ABdis: Approach to Estimate Available Bandwidth Distribution Using a Multi-rate Probe

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Abstract—**This paper proposes ABdis, a new active measurement method for estimating the available bandwidth on the communication network path. Many conventional active measurement methods/tools, however, can measure/estimate only the average of the available bandwidth and cannot measure its distribution. If the distribution of average available bandwidth over short interval is measured, the information is useful for network management, proxy selection and end-to-end admission control. We propose an end-to-end active measurement method called ABdis which can estimate the distribution of the available bandwidth in a network path. ABdis uses multiple different rate probes and a parameter-matching technique for estimating distribution. Furthermore, we show experimental results by simulation.**

I. INTRODUCTION

Available bandwidth (or avail-bw for short) measurements can be useful in network performance management, rate-based streaming applications, end-to-end admission control, server selection, and optimal route selection in overlay network. Techniques for estimating avail-bw can be classified into two categories: passive measurement and active measurement. Passive measurement tools use the trace history of existing data transfers. Even though they are potentially very efficient and accurate, their scope is limited to network paths that have recently carried user traffic. Active measurement, on the other hand, can explore the entire network.

Many different techniques and related software have been presented in the literature [1, 2, 3, 4, 5] as active available bandwidth measurement tools. However, they can measure/estimate only the average of the available bandwidth and cannot measure its distribution. If the distribution of average available bandwidth in a short interval is measured, the information is useful for network management, proxy selection and end-to-end admission control. For example, an administrator can manage the quality of networks using the α percentile of the distribution. (e.g., α is set to 90.) That is, the administrator can know "the worst-case quality", that is represented by a tail of the available bandwidth distribution.

We have developed an active measurement method called ABdis that can estimate the end-to-end avail-bw distribution. ABdis uses multiple different-rate probes and a parameter-matching technique for estimating distribution. One-way delays ($OWDs$) of probe streams are measured, and ABdis judges whether each OWD trend is an increasing trend, and classifies the judgement results to either 0, 1, or 0.5. A normal distribution is approximated using the least-squares method to minimize square error between the judgment result for each probing rates and the normal distribution. The normal distribution is determined as an avail-bw distribution to estimate.

In this paper, we first briefly explain conventional available bandwidth estimating methods as related works. Then we show a detailed description of ABdis, and explain it. Finally, we show the simulation results and verify the tool's effectiveness.

II. RELATED WORK

Many bandwidth estimation tools have been proposed. In this section, we show some estimation tools that focus on avail-bw.

PBM (Packet Bunch Mode) [5] is a typical active measurement tool for avail-bw. It extends the packet pair technique by using different-sized groups of back-to-back packets. If routers in the network implement fair queuing, the bandwidth indicated by the back-to-back packet probes is an accurate estimate of the "fair share" of the bottleneck link's bandwidth. ABwE (Available Bandwidth Estimator) [3] is based on the packet pair and can monitor avail-bw in the range from several Mbit/s to 1,000 Mbits/s. It can be used for detecting bandwidth changes caused by routing or congestions. Another technique, called TOPP (Train Of Packet Pair) [4], uses packet pairs of different spacing well separated in time and estimates available bandwidth from the time averaged spacing of packets at the receiver. However, it is known that this tool provides poor estimates when the path includes several queuing points. Another avail-bw mesurement technique, called Pathload [2], uses periodic streams. Pathload determines transimission rate of the next stream by the relation between avail-bw and the transmission rate of a stream it send now.

All these tools can estimate only an average of the avail-bw in the short interval. However, the traffic volume in networks changes. If we can seem that the avail-bw follows a probability distribution, the information provided by the avail-bw distribution is useful for network management, network control and so on. In this paper, we propose a new method, named ABdis, which can estimate the distribution of avail-bw.

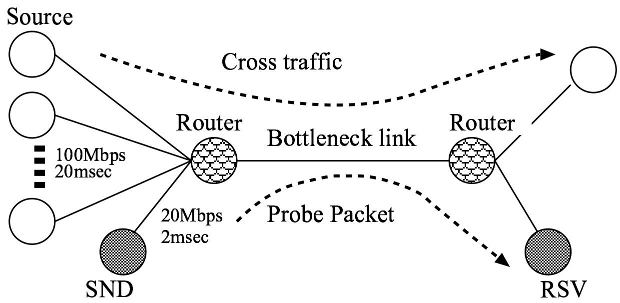

Fig. 1. Network model.

III. DISCRIPTION OF ABDIS

In this section, we first describe the basic idea of ABdis. Here, we explain its details of the method.

