Data Overhead Impact of Multipath Routing for Multicast in Wireless Mesh Networks

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***Abstract*—Multipath routing has been proved effective in mobile ad-hoc networks (MANETs) for coping with link failures resulting from node mobility. In wireless mesh networks (WMNs) where routers are generally static, the traffic carried by the backup paths may adversely impact other flows and the multicast group itself, because these paths increase the number of transmissions and thus the level of interference and congestion in the network. This impact, however, has not been examined, especially for multicast routing. We present simulation results that quantify the impact of data overhead of multicast multipath routing compared with single-path routing.**

***Keywords*-Multicast routing, multipath routing, wireless mesh networks, performance evaluation, shortest path trees, shortest pair of disjoint paths, minimum cost trees.**

I. Introduction

Wireless mesh networking is an emerging technology that supports many important applications such as Internet access provisioning in rural areas, municipal and metropolitan networking, ad hoc networking for emergency and disaster recovery, security surveillance, and information services in public transportation systems. The mesh routers in a WMN are static and provide multi-hop connectivity from one host to another, or to the Internet via the access points.

Multicast [1] is a form of communication that delivers information from a source to a set of destinations simultaneously in an efficient manner. Important applications of multicast include distribution of financial data, billing records, software, and newspapers; audio/video conferencing; distance education; and distributed interactive games.

There are two fundamental multicast routing approaches [1]: shortest path tree (SPT), which minimizes the cost of the path from the source to each receiver, and minimum cost tree (MCT), which minimizes the cost of the entire tree. The tree cost can be defined as the sum of the edge costs (i.e., minimum Steiner tree [2], [3]), or in multi-hop wireless networks, the total number of transmissions incurred by a multicast data packet [4]. Our recent work shows that SPTs give better multicast performance in WMNs than MCTs [5], [6].

Zhao et al. proposed the use of two paths between a source and a destination in SPTs to enhance the reliability of data delivery in case of link or node failures [7], [8]. Multipath routing has been proved effective for mobile ad-hoc networks (MANETs) in terms of fault tolerance because of node mobility [14], [15]. When a node moves and breaks a route, data packets can be delivered via an alternate route. In WMNs where routers are typically static, the traffic carried by the backup paths may adversely impact other flows and even the multicast group itself, because these paths increase the number of transmissions and thus the level of interference and congestion in the network. This impact, however, has not been examined, especially for multicast routing.

In this paper, we present simulation results that quantify the impact of data overhead of multipath routing for multicast in WMNs. Specifically, we compare the performance of single-path routing in SPTs computed by the Dijkstra's algorithm with double-path routing trees produced by Zhao et al.'s minimal disjoint mesh (MDM) algorithm [7]. The MDM algorithm performs the following steps for each destination repeatedly: (1) applying the Suurballe's algorithm [9] to find a pair of node-disjoint paths between the source and the destination with the minimum total edge cost; and (2) setting the costs of the edges on these two paths to zero so that these edges will be more likely to be chosen for the next destinations' paths. The purpose of step 2 is to exploit the wireless broadcast advantage: in a broadcast medium, the transmission of a multicast data packet from a given node to any number of its neighbors can be done with a single data transmission [7]. Therefore, if a node is already in the multicast tree, it should be given priority to be chosen again for future paths in order to minimize the number of transmissions in the tree.

The performance comparison is based on meaningful and useful metrics such as average packet delivery ratios of multicast groups and background unicast flows, and average end-to-end delay of multicast packets, which is an important metric for real-time applications.

The remainder of this paper is organized as follows. We first describe our simulation setting and the performance metrics in Section II. In Section III, we present experimental results that compare the performance and traffic overheads of multicast trees constructed by the SPT and MDM algorithms. Finally, we outline our future work and conclude the paper in Section IV.

