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Reflective network tomography based on compressed sensing

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Abstract

Network tomography means to estimate internal link states from end-to-end path measurements. In conventional network tomography, to make packets *transmissively* penetrate a network, a cooperation between transmitter and receiver nodes is required, which are located at different places in the network. In this paper, we propose a *reflective network tomography*, which can totally avoid such a cooperation, since a single transceiver node transmits packets and receives them after traversing back from the network. Furthermore, we are interested in identification of a limited number of bottleneck links, so we naturally introduce compressed sensing technique into it. Allowing two kinds of paths such as (fully) loopy path and folded path, we propose a computationally-efficient algorithm for constructing reflective paths for a given network. In the performance evaluation by computer simulation, we confirm the effectiveness of the proposed reflective network tomography scheme.

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Keywords: Network tomography; Compressed sensing; Implementability; Asynchronism

1. Introduction

Tomography refers to the cross-sectional imaging of an object from either *transmission* or *reflection* data collected by illuminating the object from many different directions[1]. When the object is an information network, it is called *network tomography*[2], which has been used to encompass a class of approaches to infer the internal link states from end-to-end path measurements[3]. The end-to-end path behaviors have been *transmissively* measured via a cooperation between transmitter and receiver nodes, which are located at different places in a network. However if it is possible to eliminate such a cooperation, network tomography would become a more powerful method with special properties such as *implementability* and *asynchronism* for measuring and analyzing network specific characteristics.

In this paper, according to the types of end-to-end path measurements acquisition, we first classify network tomography into *transmissive* and *reflective* network tomography, and after discussing their characteristics, we propose a new reflective network tomography scheme. Here, in the reflective network tomography scheme, we focus only

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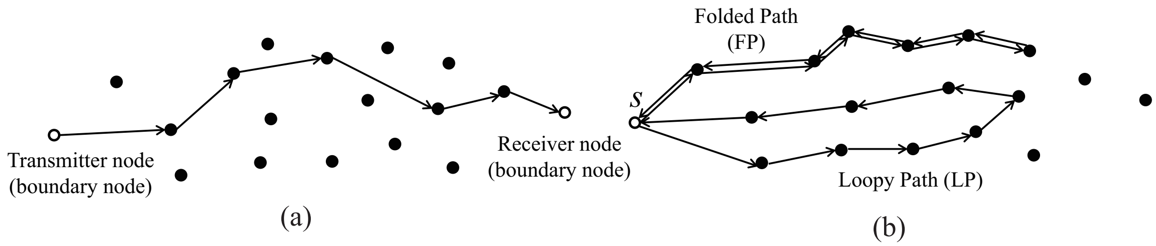

Fig. 1. (a) Transmissive end-to-end path measurement. (b) Measuring PTTs based on *s*.

on identification of a limited number of links with large delays in a network, where such links are referred to as *bottleneck links*. In this scheme, a node acts as both a transmitter and a receiver, i.e., as a transceiver: it transmits multiple packets over a network along pre-determined different paths and receives the packets after they traverse back from the network. On the other hand, network tomography is formulated as an undetermined linear inverse problem, which cannot be always solved. However, the assumption in the bottleneck link identification makes it possible to use compressed sensing technique. To propose the new reflective network tomography scheme, we tackle two problems: how to formulate the tomography scheme and how to determine *going around* paths from/to a transceiver node.

2. Network Tomography

2.1. Transmissive Network Tomography

In this subsection we define transmissive network tomography via some examples[4,5,6,7,8,9] which are characterized by *transmissive end-to-end path measurements*. Fig. 1(a) shows an example of a transmissive end-to-end path measurement[4]. In a network with a defined boundary, it is assumed that access is available to nodes at the boundary, but not to any in the interior. In order to get transmissive end-to-end path measurements, some boundary nodes are selected as *transmitter* and *receiver* nodes. For example, Takemoto *et al*[4] assigned two nodes as a transmitter and a receiver respectively, whereas Firooz *et al*[5] used many transmitter and receiver nodes. The transmitter nodes send probe packets to all (or a subset of) the receiver nodes to measure packet attributes on the paths between them. Accordingly, each probe packet transmissively penetrates the network along a *measurement path*, and brings a transmissive end-to-end path measurement. Coates *et al*[6] proposed a transmissive tomographic methodology based on unicast communication. In works by Cascares *et al*[7] and Bu *et al*[8], on the other hand, a single-source multicast transmission by a single or multiple transmitter nodes is applied to networks with tree and general topologies, respectively. From such transmissive end-to-end path measurements between transmitter and receiver nodes, the internal network states such as link-level network parameters can be estimated. For example, in work by Duffield *et al*[9], link delay variance is estimated from transmissive end-to-end path measurements in a multicast setting.

2.2. Reflective Network Tomography

Unlike transmissive network tomography, reflective network tomography eliminates the need for special-purpose cooperation from receiver nodes. Namely, an end-to-end path measurement is calculated from records on only one node. A boundary node is selected as a *transceiver* node, and it injects probe packets into the network. Each probe packet goes back to the transceiver node along a different measurement path, and brings *reflective end-to-end path measurements*. For example, Tsang *et al*[10] proposed a reflective network tomography scheme based on round trip time (RTT) measurement only along a folded path (see 4.2 for its definition) to estimate the delay variance for a link of interest. Thus, in contrast to transmissive network tomography, reflective network tomography is defined by *reflective end-to-end path measurements*.