A. Basic idea

Suppose that SND transmits a periodic packet stream to RCV (Fig.1). The stream consists of K packets, where K is the *length* of the stream. The *size* of each packet is set L bits, and the packet transmission period is set T seconds. The transmission rate of the stream is $R = L/T$ bits per second.

SND timestamps each packet i prior to its transmission with a timestamp T_i. Let a_i be the arrival time of the i'th packet at RCV. RCV computes the relative $OneWayDelay$ (OWD) of each packet as $D_i = a_i - t_i$. Note that D_i is the OWD from SND to RCV plus/minus a certain offset θ, where θ is the clock offset between the two end-hosts. Upon the receipt of the entire stream, RCV inspects the sequence of relative $OWDs$ to check whether the transmission rate R is larger than the avail-bw A. The way we find the relation between R and A is the important idea and is described next.

When the stream rate R is larger than the avail-bw A, the stream creates a short-term overload in the bottleneck link of the path. During that overload, the bottleneck link receives more traffic than what it can transmit and so the queue at the bottleneck link gradually builds up. Consequently, the queuing delay of packet i at the bottleneck link is expected to be greater than the corresponding queuing delay of packet j where $j < i$. Thus, when $R > A$, the relative $OWDs$ of the stream packets show an increasing trend. We refer to these effects as selfloading of the periodic stream. On the other hand if the stream rate R is less than the avail-bw A, the stream will not cause an overload. As a result, when $R < A$, the relative $OWDs$ of the stream packets show non-increasing trend. In this way, we can obtain the relation between R and A. Finally, when there is no strict ordering between R and A, we refer to this third possibility as “gray-region”.

B. ABdis

We discribe an outline of the our method.

Step(1) SND sends the streams to RCV and measures the $OWDs$ of each packets.

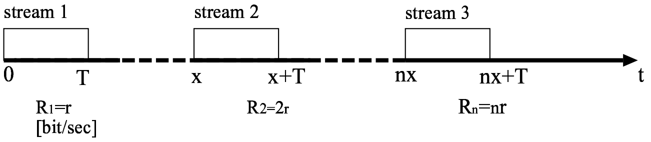

Fig. 2. Sending stream.

Step(2) RCV examines the increasing trend of each streams.

Step(3) RCV assigns each stream a judgement value $H(n)$.

Step(4) RCV estimates the avail-bw distribution using the least-squares method to minimize square error between the $H(n)$ and a normal distribution.

We show the detail of algorithm as follows. In **Step(1)**, SND sends UDP packets as the periodic packet streams (Fig.2).We use a multi-rate probe, where each stream has its own rate, for measurement.The R increase to be B from small value. The transmission rate of n-th stream is $R(n)$, and $R(n) = n \times R(1)$. Fig.2 shows the rule for sending a stream. In advance, we measure the bandwidth of bottleneck link capacity B using connection methods[10], and the first stream's rate $R(1)$ is set B/N. Each stream is transmitted periodically in every x seconds. Then, each stream must be sent after when the previous stream has been acknowledged. An idle interval must be set more bigger than one round-trip time between a pair of streams. ABdis selects packet length $L(n)$ which satisfy $R(n) = L(n)/T$, where interval T is set constant.

Packet length $L(n)$ cannot be less than a certain number of bytes and it should not be more than the path's MTU. If there is a few number of packets K in a stream, the stream will not provide RCV with enough samples to infer in a robust manner whether there is an increasing trend in the $OWDs$. In our method, we can get enough samples of $OWDs$ when R is also very small, because packet size $L(n)$ is controlled. If $R(n)$ is very large and the K is too large, the stream may flood the queue of the bottleneck link when $R > A$.

In **Step(2)**, we can find the relationship between $R(n)$ and A by detecting the increasing trend of $OWDs$ in each stream. The concrete procedure of detection is as follows. Initially, We partition the K OWD measurements to m groups of consecutive OWD measurements. Then, out of delays in each group i, we compute the median OWD D_i of the group. Next, we use two values to check if a stream shows an increasing trend. The one is a Pairwise Comparison Test (PCT) metric of a stream. S_{PCT} is calculated as

$$S_{PCT} = \frac{\sum_{k=2}^{m} I(D_k > D_{k-1})}{m-1}, \tag{1}$$

where $I(D_k > D_{k-1})$ is one if $D_k > D_{k-1}$ and zero otherwise. The PCT measures the fraction of consecutive OWD pairs. If there is a strong increase trend, S_{PCT} approaches one. PCT reports “increasing trend”

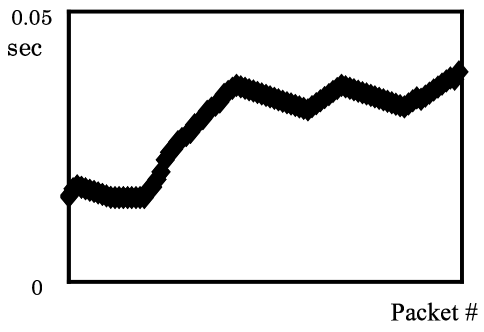

Fig. 3. OWD trend when $R > A$.

