Bandwidth Measurement in xDSL Networks

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Abstract

This paper presents a design and implementation of a scheme for accurate measurement of network bandwidth in xDSL networks, including asymmetric upstream and downstream cases. A stepwise algorithm is designed to minimize the effect of ATM traffic shaping for ABR and UBR service classes in xDSL deployments on the bandwidth measurements. The accuracy of the algorithm is achieved by implementing an original traffic generator with stable performance. Evaluation experiments have demonstrated that the algorithm can achieve accurate bandwidth measurement in xDSL networks.

Keywords — bandwidth measurement, xDSL networks, asymmetric network, network management.

1 Introduction

1.1 *xDSL Networks*

xDSL networks refer to different networking variations of DSL (Digital Subscriber Line), such as ADSL (Asymmetric DSL), HDSL (High bit-rate DSL), and RADSL (Rate Adaptive DSL). Figure 1 shows the deployment architecture of ADSL networks. The customer premises equipment is an ATU-R (ADSL Termination Unit – Remote) or an ADSL modem. An ATU-C (ADSL Termination Unit – Central Office) is located at a Central Office end of a phone company who provides the ADSL service. The ATU-C terminates multiple subscriber loops and connects the ATU-R to the Internet through a Gateway Router. Multiple ATU-Cs in ADSL network are grouped into a DSLAM (DSL Access Module or Multiplexer) unit that terminates the multiplexed traffic into an ATM switch.

In general, xDSL networks have architecture similar to the one shown in Figure 1. An important feature of xDSL networks is that an xDSL line can carry both data and voice signals and the data part of the line is continuously connected, which enables receiving data at rates up to 6.1 Mbps (of a theoretical 8.448 Mbps). For example, individual ADSL connections will provide from 512 Kbps to 1.544 Mbps downstream and about 128 Kbps upstream.

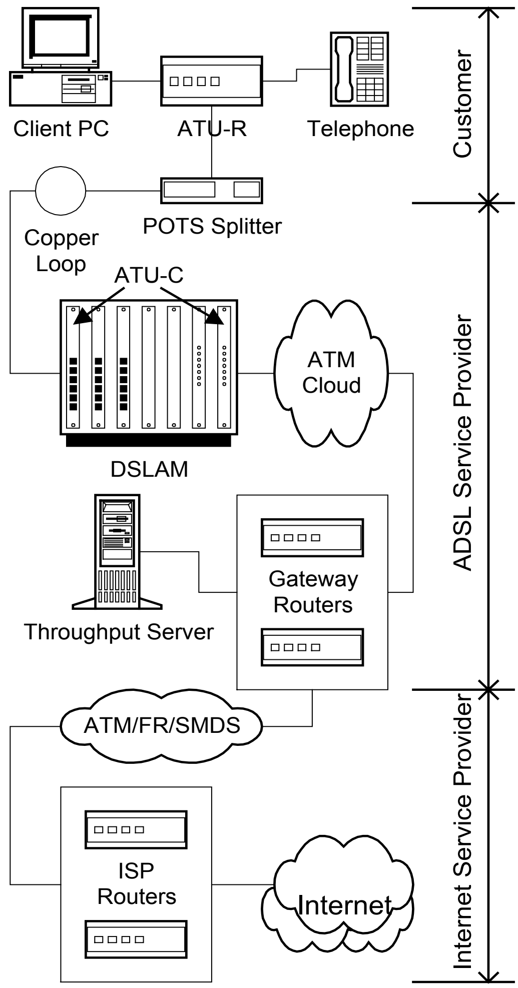

Figure 1: ADSL deployment architecture

1.2 *Bandwidth Measurement*

Emerging Internet applications require support for voice, video, and multimedia, and these are bandwidth intensive and sensitive. The available bandwidth in the Internet is shared since most of the network resources are accessed by multiple users and applications. Therefore it is becoming vital to ensure different network-service qualities for different applications in terms of available bandwidth.

In xDSL networks, accurate bandwidth measurement is useful for network management and traffic engineering, such as isolating line faults and verifying guaranteed QoS (Quality of Service) specifications, where ISP (Internet Service Provider) and xDSL providers may be involved. In the case of ADSL networks, according to Figure 1, the deployment and maintenance of the links between the ATU-R and the Gateway Router forms the responsibility of the phone company. Due to these reasons, there is a need to measure the actual physical line speed of the ADSL link.