II. Experiment Parameters

Our experiments were carried out using QualNet simulation software [10]. The following metrics are used to evaluate the SPT and MDM algorithms:
– *Average multicast packet delivery ratio*. The packet delivery ratio (PDR) of a receiver is the number of data packets actually delivered to the receiver versus the number of data packets supposed to be received. The average PDR of a multicast group is the average of the PDRs of all the receivers in the group.
– *Average end-to-end delay*. Packet end-to-end delay is an important metric in real-time applications. The end-to-end delay of every multicast packet received at every receiver is recorded; the average over all the packets received is then computed.
– *Average unicast packet delivery ratio*. To measure the impacts of multicast data traffic on the unicast flows in a network, we recorded the PDR of every unicast flow and then took the average over all the unicast flows.

Our simulation models a medium-size network of 100 wireless routers (nodes) uniformly distributed over a 2000m x 2000m area. The edge cost or the cost of each wireless link is assumed to be one. The list of parameters is given in Table I. We did not implement flow or congestion control in order to test the network performance under very high loads.

Each multicast group has one sender. The multicast group size, number of unicast flows and senders' rates are specified for each experiment (see Table I). The multicast and unicast senders and receivers were selected randomly. We assume that each sender or receiver is connected to a *different* wireless router. (In practice, there can be many hosts communicating with a wireless router, e.g., to form a wireless local area network.) All receivers of a multicast group joined at the same time and stayed until the whole group terminated.

Each data point in the graphs was obtained from one configuration and 10 runs using different randomly generated seed numbers. The collected data were then averaged over the 10 runs. The duration of each experiment (each run) was 700 seconds of simulated time. All the graphs were plotted with a confidence interval of 95%.

To confirm the results reported in this paper, we created two more configurations for each data point by changing the node placement in the network as well as unicast and multicast senders and receivers, and repeated the experiments. The results from these configurations are consistent with those presented in this paper.

Parameter	Value
Network size	100 nodes, 2000m x 2000m area
Path loss model	free space for distances below 250m two-ray for distances of 250m or longer
Path loss model	two-ray propagation [11]
Router transmission power	20dBm [12]
Router reception sensitivity	-88dBm [12]
Router transmission range	395m
Trx rate at physical layer	11Mbits/s [12]
Physical layer protocol	PHY802.11b
Medium access control (MAC)	MAC802.11 with DCF
MAC for multicast flows	CSMA/CA
MAC for unicast flows	CSMA/CA & RTS/CTS/DATA/ACK
Unicast routing protocol	AODV [17]
Packet size (excluding header)	512 bytes
Queue size at routers	50 Kbytes
Queuing policy at routers	First-in-first-out (FIFO)
Traffic model of sources	Constant bit rate (CBR)
Duration of each experiment	700s of simulated time
Number of runs per data point	10
Confidence interval	95%
Function of group size (section III-A and Fig. 1)	multicast source rate 60 pkts/s, 10-60 receivers, 20 unicast flows, 2 pkts/s per flow (40 pkts/s in total)
Function of multicast rate (section III-B and Fig. 2)	multicast source rate 10-80 pkts/s, 40 receivers, 20 unicast flows, 2 pkts/s per flow (40 pkts/s in total)
Function of unicast traffic load (section III-C and Fig. 3)	multicast source rate 50 pkts/s, 20 receivers, 40 unicast flows, total unicast load 40-180 pkts/s

