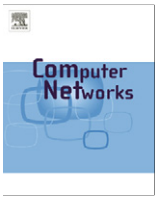
Computer Networks 55 (2011) 3694–3704

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet



Stability region adaptation using transmission power control for transport capacity optimization in IEEE 802.16 wireless mesh networks

G. Vejarano [*], D. Wang, J. McNair

Wireless and Mobile Systems Laboratory, Department of Electrical and Computer Engineering, University of zFlorida, United States

A R T I C L E I N F O

Article history:
Available online 27 May 2011

Keywords:
Power control
Transport capacity
Throughput maximization
Stability region
Wimax

A B S T R A C T

Transmission power control in multihop wireless networks is a challenging problem due to the effects that different node transmission powers have across the layers of the protocol stack. In this paper, we study the problem of transmission power control in IEEE 802.16 mesh networks with distributed scheduling. We consider the effects of transmission power control on the link-scheduling performance when a set of end-to-end flows established in the network are given. The problem is approached by means of the stability region of the link-scheduling policy. Specifically, the stability region is adapted using transmission-power control to the paths of the flows. This adaptation enables the flows to support higher levels of data traffic under lower levels of end-to-end delay. To the best of our knowledge, the approach of stability-region-based transmission power control has not been studied before. We propose a heuristic transmission-power-control algorithm for solving the problem of adapting the stability region to the flows. It is shown, by means of simulation, that the algorithm outperforms the transmission power control based on spatial reuse, which is a widely used approach. Also, it is shown that the solution of the algorithm has performance close to the optimal solution for moderate-sized networks, i.e., networks with no more than 25 nodes and 25 flows.

1. Introduction

Transmission power (TP) control in wireless multihop networks (WMNs) is an important problem due to the effects it has on the different layers of the protocol stack [1]. For example, the network connectivity, energy consumption, total physical-link throughput, spatial reuse, and total end-to-end throughput as a function of the TP have been investigated in [2–6] respectively. In this paper, we look at the problem of TP control for adapting the stability region [1] of the WMN to a given set of flows such that the total throughput and end-to-end delay are improved. Specifically, we ask the question of what are the nodes' TPs that adapt the stability region to the flows in the network when a set of source-destination pairs, the routing algorithm, and the link-scheduling policy are given.

By adapting the stability region of the WMN, the queue lengths across the network are decreased on average for a given set of input-packet rates. In this way, the flows among the source-destination pairs are able to maintain higher levels of end-to-end throughput and lower levels of end-to-end delay while guaranteeing queue stability. Therefore, the problem considered in this paper is of particular interest for applications that establish non-bursty sessions between source-destination pairs such as audio/video calls.

In order to adapt the stability region, we propose an algorithm that is executed by the flows established between the source-destination pairs. The idea behind the algorithm is to adapt a lower-bound region of the stability region (i.e., a region covered by the stability region)

---

* Corresponding author.
E-mail addresses: gavafj@ufl.edu (G. Vejarano), camelwdx@ufl.edu (D. Wang), mcnair@ece.ufl.edu (J. McNair).

[1] The stability region is defined for link-scheduling policies as the set of input-packet rates under which the queues in the network are stable (i.e., positive recurrent).

1389-1286/$ - see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.comnet.2011.03.021

by modifying the TPs. The lower-bound region is a widely accepted theoretical performance metric used for comparing different link-scheduling policies [7]. In the algorithm, once the flows' paths are determined by the routing algorithm, the flows calculate the maximum input-packet rate they can support within the lower-bound region; then, each flow tries to stretch the lower-bound region by modifying the TP of nodes surrounding it. The effect that the stretch of the lower-bound region has on the stability region is another stretch on this region. Therefore, the result is a stability region adapted to the flows that allows them to support higher input-packet rates while guaranteeing the stability of the network.

In this paper, we consider the minimum hop (min-hop) routing algorithm and the greedy-maximal reservation-based-distributed-scheduling (GM-RBDS) policy [8] in IEEE 802.16 mesh networks. However, our results can be readily extended to other WMNs, routing algorithms, and link-scheduling policies.