An additional reason for the measurement is that based on it traffic load can be balanced. By accurately measuring link bandwidth, bottleneck links can be identified so that service providers can increase the bandwidth of the bottleneck links to enhance the overall performance of network services.

2 Bandwidth Measurement Scheme

2.1 *General Method*

In this paper, the method for the bandwidth measurement in xDSL networks is based on the packet-pair technique with FIFO queueing network model. Its essential idea is using inter-packet time to estimate the characteristics of the bottleneck link, as illustrated in Figure 2. Specifically, if two packets travel together so that they are queued as a pair at the bottleneck link with no packet intervening between them, then their inter-packet spacing is proportional to the processing time required for the bottleneck link to transmit the second packet of the pair. Therefore the available bandwidth of the bottleneck link, b, can be computed as:

$$b = \mathrm{P}/\Delta \tag{1}$$

since

$$t_2 - t_1 \le \mathrm{P}/b = t_4 - t_3 \tag{2}$$

and

$$\Delta = t_4 - t_3 \tag{3}$$

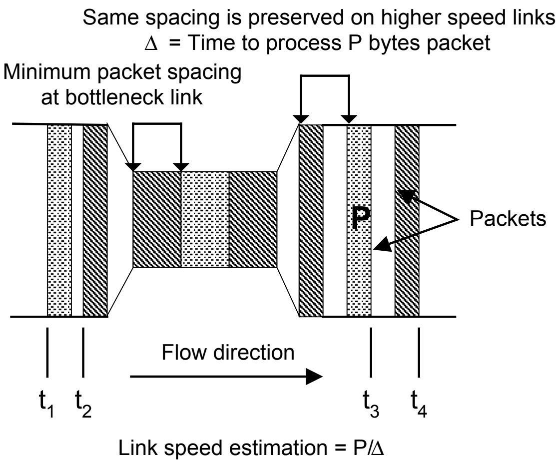

Figure 2: Packet-pair technique for bandwidth measurement

Various forms of the packet-pair technique are studied by Bolot [1], Carter and Crovella [2], Paxson [3], and Lai and Baker [4]. We modified this technique to apply it to xDSL and asymmetric DSL (ADSL) networks. In our method, the probing packets can be the payload packets as well as explicit ICMP (Internet Control Management Protocol) or UDP (User Datagram Packet) probe packets.

2.2 *Bandwidth Measurement in Asymmetric DSL (ADSL) Networks*

The bandwidth measurement scheme in ADSL networks deploys client-server computing paradigm. The client is the computer at the customer side and the server is the Throughput Server, which is shown in Figure 1. The asymmetric nature of the ADSL networks makes it necessary to have different bandwidth-measurement schemes for upstream and downstream cases.

2.2.1 Upstream scheme

A fixed number, N, of UDP packets of uniform size, P bytes, are sent from the customer client at a rate slightly higher than the nominal bottleneck bandwidth of the ADSL network. A server-process on the Throughput Server echoes back the packets as they arrive at the server end. Figure 3 shows this scheme. The time difference, T, in milliseconds, between the arrival of the first packet at the client end and the arrival of the last packet at the client end is measured and the upstream bottleneck speed, b_1, is computed as:

