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ScienceDirect
Electronic Notes in DISCRETE MATHEMATICS
Electronic Notes in Discrete Mathematics 52 (2016) 277–284
www.elsevier.com/locate/endm

Differential delay constrained multipath routing for SDN and optical networks

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Abstract

In multipath routing, maximization of the cardinality K of the disjoint-path set for a given source and destination assuming an upper bound on the differential delay D is one of the key factors enabling its practical applications. In the paper we study such an optimization problem for multipath routing involving maximization of K under the D constraint as the primary objective, and then minimization of the average end-to-end transfer delay for the fixed (maximum) K under the same D constraint. The optimization approach is iterative, based on solving an inner mixed-integer programming subproblem to minimize the delay for a given value of K and D. In order to increase the solution space, we consider the strategy of allowing controlled routing loops. Such a technique is implementable in software defined networks and optical networks. We present numerical results illustrating the gain achieved by using controlled loops in comparison with the traditional loop-free approach.

Keywords: multipath routing, differential delay, loops, integer programming

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http://dx.doi.org/10.1016/j.endm.2016.03.037

1 Introduction

Multipath (MP) routing is a network functionality controlling splitting of the data flow from a source to a destination among multiple paths, and reconstructing it at the destination as a single flow, prior to being delivered to an upper layer. In SDH networks, for instance, the MP VCAT technique allows for a better utilization of network resources [3]. In optical transport networks (OTN), MP can be exploited to drastically decrease the amount of bandwidth reserved for protection [7]. In another context, MP is used by the Multipath Transport Control Protocol (MPTCP) [5] to augment the throughput of the TCP-based applications in a transparent way, i.e., without modifying the applications and yet preserving backward compatibility with TCP.

Today's networks generally offer MP capability, but the common networking practice seldom exploits this. One of the major obstacles is the data reconstruction operation at the destination: if significant differences in the delays occur between the paths of the MP set, the reconstruction buffer has to be increased in size and the reordering task becomes time consuming. Consequently, the quality of the service delivered over the MP connection starts degrading, causing users experiencing unacceptable waiting times to receive the data (e.g., in conversational or gaming applications) or – even worse – an unexpected bursty-mode operation (e.g., in video streaming). Another issue is related to routing: MP improvements in terms of throughput, load balancing, reliability and protection bandwidth are all fully achievable only provided that the paths of the MP are link disjoint. For example, it was proven that the TCP performance can be enhanced by MPTCP only if physical path-disjointness is enforced [4]. In a highly loaded network the throughput of the MP connection will increase as the number of paths K grows.

The problem of Differential Delay Routing (DDR) was first studied by [1] and [3] for the Ethernet over SONET architectures. The DDR problem was defined as follows: given a graph $\mathcal{G}(\mathcal{V}, \mathcal{E})$, find K paths of unit capacity from source S to destination T such that their differential delay D is upper bounded by a given constant Δ. D is defined as the maximum end-to-end delay difference between the K paths of the MP set. Link disjointness was not considered in that DDR problem. More recently, the work presented by Sheng *et al.* [7] included link disjointness as a constraint. However, the authors relied on heuristics to solve the problem, as DDR (and consequently DDR with disjointness) is NP-hard [3].

In this paper we extend the previous work by redefining the problem as follows: (a) find a set of K link-disjoint paths from source S to destination