An Efficient Host-to-Host Available Bandwidth Estimation Scheme

Article · January 2006

CITATIONS
0

READS
41

4 authors, including:

Ayodeji Oluwatope
Obafemi Awolowo University
36 PUBLICATIONS **106** CITATIONS
SEE PROFILE

Olufemi Obembe
Obafemi Awolowo University
1 PUBLICATION **0** CITATIONS
SEE PROFILE

Francis Joseph Ogwu
University of Botswana
28 PUBLICATIONS **44** CITATIONS
SEE PROFILE

An Efficient Host-to-Host Available Bandwidth Estimation Scheme

Ayodeji O. Oluwatope[a], Adesola G. Aderounmu[b], Olufemi. Obembe[c] Francis J. Ogwu

[abc]Comnet Laboratory,
Computer Science and Engr.,
Obafemi Awolowo University,
Ile-Ife. NIGERIA

University of Botw.
Computer Sci. Dept
Botswana

aoluwato@oauife.edu.ng, gaderoun@oauife.edu.ng olufemiobembe@yahoo.com,

ABSTRACT
This paper takes an initiative from TOPP [3] and SLoPS [1]and its essence is to reduce the number of probing and error inherent in estimating the available bandwidth along a network path. This paper aims at proposing an algorithm for estimating available bandwidth with shorter measurement latency. Our method that is iterative generates new probing rates by proportionally decreasing an initial probing rate as a function of backlogged delays as a result of extra traffics along the path. The proposed algorithm, when implemented in ns2 under same simulation setup in TOPP; produced the available bandwidth estimate at about 30% of the number of iterations required for TOPP with a relative estimation error of 5% against 9% in TOPP.

KEYWORDS: Bandwidth, Available Bandwidth, Host-to-Host, and Estimation Error.

1. Introduction

Host-to-host or end-to-end available bandwidth is the aggregate untapped/unused instantaneous data space across several routers along a network path. To ensure quality of service stability on the internet, send rate of applications must ensure untapped instantaneous data space is greater than or equal to aggregate flows from source to destination. Research efforts have been in this direction for about two decades. These have produced several estimation techniques and software tools including TOPP , SLoPS, Pathchirp[12]Spruce [13], and Bfind [14] Delphi [11] with many undergoing reviews.

This paper presents an enhancement of TOPP end-to-end probing method. Our propose method formalizes the estimation problem and include an estimation algorithm that measures available bandwidth with shorter measurement latency. The choice of TOPP is informed by its network friendliness-minimal perturbation [3]. The rest of the paper is organized as follows. Section two presents a review of existing methods, algorithms and problem formalization. Section three presents new technique, algorithm and more formalisation. Section four contains the model build up and simulation setup in NS2 and results discussion. Concluding remarks and future research direction presented in section five.

2.0 Existing Systems

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. There are two types of methodology used in estimating available bandwidth. The first measures either capacity hop-by-hop or end-to-end (path) while the second category measures available bandwidth on a path. Two bandwidth metrics that are commonly associated with Path P are the capacity and available bandwidth. The capacity C of a path is described as

$$C = \min\left[C_i\right]_1^H \qquad (1)$$

C also, can be interpreted as the minimum transmission rate along a path P where H signifies number of hops along the path and C_i is the capacity of the i-th hop (link). The hop with the minimum capacity is the *narrow link* on the path [4] Available bandwidth (A_{bw}), on the other hand, is the unused or spare capacity of a link during a certain period of time. If U_i is the utilization of link i over an interval (0, t), the average spare capacity of the link is modeled as $C_i(1\text{-}U_i)$. Thus, the A_{bw} on path P over the same interval is modeled as

$$A_{bw} = \min\left[C_i(1-U_i)\right]_1^H \qquad (2)$$

[4] in their model describes a *tight link* as the link with the minimum available bandwidth which then determines the available bandwidth along the path.

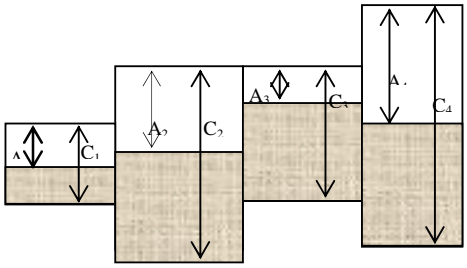

Figure 1: Pipe Model with fluid traffic for 4-hop network path

Figure 1 above shows that the first link is a narrow link (C_1) while the third is the tight link (A_3). The width of each pipe corresponds to the relative capacity of the corresponding link. The shaded area of each pipe shows the utilized part of that link's capacity, while the unshaded area shows the spare capacity. It should be noted that narrow link might occur differently from the tight link as demonstrated in figure 1 and a times occur on the same link.