$$b_1 = N{*}P{*}8/T \text{ Kbps} \tag{4}$$

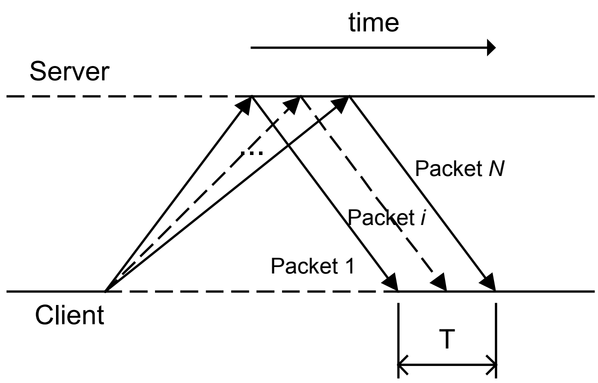

Figure 3: Upstream scheme of bandwidth measurement

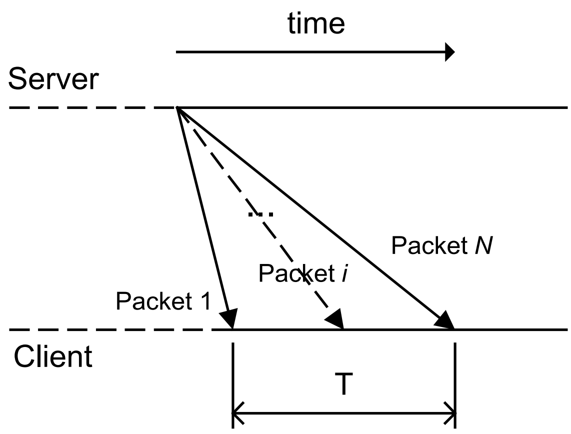

Figure 4: Downstream scheme of bandwidth measurement

2.2.2 Downstream scheme

A traffic generator at the Throughput Server generates a downstream traffic. A receiving process at the client measures the arrival time of the packets. Because of the nature of ADSL that the upstream bandwidth is smaller than the downstream bandwidth, the client does not echo the probe packets back. Instead, the client computes the downstream bandwidth using the same Eq. (4) as for the upstream case. Figure 4 shows the downstream scheme.

2.3 *Traffic Generator with Stable Performance*

Since the accuracy of the bandwidth measurement depends on whether the traffic generator can generate traffic at a stable rate, it is crucial to implement it with stable performance. Due to different scheduling mechanisms of operating systems, the packets are not necessarily sent at a uniform rate with uniform spacing. Generally there are possibilities of bursts in traffic generating.

A straightforward method of generating packets at a known rate employs Algorithm 1 shown below. Although it seems to be correct in theory, it does not give the expected behavior. Consider a case when the call to `sleep()` returns and the process is scheduled out. Instead of sending a packet immediately the packet is sent only when the operating system reschedules the process. Moreover, *delay* may not be an integer while `sleep()` generally can only accept an integer as an input value.

To overcome this problem an alternative way of generating traffic at the desired rate was devised (Algorithm 2). The algorithm achieves the expected behavior, i.e., it stably generates a smooth flow of traffic at the expected rate.

Algorithm 1

```
Initialize:
// rate in Kbps, packet size in byte
// delay in millisecond
delay = 8 x packet size x 1000 / rate;

for (i = 0; i < # of packets; i++)
{
     send_packet();
     sleep(delay); // in millisecond
}
```

Algorithm 2

```
Initialize:
// rate in Kbps, packet size in byte
// pps: # of packets to be sent in a second
pps = rate x 1000 / (8 x packet size);

Fraction = 0;
stopSleep = getTimeMillis();

for(i = 0; i < # of packets, i++)
{
    startSleep = stopSleep;
    sleep(1); // sleep for 1 ms
    stopSleep = getTimeMillis();

    packetCount = (fraction + pps x (stopSleep
                - startSleep))/1000;
    fraction = (fraction + pps x (stopSleep -
              startSleep))%1000;

    upLimit = i + packetCount;
    if(upLimit > # of packets)
         upLimit = packetCount;

    for(; i < upLimit; i++)
         send_packet();
}
```

2.4 *Stepwise Bandwidth Measurement Algorithm*

2.4.1 Effect of ATM traffic shaping

According to Figure 1, a DSLAM unit terminates the multiplexed traffic from multiple xDSL lines into an ATM switch and to the Internet. Since xDSL deployments are typically done over ATM to provide guaranteed quality of service, the effect by ATM traffic shaping on bandwidth measurement should be taken into consideration.

There are two service categories defined by ATM Forum for best effort traffic in ATM networks: UBR (Unspecified Bit Rate) and ABR (Available Bit Rate) services. UBR service does not offer any guarantee with regard to the delay, loss or bandwidth, but should be able to handle the fluctuations in these parameters by using error-correction and flow control techniques. On the other hand, ABR service guarantees the upper bound on loss rate, which is achieved by exchanging resource management cells between the source and sink ATM nodes. Based on the synchronization speed of xDSL modem, the ATM switch sets the service class for the virtual circuit to which a particular customer has been mapped. In general commercial xDSL deployments, the ABR service class is chosen.

With the ABR service class setting, an increase in the data rate beyond the provisioned bandwidth results in a heavy packet loss. This is caused by the ATM traffic shaping. Its effect on bandwidth measurement is that it distorts the results since the accuracy of the packet-pair technique depends on the success of receiving back-to-back packet pairs. To minimize the effect of ATM traffic shaping, we designed a stepwise bandwidth measurement algorithm to make the probe traffic have the sending rate near the available bandwidth. The stable traffic generator is implemented as described above to make the probe traffic less bursty.

2.4.2 Stepwise Bandwidth Measurement Algorithm

The algorithm consists of at least two steps. It can be used for both the downstream and upstream measurements.