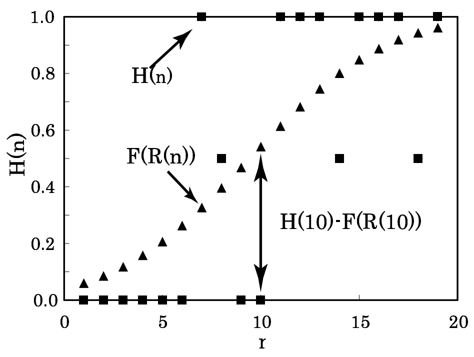

Fig. 4. Parameter matching.

if $S_{PCT} > 0.66$, or "non-increasing trend" if $S_{PCT} < 0.54$ and "ambiguous" otherwise.

The other test is Pairwise Difference Test (PDT)

$$S_{PDT} = \frac{D_m > D_1}{\sum_{k=2}^{m} |D_k > D(k-1)|}. \tag{2}$$

The PDT quantifies how strong is the start-to-end OWD variation. If there is an increasing trend, S_{PDT} also approaches one. The PDT reports "increasing trend" if $S_{PDT} > 0.5$, "non-increasing trend" if $S_{PDT} < 0.45$ and "ambiguous trend" otherwise.

If we use only one of that two statistic, we may miss the detection. Fig.3 shows the actual OWD's trend in a stream when $R > A$. We can find that the OWD's variation does not increase in monotone. PCT can miss detection when the trend does not have consecutive increasing trend, and on the other side PDT can miss the detection when the case that the last packt's OWD is small. Reference [2] describes details of PCT and PDT.

In **Step(3)**, ABdis gives each stream a judgment value (0, 1, or 0.5) referring to the case which the each stream is classified as follows.

Case(1) If one of the PCT or PDT metrics reports "increasing trend" while the other is either "increasing" or "ambiguous" the stream assigned given 1 as a judgement value $H(n)$.

Case(2) If one of the PCT and PDT metrics reports "non-increasing trend" while the other is either "non-increasing" or "ambiguous" the stream is assigned 0 as a judgement value $H(n)$.

Case(3) When both metrics report "ambiguous" or one is "increasing" and the other is "non-increasing" the stream is assigned 0.5. By this rule, the nth stream has its own judgment value $H(n)$ as a judgement value $H(n)$.

Finally, we describe the detail of **Step(4)**. ABdis assumes that the distribution of avail-bw is a normal one [8], and tries to find the normal distribution that describes the relationship between $R(n)$ and $H(n)$ as accuracy as possible. $F(R)$ is a cumulative distribution function, with mean μ and variance σ^2, and ABdis minimizes the $S(\mu, \sigma^2)$, which is

$$S(\mu, \sigma^2) = \sum_{n=1}^{N} (H(n) - F(R(n)))^2. \tag{3}$$

In this way, the normal distribution $F(R(n))$ is determined as an avail-bw distribution to estimate (Fig.4). Abdis assumes that the relation of $R(n)$ and $H(n)$ can express the distribution of avail-bw. Because case(1) corresponds to that avail-bw may be less than $R(n)$ with high probability (it means that $F(R(n))$ is near one), and case(2) corresponds to that avail-bw may be less than $R(n)$ with low probability (it means that $F(R((n))$ is near zero).

IV. Simulation experiments

In this section, we describe simulation experiments of ABdis using NS simulator. Fig. 1 shows the network model for simulations. Capacities of bottleneck link was set 10 [Mbps] and capacities of access links were set 100 [Mbps]. As a cross traffic file transfer is assumued, having Pareto-distribution (shape parameter 1.5) as file size and poisson distribution as file generation. The end-to-end propagation delay in the path was set 50 [msec]. We varied the mean inter-arrival time to simulate under various load conditions. Moreover, we set the number of streams $N = 20$, the stream input interval $x = 1$, the probe group size $m = 10$, the stream length $K = 100$, and the unit-time for avail-bw to estimate $T = 0.1$ [sec]. The time to measure is set $(N - 1) \times x + T = 19.1$ [sec]. We compare cumulative distributions estimated using our method with ones obtained from actually measured avail-bw distribution in simulations.

