], ETX [3], Packet Pair (PP) [4], Multicast ETX (METX) and Success Probability Product (SPP) (adapted from two energy-efficient metrics in [5], [6]).

Second, we comparatively studied the performance of these five metrics through extensive simulations and testbed experiments. For our evaluation we used ODMRP [7], a state-of-the-art multicast protocol. Our simulation study shows that ODMRP equipped with any of the link quality-based routing metrics can achieve higher throughput than the original ODMRP and SPP and PP achieve the highest gain (up to 34%).

### B. Interference-Aware Fair Scheduling for Multicast

This section summarizes our current work on an Interference-Aware Fair Scheduling (IAFS) for multicast in WMNs (under review at the Elsevier Journal on Parallel and Distributed Computing). IAFS is a TDMA-like MAC layer for multicast, consisting of a measurement-based interference model and an interference-aware scheduler that assigns transmission time slots to forwarding nodes in the multicast tree(s) while maximizing the spatial reuse for high throughput. To our best knowledge, we are the first to incorporate measurement-based interference awareness in a scheduling algorithm and study fairness in multicast in a realistic environment.

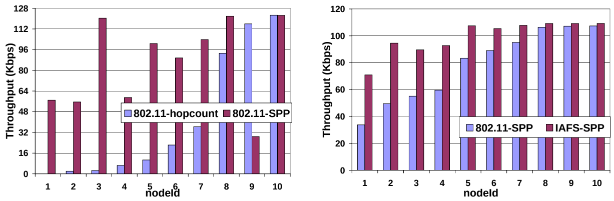


Fig. 1. Throughput comparison of two multicast trees with 10 multicast members in a 50-node WMN. (a) a hop-count and an SPP-based tree both using 802.11. The source sending rate is 128Kbps. (b) two SPP-based trees using 802.11 and IAFS. The source sending rate is based on the cycle length of IAFS's computed schedule.

Although in our previous work we showed that high-throughput metrics can improve throughput significantly compared to the widely used hop-count metric, one significant problem – unfairness among different members of a multicast session – remains unsolved. As an illustration, Figure 1(a) plots the throughput achieved by the 10 members of a multicast session when the metric used to construct the multicast tree is hop-count and SPP, respectively. With the hop-count metric, 5 members totally starve, achieving throughput between 0 and 10 Kbps. Although SPP offers significant throughput improvement for 9 out of 10 members, significant unfairness remains: some receivers have throughput as high as 122 Kbps and others have throughput as low as 30 Kbps.

In this work, we propose IAFS as a first attempt to solve this problem. IAFS consists of the following three components:

*a) Tree construction:* Since the problem of joint tree construction and scheduling is NP-hard, in this work we decouple the two problems. For the tree construction, we use the SPP metric which was shown in [1] to give the highest throughput among the five metrics we examined.

*b) Interference model:* In IAFS we use measurement-based interference models, similar to the ones proposed in [8]. Since multicast forwarders use MAC layer broadcast to send data packets, the interference of interest in IAFS is *between nodes* as opposed to *between links* in [8].

*c) Scheduling algorithm:* Our scheduling algorithm is based on spatial TDMA [9], and consists of three phases: compatibility matrix (CM) construction, clique enumeration, and clique selection. These phases are similar to [10] but adapted for multicast. For clique selection, we propose a heuristic called Least Overlapped First (LOF).

Our simulation study show that our solution significantly increases fairness compared to the 802.11 protocol: (1) without fading (ideal environment), IAFS achieves perfect fairness among multicast receivers; (2) with fading, IAFS achieves close to perfect fairness among multicast receivers; and (3) IAFS gives much better tradeoff than 802.11 between throughput and fairness, by allowing weakly interfering nodes to transmit simultaneously. As an example, Figure 1(b) shows the throughput achieved by the 10 members of a multicast session in an SPP-based tree, when the MAC layer is 802.11 and IAFS, respectively.

## III. Proposed Future Work

*a) IFAFS: An interference and fading-aware fair scheduling:* We have observed that in general, in spite of not taking fading explicitly into account, IAFS is able to achieve close to perfect fairness in realistic environments with fading. However, there are some cases where fading can have a severe impact on the performance of IAFS. In our future work, we plan to take such cases into account into our scheduling algorithm.

*b) Supporting multi-rate multimedia multicast in WMNs:* Current MAC protocols such as 802.11 support only one rate for multicast. In the future, it is possible that many multimedia applications will require higher data rates. We plan to modify our architecture to support multiple data rates. Such an extension introduces an interesting rate-range tradeoff for TDMA-based MAC layers: a higher rate can potentially increase throughput, but it reduces the transmission range, resulting in larger trees, and consequently longer cycle lengths. On the other hand, a lower transmission range also reduces interference which can possibly allow for more concurrent transmissions in a larger tree, thus reducing the cycle length.

*c) Implementation and evaluation of the proposed architecture on MAP:* The final goal of the thesis is to implement and extensively evaluate the proposed architecture on the MAP testbed [11]. Our work on IAFS described in Section II-B includes a preliminary implementation study at the application layer, which introduces many inefficiencies. In our future work, we plan to remove these inefficiencies by implementing IAFS at the MAC layer. Other issues that we need to deal with for a complete solution include propagation of the schedule and time synchronization of mesh routers.

## Acknowledgment

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