Analysis and Evaluation of Link Capacity Estimation Tools

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Abstract: - Bottleneck link capacity tools or methods can be used according to different application requirements. Some applications require not only measurement accuracy but also very short sampling time and high sampling frequency. In the paper, first, we decribe the principles of some concepts according to the literatures. Next we introduce the techniques of PPTD. At last, we choose the three tools that are using the techniques of PPTD for compare and analysis.These tools are all used to measure bottleneck link capacity. We made experimental simulations to analyze tools from four aspects which are measurement accuracy, total probe traffic generated, total estimation time and stability. From the experiments, we find the Nettimer is the most accurate but with low probe bandwidth and short estimation time. The results also indicate that which tool is the best in different applications.

Key-Words: - Capacity; Bottleneck Link Capacity; Packet Pair/Train Dispersion

1 Introduction

In the process of Internet performance measurement, the bandwidth in a network path is of major importance in congestion control, streaming applications, QoS verification, server selection, and overlay networks. Measuring bandwidth is not only for knowing the network status, but also to provide information to network applications on how to control their outgoing traffic and fairly share the network bandwidth [1]. Some applications require very short sampling time and high sampling frequency, not only measurement accuracy. In this paper, we discuss what link bottleneck capacity tools or methods can be used according to different application requirements. The organization of this article is as follows. The section 2 introduces some concepts. The section 3 introduces the techniques of packet pair/train dispersion (PPTD) for measuring link bottleneck capacity. The section 4 introduces the experiments of analyzing of link bottleneck capacity estimation tools. The section 5 is the conclusion.

2 Some concepts

From the literature[2], we know that in physical layer communications, the term bandwidth relates to the spectral width of electromagnetic signals or to the propagation characteristics of communication systems. In the context of data networks, the term bandwidth quantifies the data rate that a network link or a network path can transfer.

We also know that the concept of bandwidth is central to digital communications, and specifically to packet networks, as it relates to the amount of data that a link or network path can deliver per unit of time. For many data intensive applications, such as file transfers or multimedia streaming, the bandwidth available to the application directly impacts application performance. Even interactive applications, which are usually more sensitive to lower latency rather than higher throughput, can benefit from the lower end-to-end delays associated with high bandwidth links and low packet transmission latencies.

From the literature[3], we know that network measurement techniques can be classified into two categories: passive measurement [4], [5] and active probing [6-10]. Passive measurement tools use the trace history of existing data transmission. While potentially very efficient and accurate, their scope is limited to network paths that have recently carried user traffic. Active probing, on the other hand, can explore the entire network. The packet pair technique is one of the most popular active probing techniques. The basic idea of packet pairs is that the sender sends a pair of packets, which are echoed back by the destination. By measuring the changes in the packet spacing, the sender can estimate the bandwidth properties of the network path. While the packet pair mechanism is a reliable method for measuring the bottleneck link capacity of a network path [6], [7], [10], its use to measure the available bandwidth has had more mixed results.

From the literature[2], we know important metric which is capacity of a link or end-end path.

Let's define the capacity C of an end-to-end path is the maximum IP layer rate that the path can transfer from source to destination. In other words, the capacity of a path establishes an upper bound on the IP layer throughput that a user can expect to get from that path. The minimum link capacity in the path determines the end-to-end capacity C, i.e.,

$$C = \min_{i=1,\ldots,H} C_i \qquad (1)$$

Where C_i is the capacity of the i-th hop, and H is the number of hops in the path. The hop with the minimum capacity is the narrow link on the path.

A layer-2 link, or segment, can normally transfer data at a constant bit rate, which is the transmission rate of the segment. For instance, this rate is 10Mbps on a 10BaseT Ethernet segment, and 1.544Mbps on a T1 segment. The transmission rate of a segment is limited by both the physical bandwidth of the underlying propagation medium as well as its electronic or optical transmitter/receiver hardware.

At the IP layer a hop delivers a lower rate than its nominal transmission rate due to the overhead of layer-2 encapsulation and framing. Specifically, suppose that the nominal capacity of a segment is CL2. The transmission time for an IP packet of size LL3 bytes is

$$\Delta_{L3} = \frac{L_{L3} + H_{L2}}{C_{L2}} \qquad (2)$$

where H_{L2} is the total layer-2 overhead (in bytes) needed to encapsulate the IP packet. So the capacity C_{L3} of that segment at the IP layer is

$$C_{L3} = \frac{L_{L3}}{\Delta_{L3}} = \frac{L_{L3}}{\frac{L_{L3} + H_{L2}}{C_{L2}}} = C_{L2} \frac{1}{1 + \frac{H_{L2}}{L_{L3}}}$$

(3)

