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An end-to-end measurement and monitoring technique for the bottleneck link capacity and its available bandwidth

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ABSTRACT

An efficient and accurate measurement technique for the network bandwidths information can be utilized for various areas including the application layer services improvement, congestion control and for the network administration support. For these purposes, we propose an end-to-end measurement and monitoring technique for the bottleneck link capacity and its available bandwidth. This novel technique based on a new packet-pairs scheme figures out and utilizes the path signatures and sampling of the cross traffic density, through which both bandwidth metrics can be obtained from the same measurement data. This feature enables us to measure multi-metrics in a single measurement framework, reducing the probe overhead and the measurement time without causing congestions. We used ns-2 simulations and Internet measurements for the bottleneck link capacity and simulation comparisons for the available bandwidth to evaluate the performance of our proposed methodology. The results showed a high level of accuracy and a short probe time with very low intrusiveness, providing the capability of estimating the dual bandwidth metrics.

1. Introduction

The network administrative operations and the application-layer services that have been widely deployed may get benefits from the end-to-end network status information. Application layer services such as the overlay networks and P2P systems can probe the traffic paths between their end nodes, searching for the paths that have larger link capacity than others. In addition to the capacity aspect, estimating and monitoring the available bandwidth and detecting the occasional route changes may also be useful for more reliable assessment of the end-to-end network paths status.

The scopes of network measurements range from a simple distance-only metric to the complex standard QoS metrics such as the loss rate, latency and network bandwidths, and the most critical metrics are often the bottleneck link capacity and the available bandwidth. So far, the methods for measuring the bottleneck link capacity have been based mainly on the principle of the packet-pair dispersion, which represents the transmission time of a probe packet into the network. On the other hand, the available bandwidth has been estimated commonly through the packet train intrusions into the network to assess the amount of additional traffic rate that can cause a congestion state, at which the probe rate would be the available bandwidth. In this way, the bottleneck link capacity and the available bandwidth have been measured by separate methods, and no light-weight and efficient method is available yet for estimating both bandwidth metrics using a single measurement framework, without causing repeated congestions on the network path.

Our new methodology, SigMon, can support the capability of measuring both of the bottleneck link capacity and its available bandwidth on a path that has up to a few bottleneck links, using a single measurement

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framework. It is based on the packet-pairs having the specific pattern of the linearly increasing intra-pair gaps. This new scheme is a novel design compared to the traditional back-to-back packet-pairs for the link capacity measurements by the following reasons. The traditional back-to-back packet-pairs generate output dispersions which do not have orders or bounds among them, so that many packet-pairs for finding statistical modes or a specialized algorithm for detecting the preferable target dispersion are required. But, the former approach needs heavy probing overhead and the latter approach occasionally fails to select the desired target dispersion under high speed networks. In our new scheme, if non-interfered by the cross traffic packets, a group of packet-pairs that have input intra-pair gaps smaller than the bottleneck link dispersion of a probe packet will have all the same output dispersion gaps, by expansion to the magnitude of the bottleneck link packet-pair dispersion. The other group of packet-pairs with larger input intra-pair gaps will have the output gaps which are same to their input gaps in an ideal case. So, this scheme can be modeled as a system with the specific input–output relationships, where a turning point or breakpoint can be generated on the input gaps vs. output dispersions spectrum by the above two groups. In addition, a rich set of geometrical and mathematical properties can be derived even from a small set of measurements data, and those properties can be utilized as the delimiters for the orders and bounds in the dispersions or used as the criteria for detecting distorted dispersions. Consequently, these graphical analyses can be utilized for shaping or recovering the distorted data toward the non-interfered, theoretical dispersions. This shaping process based on the various properties is at the core of the SigMon and serves to improve the accuracy and robustness of the bottleneck link capacity estimation aspect in our methodology.

The basic aspects of estimating the bottleneck link capacity were briefly introduced in our previous work SigProbe [8], and the SigMon extends it with an additional feature of estimating the available bandwidth of the bottleneck link. Once the capacity of the bottleneck link is estimated, SigMon obtains its available bandwidth through the gap sampling-based cross traffic estimation from the same raw measurements data used for finding the bottleneck link capacity. This gap-sampling model utilizes both the intra-gaps and the cumulative queuing delays of the packet-pairs to extract the occupation portion by the cross traffic packets within the sampling time window. So, the main contribution of this paper is to simultaneously estimate the bottleneck link capacity and its available bandwidth from the same measurement data using a single measurement framework. This sampling-based estimation of the available bandwidth, simultaneously with the capacity, can give significant benefits for reducing the probe overhead compared to the congestion-based approach prevailing in existing methods, and minimizing the probe traffic intrusiveness into the network. These aspects also imply that the probe speed of SigMon would be faster than the common approaches that repeatedly cause congestions to get just one effective measurement. Furthermore, our approach can detect the paths that have multiple tight links, based on examining the post-bottleneck link path status and the relative deviations by the cross traffic in the intra-pair gaps and the queuing delays.

In this paper, a few terminologies are defined for the descriptions. The bottleneck link is normally defined as two instances: the narrow link and the tight link. The narrow link is the link having minimum capacity on a network path, and the tight link is the link having minimum available bandwidth on a path. The available bandwidth is commonly defined as the unused spare portion of the link capacity during a time period. In our study, bottleneck capacity link is used as the narrow link and the bottleneck capacity link is assumed to be either the single tight link or at least one of the tight links in the case of multiple tight links on the path.

The remainder of the paper is organized as below. Section 2 describes the related works. Section 3 describes our estimation concepts and methodology for the bottleneck link capacity. Section 4 analyzes the status of the post-bottleneck link path. Section 5 elaborates the procedures that estimate the available bandwidth. Section 6 deals with the performance evaluation, and we conclude in Section 7.

2. Related work

The techniques developed so far to measure the end-to-end network bandwidths are numerous, but are based on a few principles, which can be classified into the one-packet, packet-pair and packet train techniques. The packet-pair principle based methods for estimating the bottleneck link capacity can be further categorized into two subgroups: the statistical and the pinpointing approaches. The available bandwidth has been estimated using two basic approaches: congestion by intrusion via varying rates of iterative packet trains and sampling-based approaches. These are described subsequently for each metric.

2.1. Bottleneck link capacity measurement

The statistical approach is common in the earlier works and relies on many probing packets, and the target dispersion is computed from a sharp mode. But, this approach incurs large overhead. Pathchar [1] is the unique one-packet technique for the per-hop link capacity, based on the minimum RTTs as a function of the probe packet sizes, through the linear regression. Nettimer [2] uses the kernel density estimator as the statistical filtering that can identify the dominant mode in the data. Pathrate [3] uses many packet-pairs and packet-trains to get the strongest mode from all the local modes via various probe sizes.

The pinpointing approach relies on a single data that meets specific criteria. SProbe [4] is a lightweight, fast method that uses TCP SYN packets with one large packet-pair in them. Its heuristic test detects the presence of the cross traffic packets. But, it may still have distortions in the large SYN packet-pair dispersion when the utilization is high. CapProbe [5] combines the dispersion and delay of the two packets in each packet-pair to find a sample with the minimum delay sum, which can be said to have