Table I
EXPERIMENT PARAMETERS

III. Experimental Results

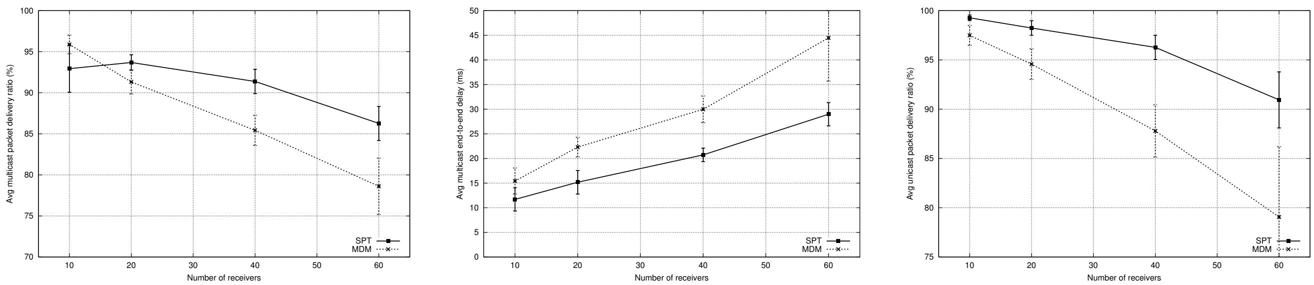
We conducted three sets of experiments by varying (1) the multicast group size (or the number of destination routers), (2) the sending rate of the multicast source, and (3) the total traffic load of the unicast flows. These various scenarios allow us to obtain a comprehensive comparison with small and large groups as well as low and high traffic loads.

A. Performance as Function of Group Size

The group size was varied from 10 to 60 receivers. The multicast source rate was set to a moderate load of 60 pkts/s. There were 20 unicast flows in the background, each sending at a rate of 2 pkts/s (or 40 pkts/s in total), a low value so that we can observe their loss rates caused by the multicast traffic rather than by the unicast flows themselves.

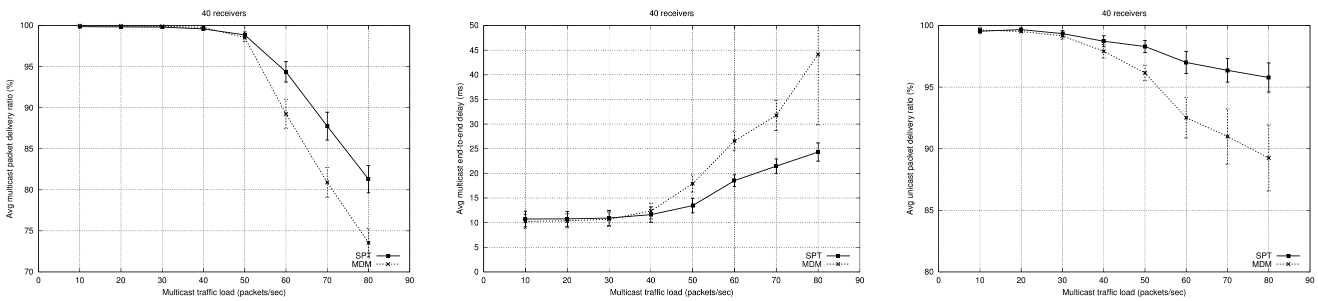
The results in Fig. 1 show that when the multicast group size is small (10 receivers), the MDM algorithm offers better multicast PDR, about 3% higher (Fig. 1(a)). When the number of receivers is low, the SPT is parse while the MDM tree is more dense thanks to more paths and thus more forwarding nodes, which provide better connectivity and thus higher PDR. However, MDM gives 32% higher average packet end-to-end delay (Fig. 1(b)) and 2% more packet loss to the unicast flows (Fig. 1(c)) than SPT in this case.

When the group size is 20 receivers or more, SPTs outperform MDM trees in all aspects. The difference is up to 8% multicast PDR and 12% unicast PDR for the 60-receiver group. MDM also gives 53% higher average end-



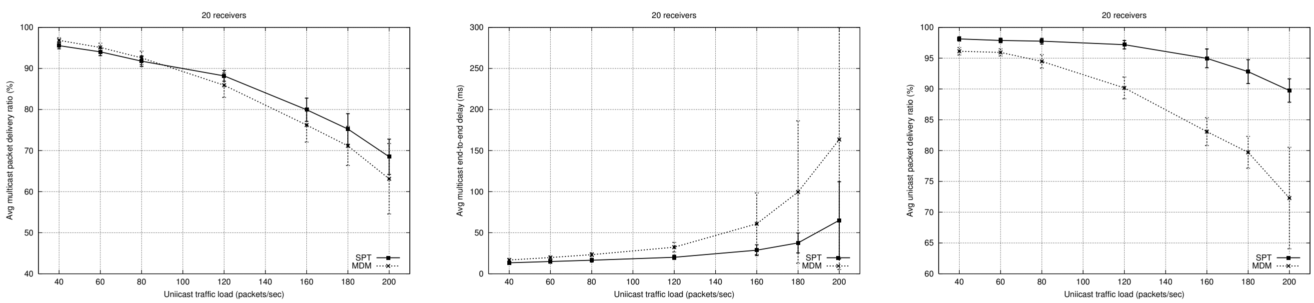
(a) Average multicast PDR (b) Average multicast end-to-end delay (c) Average unicast PDR