Note that the IP layer capacity depends on the size of the IP packet relative to the layer-2 overhead. For the 10BaseT Ethernet, C_{L2} is 10Mbps, and H_{L2} is 38 bytes (18 bytes for the Ethernet header, 8 bytes for the frame preamble, and the equivalent of 12 bytes for the interframe gap). So the capacity that the hop can deliver to the IP layer is 7.24Mbps for 100-byte packets, and 9.75Mbps for 1500-byte packets. Figure 1 shows the fraction of layer-2 transmission rate delivered to the IP layer as a function of packet size for Ethernet and PPP layer-2 encapsulations. For PPP transmissions we assume that the Maximum Transmission Unit (MTU) is 1500 bytes while the layer-2 overhead (without any additional data-link encapsulation) is 8 bytes.

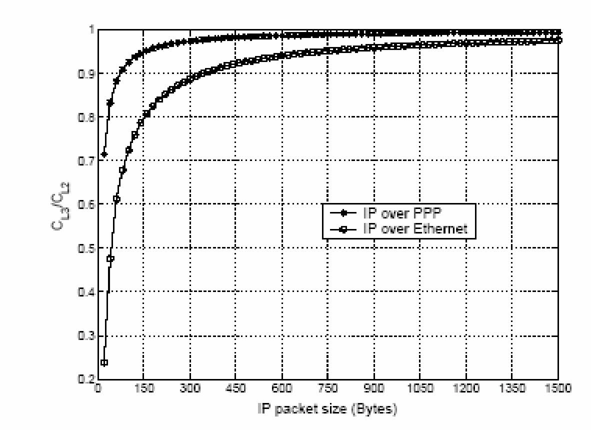

Fig.1. Fraction of segment capacity delivered to IP layer, as a function of the packet size.

3 Analysis of Capacity Estimation Methodology

3.1 The Technique of Packet Pair/Train Dispersion(PPTD)

From the literature[11,12], we know that a packet-pair measurement can be described more formally as follows. Consider a network path *P* defined by the sequence of link capacities P={C_0, C_1, …, C_H}. Two packets of the same size *L* are sent from the sender S to the receiver *R*. These packets are called probing packets of size *L*. The dispersion Δ_i of the packet pair after a link *i* is the time interval between the complete transmission (up to the last bit) of the two packets by link *i*. The dispersion of the probing packets after the sender S is $\Delta_0 = L / C_0$, i.e., the two probing packets are sent "back to back." First, let us assume that there is no cross traffic in the path. It is easy to see that the dispersion Δ_i cannot be lower than the dispersion Δ_{i-1} at the previous hop and the transmission delay $\Delta_i = L / C_i$ at hop *i*, i.e., $\Delta_i = \max\{\Delta_{i-1}, L / C_i\}$. Applying this model recursively from R back to S, we find that the dispersion at *R* is

$$\Delta_R = \max_{i=0,\ldots,H}\left(\frac{L}{C_i}\right) = \frac{L}{\min_{i=0,\ldots,H}(C_i)} = \frac{L}{C} \qquad (4)$$

Where C is the capacity and the capacity $C = L / \Delta_R$. Consequently, without cross traffic, all packet-pair bandwidth measurements are equal to the capacity, independent of the probing size *L*. Note that the two probing packets of the same packet pair should have the same size *L*, so that both packets encounter the same transmission delay at each link.

From the literature[12], we know that the concept of packet dispersion, as a burst of packets traverses the narrow link of a path, was originally described in [13], and it is closely related to the TCP self-clocking mechanism. However, Jacobson did not consider the effects of cross traffic, and so he did not distinguish between capacity and available bandwidth. Keshav explored the same concept in the context of congestion control [14] and recognized that the dispersion of packet pairs is not related to the available bandwidth when router queues use the First-Come First-Served discipline, and so he focused on fair-queueing instead. Bolot used packet-dispersion measurements to estimate the capacity of a transatlantic link and to characterize the traffic interarrivals [15].

4 Experiments and Analysis

Link capacity tools or methods can be used according to different application requirements. Some applications require very short sampling time and high sampling frequency, not only measurement accuracy. So we choose the three tools that are using the techniques of PPTD for compare and analysis. These tools are all used to measure bottleneck link capacity. We evaluate tools not focusing on their techniques, but on the design and implementation details that affect measurement accuracy, total probe traffic generated, total estimation time and stability. We put the focus on analyzing experimental results for testing performance.

4.1 Measurement method

In order to show the accuracy of our evaluation, we use real environment to do our experiments. In the experiments, we choose the tools that are Pathrate[10], Nettimer[6] and Sprobe[19]. The illustration of experiment is as Fig 2.