Figs. 5, 6, and 7 show the result of estimation of a light-load case, a heavy-load case, and a middle-load case, respectively. In Fig.4, (6.69, 1.46) means that the average is 6.69 and sample variance is 1.46. These figures show that our method estimated the overall avail-bw distribution fairly accurately. However, when the load of network is heavy, the accuracy of measuring avail-bw deteriorates.

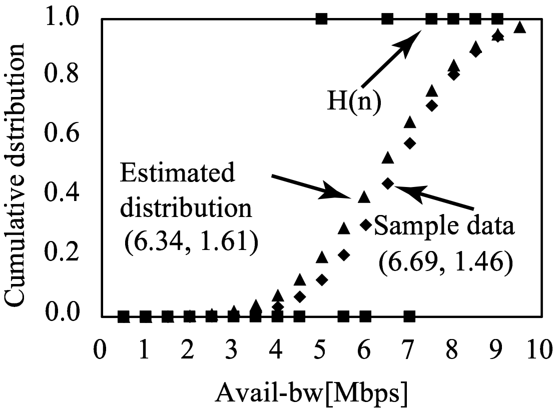

Fig. 5. Estimated distribution (light load case).

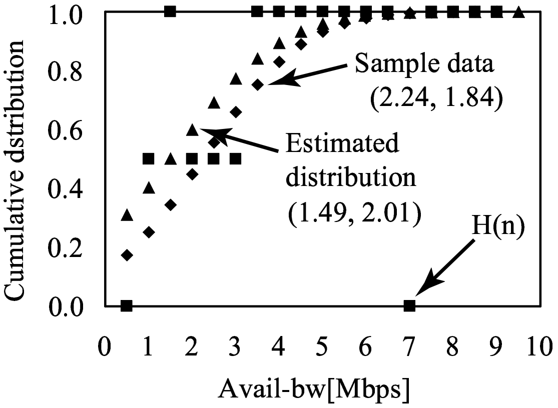

Fig. 6. Estimated distribution (heavy load case).

We verify whether the probe packets of ABdis affect the measured distributions. Figure 8 shows three samples of avail-bw distribution. Sample data 1 is measured during a period in which ABdis was sending probes. Sample data 2 is measured during whole time of the simulation in which seven percent working period is included. Sample data 3 is measured during an idle period with the same length as sample 1. These three types of distribution are similar in shape and average. Thus, ABdis does not cause a significant decrease in the avail-bw.

V. Conclusion

In this paper, we proposed the method called ABdis which can estimate distribution of avail-bw. Moreover, we showed the results of simulation and verify the usability. ABdis can measure it precisely in our simulation model, and it dose not cause significant decrease in the avail-bw.

Some research problems remain. One is the performance of estimations under various practical traffic patterns and network topologies. Also, the effects of congestion control of transport protocols need to be investigated.

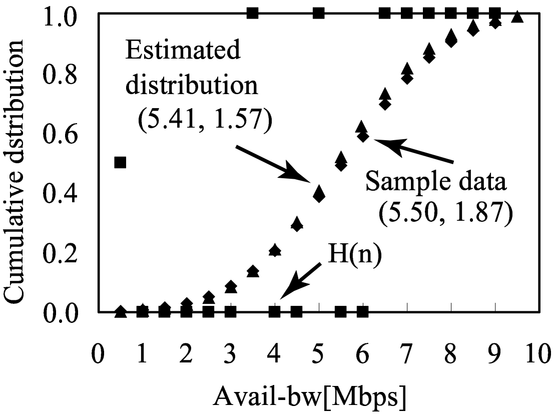

Fig. 7. Estimated distribution (middle load case.)

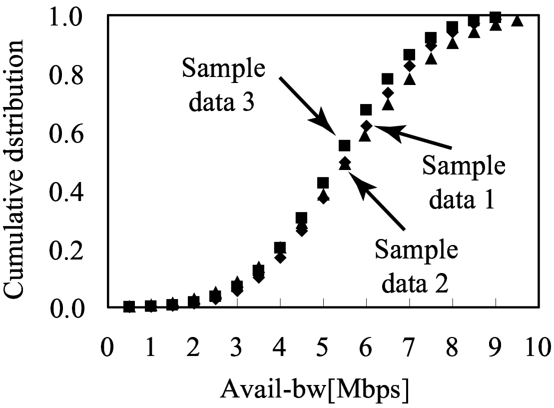

Fig. 8. Influence of ABdis.

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