During the first step, a small number of packet-pair sequences, e.g., 5, are sent back-to-back from the client to the server. This small number of packets will not suffer significant packet loss, as most xDSL networks are capable of handling such small bursts. The computed result at the client in the first step is used as the trial bandwidth of the xDSL link.

The next step(s) assumes that the accurate xDSL bandwidth is close to the trial result obtained from the first step. In fact, only packet loss deteriorates the result. If the packet loss in the first step is minimal or zero, which has also been taken into account by our implementation, then the result of the first trial is accurate. In the next step(s), probe packets are sent at a rate slightly higher than the nominal bandwidth of the xDSL link. More packet pairs are used to make the measurement to ensure that the results are convergent and finally consistent.

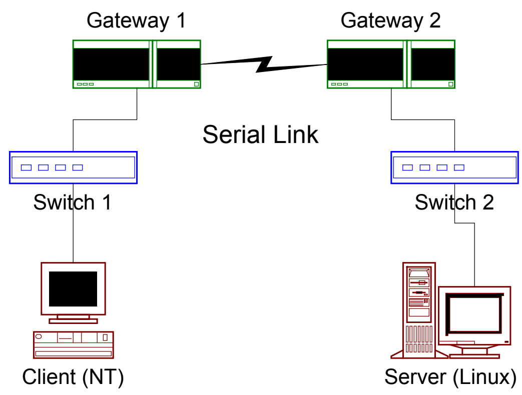

Figure 5: Testbed topology

3 Experiment

3.1 Testbed

For experiments, in addition to ADSL links, we tested the bandwidth-measurement methods using a serial link in a laboratory testbed network since its bandwidth could be altered manually. Figure 5 shows the topology of the testbed. The client and the server are in different subnets that are connected by the serial link by introducing a High-Speed Serial Interface (HSSI) between the two gateways. The endpoints for the tests were located across the two ends of ADSL links or the HSSI.

Figure 6 compares the performance of our bandwidth measurement tool to that of a popular tool called Pathchar [5]. The latter uses ICMP error packets in estimating the link characteristics and also relies on injecting UDP packets to measure the link characteristics. Figure 6 shows an almost linear curve for our tool whereas Pathchar shows significant

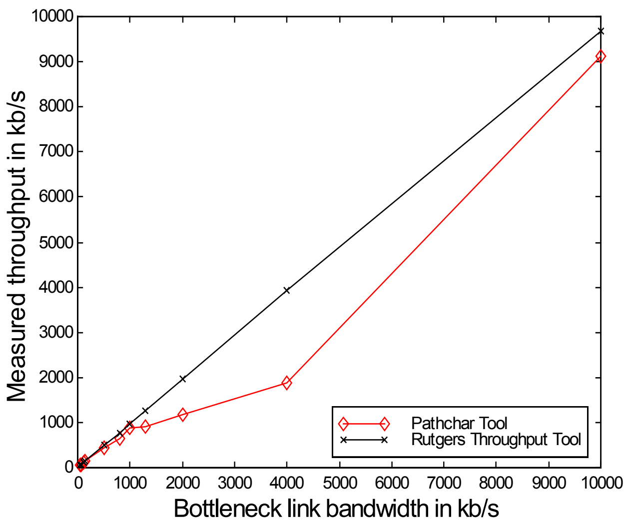

Figure 6: Comparison of tools for bandwidth measurement

deterioration starting at about 1 Kbps. Since the HSSI clock is only able to accurately set the link speeds up to 4000 Kbps, consequently there is a gap from 4000 Kbps to 10000 Kbps, which is the link speed for a 10Mbps Ethernet LAN.

4 Conclusion

The growth in deployment of high-bandwidth applications over the Internet has created a need for reliable and fast local loops for both home-user communities and corporate communities, who connect to the Internet through a dial-in ISP. In most cases, a serial modem solution that offers the maximum bandwidth of about 56 Kbps is not sufficient. Therefore, various technologies, such as xDSL, have emerged to achieve high-speed connectivity to the Internet.

This paper presents a design and implementation of a scheme for accurate measurement of network bandwidth in xDSL networks, including asymmetric upstream and downstream cases. A stepwise algorithm is designed to minimize the effect of ATM traffic shaping for ABR and UBR service classes in xDSL deployments on the bandwidth measurements. The accuracy of the algorithm is achieved by implementing an original traffic generator with stable performance. Evaluation experiments have demonstrated that the algorithm can achieve accurate bandwidth measurement in xDSL networks.

Acknowledgments

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