In the Fig 2, there are three links from PC1 to PC2. The link1 is from PC1 to Router1.The link2 is from Router1 to Router2. The link3 is from Router2 to PC2. We use automatic traffic generation tools such as Iperf to make traffic in sender as in Fig 2. In the experiment, Sender sends packets to PC2 using Iperf. Two hosts are required to run the tools such as Pathrate, Nettimer and Sprobe. Repeated procedures have led to the development of tests automation such as results processing and recording scripts in two hosts.

The machines that are used in the experiments all have 100M Ethernet network cards. Router1 and Router2 also have 10M Ethernet network cards that are used to translate packets through link2. So we know the capacity of link1 is 100M. The capacity of link2 is 10M and the capacity of link3 is the same as the capacity of link1. PC1 and PC2 are only running the tools that are Pathrate, Nettimer and Sprobe. We use tools to measure the capacities on the link2 which is the bottleneck link under three conditions which are no competing traffic, light competing traffic and heavy competing traffic. During the experiments, we use Iperf that is traffic generation tool in Sender to generate 0M competing traffic, 20M competing traffic and 80M competing traffic at the rate of CBR. The length of packet is 1470 Bytes using UDP protocol. In the experiments, we call the real capacity as the standard capacity and we call the capacity that is measured by the tools as the measurement capacity. From the experiments, we evaluate tools not focusing on their techniques, but on the measurement accuracy, total probe traffic generated, total estimation time and stability.

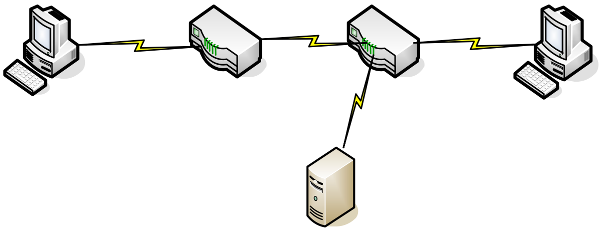

Fig.2. the Illustration of Experiment

4.1.1 Six experiments

Experiment 1: the measurement accuracy of using tools

Experiment 2: the total estimation time of using tools

Experiment 3: the total probe traffic of using tools

When we perform the experiment, Pathrate and Nettimer require the cooperation of both the hosts that are PC1 and PC2. The tool of Sprobe only needs to run on one host.

4.2 Experiment results and analysis

1. Measurement accuracy

In the experiment, we measure the influence of the changes of competing traffic on the measurement capacity.

From the fig3, we can find that the values given by the Pathrate are the most close to values of the standard capacity. With the difference of the competing traffic, the fluctuating values of measurement capacity are the 9.6Mbps around. When the competing traffic is 80Mbps, the fluctuating values are the highest and deviate the most from the values of standard capacity. From the fig3, we can also know that the values of measurement capacity are all very close to the values of standard capacity and have the high stability.

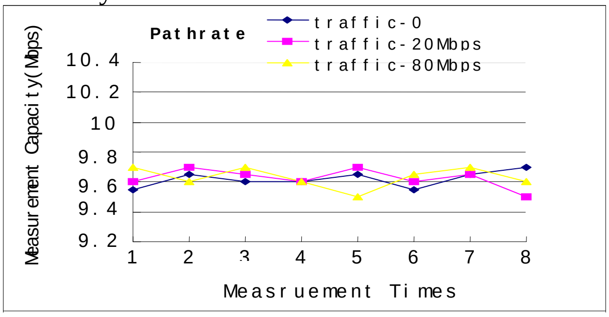

Fig.3. the Measurement Accuracy of Using Pathrate

From the fig4, we can find that the values of measurement capacity given by the Nettimer are all near to the values of standard capacity under three conditions. Even if the competing traffic is 80M, the fluctuating values are range from 9.43M to 10.22M. But from the fig4, we also find that the stability of using the Nettimer is worse than the stability of using the Pathrate

