

Maximum Entropy Based One-Way Delay Estimation

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Abstract

We present a novel approach for the estimation of one-way delays between neighboring nodes without requiring any time synchronization in the network. The approach is based on the maximum entropy principle and is taking into account the asymmetric nature of the network and links, and the fact that traffic flows are not necessarily the same in both directions. Our approach is based on conducting multiple and simple delay measurements among multiple neighboring pairs of nodes, and estimating the one-way delays by maximizing the value of an objective function (entropy based) and by exploiting the graph topology. The procedures described in the paper provide estimation for both the fixed part (i.e., propagation) and the variable part (i.e., queueing) of a link one-way delay. These procedures are easy to implement and require only minor modifications in the algorithms and message formats already used in the Internet. Numerical examples show the advantages of the proposed estimation schemes.

Keywords

Mathematical optimization, network measurements, delay estimation, one-way delay, maximum entropy.

I. INTRODUCTION

Accurate measurements and adequate analysis of network characteristics are essential for robust network performance and management. Such real-data analysis plays a key role in network design and in the control of its dynamic behavior. One of the most important network performance quantities is the delay as it strongly influences the configuration and performance of network protocols such as routing and flow control and network services such as voice and video over IP. Delay measurements are common in such networks. For example, ad-hoc networks use delay measurements for the estimation of pair-wise distances between group members that are needed for the routing layer [1],[2]. Furthermore, continuous monitoring of the delay is essential in many applications in order to check compliance with critical delay constraints.

For many essential applications the quantity of interest is the one-way delay between a source and a destination rather than the round-trip delay. This is motivated by several factors [3]. In many networks the path from a source to a destination may be different from the path from the destination back to the source (asymmetric paths). Measuring each path independently highlights the performance difference between the two paths which may traverse radically different types of networks. Even when the two paths are symmetric, they may have different performance characteristics due to asymmetric loads or different QoS provisioning. Performance of many applications depends mostly on the performance in one direction. For example, a file transfer performance depends more on the performance from the source to destination. A typical client server transaction depends more on the quality of the path from the server to the client. Finally, for voice and video conferencing each unidirectional path is responsible for timely delivery.

The basic difficulty of measuring one-way delays is that clocks in a network are not tightly synchronized. Obviously, if clocks in the network were synchronized the task of measuring one-way delays would be simple: one end node sends a probe packet with its time stamp on it; the difference between the arriving time and the transmission time is the one-way link delay. Global Positioning Systems (GPS) provide accurate time synchronization; unfortunately GPS are scarce in computer networks. Moreover, an embedded GPS requires continuous reception of multiple satellites which is hard to accomplish indoors or at secured data centers.

Network Time Protocol (NTP) is the current standard for synchronizing clocks on the Internet [4], [5], [6]. NTP is designed to synchronize clocks in a network with respect to Universal Time-Coordinated (UTC). NTP is based on symmetric link models, and even for these models it gives only a good estimate regarding the