Figure 1. Performance as function of group size



(a) Average multicast PDR (b) Average multicast end-to-end delay (c) Average unicast PDR

Figure 2. Performance as function of multicast source rate



(a) Average multicast PDR (b) Average multicast end-to-end delay (c) Average unicast PDR

Figure 3. Performance as function of unicast traffic load

to-end delay than SPT in this case. The MDM trees use more paths than the SPTs, which create more interference and congestion in the network, degrading the performance of both the multicast group and the unicast flows. Furthermore, the larger the multicast group, the wider the difference gap between SPTs and MDM trees.

B. Performance as Function of Multicast Source Rate

In this set of experiments, the multicast group had 40 receivers, and the multicast source rate was varied from 10 to 80 pkts/s. The graphs in Fig. 2 show that under light loads (40 pkts/s or under), both SPTs and MDM trees offer similar performance. Under higher loads, SPTs again outperform MDM trees thanks to less forwarding nodes (transmissions) used. For instance, when the load is 80 pkts/s, the multicast PDR of SPTs is higher by 8%; the unicast PDR, by 7%; the end-to-end delay is 25% lower. Note also that as the traffic load increases, the performance gap between SPTs and MDM trees widens.

C. Performance as Function of Unicast Traffic Load

We increased the number of unicast flows to 40, and varied their aggregate rate from 40 to 180 pkts/s (i.e., 1 pkt/s to 4.5 pkts/s per flow). The multicast group had 20 receivers, and the source rate was set to a moderate load of 50 pkts/s. The graphs in Fig. 3 show that SPTs and MDM trees offer similar multicast PDRs and average packet end-to-end delay under light to moderate traffic loads (under 120 pkts/s). When the traffic load is high, the MDM trees offer slightly lower multicast PDR, and significantly higher end-to-end delay (up to 165% higher). Yet, the most critical result is the average unicast PDR: MDM trees cause considerably more packet loss to the unicast flows than SPT, with a difference of up to 13% (Fig. 3(c)). This results from MDM using two paths per destination, causing more interference and congestion. Note also that as the traffic load increases, the difference in unicast PDR between SPTs and MDM trees widens.

D. Summary

MDM offers comparable performance to SPT only when the group size is small or the traffic load is very light. In the other cases, MDM trees suffer from lower PDRs (by up to 8%) and higher end-to-end delay (up to 165% higher), and cause more packet loss to the background unicast flows than SPTs (by up to 13%).

IV. Conclusion

We examine the impact of multipath routing for multicast in the context of fault tolerance. Our simulation results show that double-path routing (MDM) causes considerably more packet loss and higher end-to-end delay to both multicast and unicast receivers than single-path routing (SPT) in a large number of cases (e.g., medium to large group sizes, moderate to high traffic loads). This results from the transmissions on the extra paths combined with the effect of interference in 802.11-based networks and the lack of RTS/CTS exchanges in multicast transmissions (which are needed to combat the hidden terminal problem). To more efficiently use multipath routing for recovery from node or link failures, a mechanism implemented in Cisco's Interior Gateway Routing Protocol [16] could be employed: Dual paths run a single stream of traffic in a round-robin fashion, with automatic switchover to the remaining path if one path fails. This scheme requires a more complex implementation though.

Our future work includes studies of multicast multipath routing in WMNs for improved throughput, load balancing and quality of service provisioning.

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