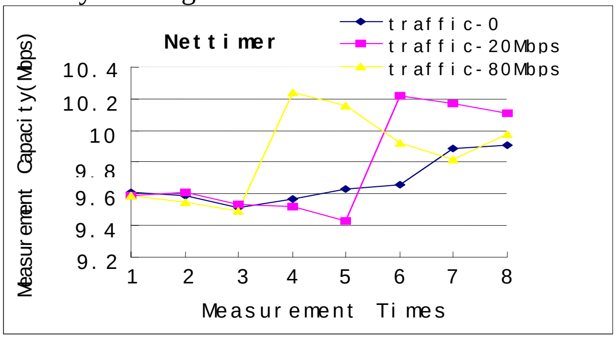

Fig.4. the Measurement Accuracy of Using Nettimer

We also test the accuracy of using Sprobe. When the competing traffic is 0M,we have tested 30 times and only got sixteen results. The distribution of measurement values is as follows. The values of two results are 12000Mbps. The values of ten results range from 5Mbps to 10Mbps. The values of four results range from 95Mbps to 105Mbps. When the competing traffic is 20M,we have tested 30 times and only got seventeen results. The distribution of measurement values is as follows. The values of two results are 12000Mbps. The values of eight results range from 5Mbps to 10Mbps. The values of seven results range from 95Mbps to 105Mbps. When the competing traffic is 80M,we have tested 30 times and only got thirteen results. The distribution of measurement values is as follows. The values of two results are 12000Mbps. The values of four results range from 5Mbps to 10Mbps. The values of seven results range from 95Mbps to 105Mbps. The data above show that the values are so unstability. It doesn't seem to have much meaning to analyze the Spobe. So we only analyze two other tools that are Pathrate and Nettimer.

2. Total estimation time

In the experiment, we measure the total estimation time for different competing traffics.

From the fig5, we can find that the data of estimation time can be divided into two groups. The data of one group is around 50s. The data of the other group is around 1050s. Why the data has so great disparity? It is because of the principle of the tool of Pathrate. Pathrate has a phase of Quick-Estimation that happens when the competing traffic is quit lightly loaded. Specifically, Pathrate measures a certain variation during the phase of Quick-Estimation. If the certain variation is less than a certain threshold, Pathrate exits. The final capacity estimates in that case is calculated as the average of the preliminary measurements, after removing the 10% smallest and largest values. So some of the data of estimation time are around 50s. If the certain variation is larger than a certain threshold, Pathrate will continue other execution phases. It must be increasing the estimation time. So some of the data are around 1050s. And we also know the reason why the data of estimation time is around 1050s when the competing traffic is 80M.

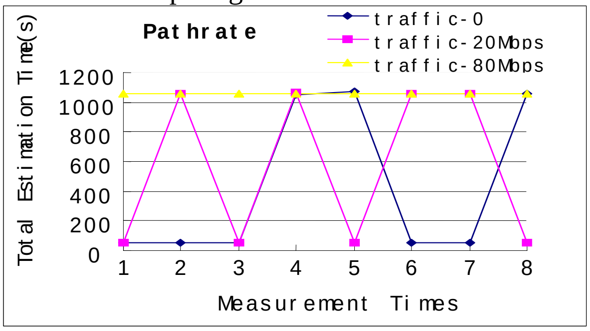

Fig.5. the Total Estimation Time of Using Pathrate

The estimation time of using Nettimer is recorded in the log. From the log, we find the interval of recording the results is 1 millisecond. So it has no meaning to analyze the estimation time of the Spobe.

3. Total probe traffic generated

In the experiment, we measure the probe bandwidth of two tools.

From the fig6, we find that the probe bandwidth that is measured when the competing traffic is 80M is larger than the probe bandwidths that are measured when the competing traffic is 20M and 0M. The reason is mentioned above. When the competing traffic is 80M, Pathrate will continue other execution phases during which packet-pair will also be sent after the preliminary measurements. So it must be increasing the probe bandwidth.

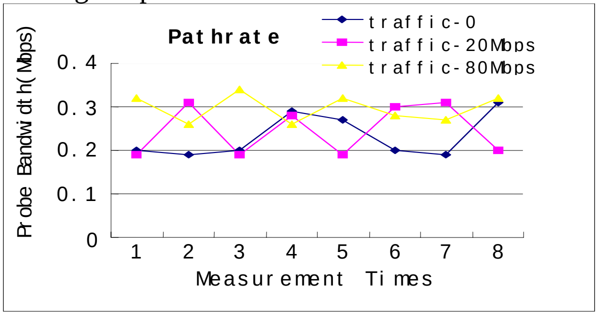

Fig.6. the Probe Bandwidth of Using Pathrate

Because of the measurement mode of Nettimer, we have sampled eight group results from the log of continuous 8-minutes measurement. We calculated the average probe bandwidth during the 8-minutes measurement and the average probe bandwidth is 0.001Mbps. Why the Nettimer has so small probe bandwidth? The reason is that the Nettimer is a passive measurement tool. It doesn’t send probe packet to estimate the capacity. During the measurement period, it only sends some packets which length is 52B or 106B to keep the connection.

5 Conclusions

We have presented the measurement plan to compare and analyze of bottleneck link capacity tools. In the paper, we evaluate these tools not focusing on their techniques, but on the design and implementation details that affect measurement accuracy, total probe traffic generated, total estimation time and stability. We made experimental simulations to analyze tools. From the experiments, we find Nettimer is the most accurate but with the low probe bandwidth and short estimation time. So if accuracy is focused on in network applications, you can choose the tool of Nettimer. Otherwise, considering all aspects, you might have other choice.

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