Decentralized Optimal Traffic Engineering in the Internet *

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ABSTRACT

Distributed optimal traffic engineering in the presence of multiple paths has been found to be a difficult problem to solve. In this paper, we introduce a new approach in an attempt to tackle this problem. This approach has its basis in nonlinear control theory. More precisely, it relies on the concept of Sliding Modes. We develop a family of control laws, each of them having the property that the steady-state network resource allocation yields the maximum of the given utility function, subject to the network resource constraints. These control laws not only allow each ingress node to independently adjust its traffic sending rate but also provide a scheme for optimal traffic load redistribution among multiple paths. The only nonlocal information needed is binary feedback from each congested node in the path. Moreover, the algorithms presented are applicable to a large class of utility functions, namely, utility functions that can be expressed as the sum of concave functions of the sending rates. We show that the technique can be applied not only to rate adaptive traffic with multiple paths, but also to assured service traffic with multiple paths. Preliminary case studies show that this technique is potentially very useful for optimal traffic engineering in a multiple-class-of-service and multiple-path enabled Internet, e.g., differentiated services enabled multi-protocol label switching networks.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design

Keywords

Traffic Engineering, Distributed Control, Sliding Modes, Nonlinear Control, MPLS

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1. INTRODUCTION

The focal point of this paper is a network (e.g., an autonomous system) which has several paths available for routing flows between edge node pairs. The objective is to provide distributed control algorithms that will accommodate incoming traffic in an optimal way.

Network traffic management and control have become increasingly important as the Internet evolves into a global commercial communication infrastructure. The increase in complexity leads to the need for the development of the so-called automated Traffic Engineering (TE). TE improves network resource utilization and thus leads to an increase of revenue as well as satisfaction of diversified application requirements. As value-added services are being added to the Internet, TE algorithms should be able to address not only elastic Classes of Service (CoSs) but also inelastic CoSs in the presence of multiple paths.

Different methodologies have been proposed for TE. In [1], TE methodologies are classified into two basic types: time-dependent and state-dependent. In time-dependent TE, traffic control algorithms are used to optimize network resource utilization in response to long time scale traffic variations. They make no attempt to adapt to random short term traffic variations or changing network conditions. An example of time-dependent algorithm is the optimization-based centralized control algorithm proposed by Mitra, et al. [2]. In [2], the TE problem with multiple CoSs and multiple paths is formulated as a multi-commodity linear programming problem under the assumption that global information is available.

In contrast to time-dependent TE, in state-dependent TE, traffic control algorithms adapt to relatively fast network state changes. An example of state-dependent TE that operates in a relatively long time scale is constraint-based routing; e.g., see [3]. An example that operates in a relatively short time scale is load-balancing among multiple paths; e.g., see [4]. Our paper focuses on the state-dependent methodologies and explores the control issues for *globally optimal TE* in the presence of both multiple CoSs and multiple paths.

1.1 Decentralized Traffic Engineering

It has been widely recognized that there should be a development of distributed traffic control mechanisms for state-dependent TE which can quickly react to changes of the