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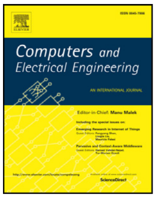

Dynamic traffic engineering for high-throughput data forwarding in wireless mesh networks

Maheen Islam[a], Md. Abdur Razzaque[a,*], Md. Mamun-Or-Rashid[a],
Mohammad Mehedi Hassan[b], Ahmad Almogren[b], Abdulhameed Alelaiwi[b]

[a] *Department of Computer Science and Engineering, University of Dhaka, Bangladesh*
[b] *College of Computer and Information Sciences, King Saud University, Riyadh, Saudi Arabia*

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ABSTRACT

High-throughput data delivery in Wireless Mesh Networks (WMNs) is a challenging problem due to dynamic changes of link quality, interference and congestion. In this work, we first develop an optimization framework for Dynamic Traffic Engineering (O-DTE) in WMNs that aims to minimize the interference and congestion at each hop through joint power and rate control so as to achieve high-throughput data delivery. Due to NP-hardness of the O-DTE framework, we then develop a greedy heuristic alternate solution (G-DTE) that enables routers, at each hop, to select outgoing links offering higher data rates and reduced interferences. Thus, the proposed G-DTE produces near optimal results by taking multi-path data forwarding decisions in distributed fashion; it exploits single-hop neighborhood information only and thus it is scalable. The simulation results, carried out in ns-3, demonstrate that the proposed G-DTE significantly outperforms the state-of-the-art works in terms of throughput, delay, reliability and fairness performances.

1. Introduction

Wireless Mesh Network (WMN) has been recently emerged as a promising technology for wireless Internet infrastructure development because of its low cost, ease of deployment and installation [1]. The increasing number of users and diversified application usages as well as the incorporation of sensors and Internet of Things (IoT) devices with the WMNs has caused exponential growth in traffic flows [2]. This increased traffic volume, however causes congestion in the network, degrading application throughput and reliability and delay performances. Therefore, how to provide satisfactory network performance, by utilizing the limited offered bandwidth, has emerged as a problem. This paper explores traffic engineering policies that dynamically adjust transmission powers and data rates over outgoing links at each router so as to enhance the network throughput.

A good number of works in the relevant literature focus on the use of emerging wireless technologies including directional antennas [1], multiple-input-multiple-output (MIMO) [3] and multichannel and multiradio [4] solutions at lower layers for increasing data delivery throughput of a network. However, none of these approaches take into account the sudden surge of huge data traffic generated from diverse user (human or device) applications, that cause network to become congested. In WMNs, mesh routers act as intermediate nodes and forward user traffic to mesh gateways (GWs) in multi-hop fashion. A WMN with a single GW might create a bottleneck condition and a single point of failure for the network

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* Corresponding author. Fax: +88-02-9667222.
E-mail address: razzaque@du.ac.bd (Md.A. Razzaque).

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[5]. The use of multiple GWs in a WMN and multipath data forwarding towards them have been proven to provide better throughput performance [6] since this strategy increases the aggregated bandwidth for certain traffic flow.

There is a significant body of works that focus on multipath data forwarding to enhance flow performance in WMNs. Those studies include discovery of node-disjoint or link-disjoint multiple paths [7], optimal power allocation to mitigate interference [8,9] and computing mutually interference-free multiple paths [6,10]. However, these end-to-end data delivery systems are less responsive to dynamic network conditions (link quality, interference, traffic demand, etc.) and thus they utilize instantaneous network capacity poorly. A central controller is deployed in [11] to find collision-free scheduling for all forwarding links using a backtracking algorithm. However, it does not consider rate adjustment in presence of varying link conditions and traffic demands. Authors in [12] propose a cross layer design approach to joint traffic splitting, rate control, routing and scheduling that splits traffic over multiple paths to enhance flow performance. The employment of a centralized controller would increase scheduling delays, cause a single point of failure and lead to wrong scheduling decisions due to obsolete information usage.

To counteract the aforementioned deficiencies, a distributed control agent is required at each forwarding router to determine outgoing link qualities and split traffic over them in a way that can maximize network performance. In this paper, we propose an optimization framework for Dynamic Traffic Engineering (O-DTE) in WMNs that aims to minimize interference and congestion and thus enhances throughput performance. The framework adopted belongs to a mixed integer nonlinear programming (MINLP) problem and involves both combinatorial and continuous constraints, making it an NP-hard problem. A greedy heuristic alternate solution G-DTE has also been developed that produces near-optimal results. The key contributions of this paper are summarized as follows:

- The traffic forwarding policies of the proposed O-DTE and G-DTE systems minimize neighborhood interference and backlogged traffic, and explore the least congested next-hop nodes so that the overall throughput of the network is maximized.
- We define a new weight function for each link based on its current achievable rate and the congestion level of the downstream. We allow a G-DTE router to prioritize the forwarding links based on their weights and to select less congestive and high-throughput links for traffic splitting.
- Each G-DTE downstream router controls the weighted-fair reception of data traffic from its upstream nodes and a high level of fairness is maintained.
- The proposed G-DTE routers exploit single-hop neighborhood information only to take traffic forwarding decisions distributedly and so make it scalable.
- Finally, the results of our simulation experiments, carried out in ns-3 [13], show that the proposed G-DTE system offers significant performance improvements in terms of throughput, delay, reliability and flow fairness.

The rest of the paper is organized as follows. In Section 2, we explore the existing works in the relevant literature; while the system model is presented in Section 3. The objective function and constraints of the O-DTE framework are formulated in Section 4 and the G-DTE system is designed in Section 5. The performance evaluation results are presented in Section 6; while Section 7 concludes the paper.

2. Related works

A good number of works in the literature is focused on throughput improvement of WMNs by exploiting diverse aspects of the network including congestion mitigation [14,15], rate adaptation [10,16], scheduling [11,12], channel allocation [17] and routing [16]; either independently or jointly [16]. Based on the number of paths over which a source node delivers data to a targeted destination, traffic forwarding paradigm appears to be either single path or multipath. A significant number of works in the literature is based on single path data forwarding [18], which is unable to fulfill flow demands in presence of neighborhood interference, poor channel condition, limited bandwidth and network congestion [11]. A source node may utilize the aggregated bandwidth available over multiple alternate paths towards destinations using multipath data forwarding approach [10,12], which is expected to provide improved throughput and transmission reliability [11].

In [6] and [7], traffic is forwarded over node or link disjoint multiple paths without considering path condition (interference, contention etc.) and path capacity (available bandwidth). The achievable bandwidth over forwarding paths is exploited in [19] and [11] for multipath data forwarding in presence of link error and neighboring interference. Proposals in [17], [19] and [20], remain traffic agnostic, i.e., they consider flow demand to be stable and known. However, this assumption is unrealistic and the aforementioned works don't react dynamically to any changes in network condition. Therefore, a control mechanism is required to adjust the traffic forwarding decisions following the dynamic behavior of the network.

In [16], link success probability (computed from historical SNR values) is exploited to control data forwarding rates on the links. The authors in [21] applied max-min fairness based rate control for incoming traffic by jointly solving scheduling, channel assignment and rate control problems. In addition, [14] addresses neighborhood-congestion and path-congestion by controlling flow rates. Unlike controlling data rates over the pre-computed end-to-end paths in the aforementioned works, selecting the least congested alternate paths at each hop toward the destination would have been a better strategy to raise the data delivery performance.

In [10], each router floods its own capacity information throughout the network and then each node autonomously determines traffic distribution on multiple paths aiming to minimize congestion. However, it causes excessive signaling overhead

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