The rest of this paper is organized as follows. The related work and contributions are discussed in Section 2. The network model is presented in Section 3. In Section 4, our TP control algorithm is explained. The performance of the algorithm is evaluated in Section 5 by means of simulation. Finally, the paper is concluded in Section 6.

2. Related work

2.1. Link-scheduling policies and the stability region

The stability region for WMNs was first defined in [9] as the set of input-packet rates under which the queues in the WMN are stable. The stability region is defined for link-scheduling policies. Different link-scheduling policies achieve different stability regions, and it is said that a link-scheduling policy outperforms another policy in terms of throughput when it has a larger stability region. The optimal link-scheduling policy is the one whose stability region is a superset of the stability region of any other policy [9]. In terms of complexity, it is usually the case that the less complex the link-scheduling policy is, the smaller its stability region is. Therefore, based on the tradeoff between the size of the stability region and the complexity, different link-scheduling policies have been proposed in the literature [7–16]. These policies are characterized with a provable performance guarantee which is a region within the policy's stability region. That is, a set of input-packet rates is calculated for which the policy is guaranteed to be stable. The WMN may be stable under input-packet rates outside that set, but this is not guaranteed. Therefore, the stability region of the link-scheduling policy is at least as large as the calculated set of input-packet rates. We call this set the lower-bound region.

The lower-bound region depends on certain characteristics of the physical topology of the network. For example, the stability properties of the greedy maximal scheduling (GMS) [17] and the bipartite simulation (BP-SIM) [13] policies depend on the local-pooling factor and the maximum node degree of the network respectively. The local-pooling factor is a topological property of the network whose definition can be consulted in [17], and the node degree is defined as the number of links that the node belongs to.

2.2. Stability-region expansion algorithms

The main idea presented in this paper (i.e., adapting the stability region of a given link-scheduling policy by means of TP control) is based on the results obtained in [18,19]. In [18], the network is partitioned based on the notion of local pooling, and each partition is assigned to a channel of the network. In this way, the GMS policy is guaranteed to achieve the optimal stability region in each channel. In [19], network topologies are identified for which distributed link-scheduling policies achieve the optimal stability region. However, these network topologies are not suitable for real scenarios [17] because of the conditions required to guarantee the optimal stability region. These conditions include [19], 1-hop interference, 1-hop traffic, and a topology that is a graph that belongs to one of the following perfect-graph classes: chordal graphs, chordal bipartite graphs, cographs, and a subgroup of co-comparability graphs. In real scenarios, these conditions limit the suitability of WMNs. For example, only a few physical-layer technologies such as CDMA can be approximated with the 1-hop interference model, and the traffic in WMNs is multihop by definition. Also, making the topology fall within the previous graph families imposes constraints on the locations and TPs of the nodes and the available routes. The multihop traffic case was considered in [19], and it was shown that only a subset of the previous graph families guarantee the optimal stability region in the multihop-traffic scenario. These were identified as forest of stars, where every connected component of the network graph is a star graph. Also, the results in [18,19] are valid only for GMS policies under 1-hop traffic or backpressure routing-scheduling policies under multihop traffic[2].

Our approach is built upon the idea of [18,19] that under certain topologies a link scheduling policy performs better. We modify realistically the network topology using TP control to adapt the policy's stability region to the flows. The algorithm receives any set of end-to-end paths, node locations, and scheduling policy, and adapts the policy's stability region to the paths. Such an approach is beneficial because it improves the end-to-end throughput and delay without the restrictions previously discussed. In this paper, we consider the case of min-hop routing, GM-RBDS scheduling, and randomly chosen source-destination pairs of nodes in IEEE 802.16 mesh networks.

Other heuristic algorithms have been proposed in the literature that improve the performance of the link-scheduling policy in terms of throughput by means of TP control. These algorithms include the ones reported in [20–22] whose basic idea is to increase the total throughput in the network by means of spatial reuse. The spatial reuse is increased by reducing the TP of the nodes. The algorithms differ between them in the way they are adapted to RTS/CTS-based protocols. In [23,24], it is shown

---

[2] It should be noted that the objective in [18,19] was mainly to identify the topologies that enable the optimality of the GMS policy, and not to design topology-control algorithms.