East Asian Journal on Applied Mathematics
doi: 10.4208/eajam.2022-330.120623

Vol. **14**, No. 1, pp. 179-194
February 2024

A Round Trip Time Weighting Model for One-way Delay Estimation

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Received 23 November 2022; Accepted (in revised version) 12 June 2023.

Abstract. A new delay estimation model using a round trip time as a weight of the asymmetry of each host pair is developed. It improves the estimation accuracy and is suitable for complex wide area network architecture. For large-scale scenarios in practice, we design a symmetric Gauss-Seidel alternating direction method of multipliers. It significantly reduces memory consumption and computational cost. Numerical experiments demonstrate the accuracy and efficiency of the model and algorithm.

AMS subject classifications: 68M12, 90B18, 90C20

Key words: One-way delay estimation, clock synchronization, ADMM.

1. Introduction

In this work, we present a novel optimization model with the weighted minimum norm principle for one-way delay (OWD) estimation in wide-area networks (WANs), whose mathematical formulation is as follows:

$$\min_{\boldsymbol{x}\in\Omega} \quad \sum_{i\neq j}\frac{|x_{ij}-x_{ji}|^2}{\mathrm{RTT}_{ij}^{\alpha}}, \quad \Omega=\left\{A_{loops}\boldsymbol{x}=\boldsymbol{b}_{loops},\ \boldsymbol{x}\geq\boldsymbol{0}\right\}. \tag{1.1}$$

Here x_{ij} is the delay from node i to another node j in a particular network, and RTT_{ij} is the round trip time between them. The constraints are the observations of loop measurements and natural non-negativity of delays, inheriting from [16]. Note that model (1.1) is actually a loop estimation method using RTT weighting (LERW), in which α controls the effect of RTT in weighting.

With the continuous complexity and scale of computer networks, network performance analysis becomes intractable, bringing challenges to downstream tasks, including robust

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network design, scheduling, and congestion control. LERW provides an improved methodology for accurate OWD estimation, which is desired extremely in characterizing network performance. Informally, OWD refers to the time it takes for a data packet to be sent from one network node to another. It plays a vital role in presenting the real-time status of the network [2]. One should note that the sending is only one-way, which means OWD focuses only on unidirectional characteristics. In contrast, RTT, another standard delay metric, provides a clear view of bidirectional characteristics. It is generally believed that the measurement of OWD is more critical than that of other delay metrics, including RTT. This is because the performance of an application may greatly depend on unidirectional characteristics [2]. For example, the quality of video on demand mostly depends on the performance of the links from servers to clients. File transfer only relies on the path from sender to receiver [26]. For this reason, service level agreements (SLAs) that aim at ensuring QoS in real-time applications, such as Voice over IP (VoIP) [4], use OWD as a parameter.

However, measuring OWD directly is impossible because the clocks of hosts in the network are not synchronized [27]. This asynchrony stems from the different frequencies of the quartz crystal oscillators of hosts, which is severe in WANs. Generally, two timestamps representing the transmission time at the transmitter and the reception time at the receiver are stamped when a probe packet is sent. The clock offset causes their difference to deviate from the real OWD. The immediate idea is to achieve OWD estimation through high-precision clock synchronization, but the common methods do not work well due to fundamental limits [12]. NTP [21] is one of the oldest clock synchronization protocols, which calculates the clock offset by simply combining the four timestamps obtained from a pair of packets sent in opposite directions. It has an unsatisfying accuracy of tens of milliseconds in WANs [22], thanks to inaccurate timestamps and the unrealistic assumption that the forward and reverse delays are symmetrical. PTP, also known as IEEE 1588 [11], is another usual method for synchronization, adopting hardware timestamps to counter stack delays occurring in time stamping. It is superior to NTP and suitable for high-precision scenes. If deployed properly, it will reach an accuracy within $3.2ms$. Nevertheless, it suffers from asymmetry like NTP. GPS is the most reliable clock synchronization method, providing the highest clock synchronization accuracy [27]. Unfortunately, unique hardware and high expense hinder its application on the Internet, making it impractical to synchronize using GPS.

A novel method called loop estimation for OWD measurement without clock synchronization was proposed by Gurewitz *et al*. [15–17], who suggested considering the OWD measurement as an optimization problem. They offered to perform measurements along loops to form an underdetermined system of equations with OWDs as variables. Then a convincing optimization model aiming to minimize the asymmetries of all node pairs was proposed to help select a solution in the colossal solution space, taking the form of LERW with $\alpha = 0$. For the sake of distinction, we shall hereafter call it LE. Benefiting from a great deal of information provided by loop measurements, LE works remarkably in multiple network architectures, far superior to previous methods. Considering its excellence, one did some transformations later and then applied it to the last step of the Huygens algorithm, a recognized clock synchronized method for local area networks (LANs) in industry [13].