2.1 Methodologies

The two known methodologies for measuring capacity are Variable Packet Size (VPS) probing [6] and Packet Pair Dispersion [5] probing. On the other hand, the two known methodologies for measuring available bandwidth are Train of Packet Pair (TOPP)[9] and Self Loading Periodic Streams (SLoPS) ([1] Measuring tools in general can either be active or passive. Active measurements inject probe packets into the network and observe their behaviour. In contrast, passive measurements observe actual traffic without perturbing the network.

2.1.1Variable Packet Size (VPS) Probing

[7] originally proposed this method. The idea here is to measure variation in response times (as a function of packet size) from source to each hop of the path. VPS however, may yield significant capacity underestimation if the path includes store and forward procedure. Besides different routers might have different ICMP response time, thus producing wrong link capacity. End-to-end bandwidth can be computed from hop-by-hop bandwidth metrics if the latter is known; estimating hop-by-hop bandwidth metric is significantly harder (Claffy and Dovrolis, 2001).

2.1.2 Packet Pair Dispersion (PPD) probing.

It measures the end-to-end capacity of a path [8]. PPD involves sending packet pair of the same size back-to-back from sender to receiver and the dispersion that the receiver estimate is highest at the narrow link. Since the size of the packet is known, the packet pair dispersion can be used to calculate the narrow capacity. The dispersion of a packet pair at a specific link of the path is the time distance between the last bits of the packet pair. In general, let the dispersion prior to a link of capacity C_i be D_{in}, the dispersion after the link is

$$D_{out} = \max\left([D_{in} * L]/C_i\right) \qquad (3)$$

Assuming there is no cross traffic on that link. When a packet goes through a link along an empty path, the dispersion D_r that the receiver measures is

$$D_r = \max[(L/C)]_1^H = L/(\min[C_i]_1^H) = L/C \qquad (4)$$

where C is the capacity of the path. Thus, the receiver can estimate the path capacity from $C=L/D_r$. Packet Pair technique, though straightforward, can produce widely varied measurement and erroneous capacity estimates. The reason is simple, cross traffic can either increase or decrease the dispersion, causing underestimation or overestimation of the path capacity [4]. Assumption that a path is free of cross traffic is unrealistic.

2.1.3 Train of Packet Pair (TOPP)

Suppose that a packet pair is sent from source with initial dispersion D_s. Let some probing packets of size L bytes, have offered rate of the packet $R_i=L/D_s$. Should R_i be more than A_{bw}, the second probing packet queues behind the first probing packet and the measured rate at the receiver is $R_o < R_i$. On the other hand, if $R_i < A_{bw,}$ Melandar et al. (2002) assumes that the packet pair arrives at the receiver with the same rate it had at the sender i.e. $R_o < R_i$. TOPP sends several packet pairs at gradually increasing rates from source to sink. To demonstrate how TOPP works, let C be the capacity of a link, A_{bw} be the available bandwidth and R_c be the cross traffic rate on the link such that $R_c = C - A_{bw}$. It sends packet pairs with increasing offered rate R_i. When $R_i > A_{bw}$, the measured rate of the packet pair at the receiver, R_o, becomes

$$R_o = [R_i/(R_i + R_c)] * C \qquad (5)$$

It estimates the A_{bw} to be the maximum offered rate $R_i=R_o$. It employs linear regression algorithm to obtain the A_{bw}. It can also estimate the capacity of the tight link from the formula below.

$$R_i/R_o = (R_i + R_o)/C \qquad (6)$$

If the graph of R_i/R_o is plotted against R_o, the slope gives 1/C. However the number of probing required to obtain maximum R_i at which $R_i = R_o$ may be significantly high.

2.1.4 Self Loading Periodic Streams (SLoPS)

SLoPS is a recent measurement methodology for measuring end-to-end available bandwidth. It is based on the observation that the successive periodic probing packets increase when probing rate is higher than the A_{bw} in the path. According to [1], the basic different between TOPP and SLoPS is the algorithm used to estimate $A_{bw.}$ It involves variation in one-way delay of probing packet.

3.0 The New Scheme

This section presents our network model, some analysis and an algorithm for the new scheme.

3.1 Network Model

A network path P can be seen as a set H of successive first-come first-served store-and-forward links and a set N of elements called Nodes that serve as the source S and sink R for the probing packets as shown in figure 2. Assuming that the path is fixed

and unique i.e. no routing changes or multipath forwarding occurs during the measurements, a network path (P) of length n from node S to node R is defined as a sequence of successive n Hops. Suppose the hops of path P have been ordered H_1, H_2,….H_n and that H_i is adjacent to H_{i+1} for i=1,2,3,…n-1, then node S which is the source is adjacent to H_1 and H_n is adjacent to node R which is the destination or the sink.

$P = \{H, N\}$

$H = \{H_1, H_2, ...H_n\}$ where n is number of hops between source and sink nodes

$N = \{S, R\}$

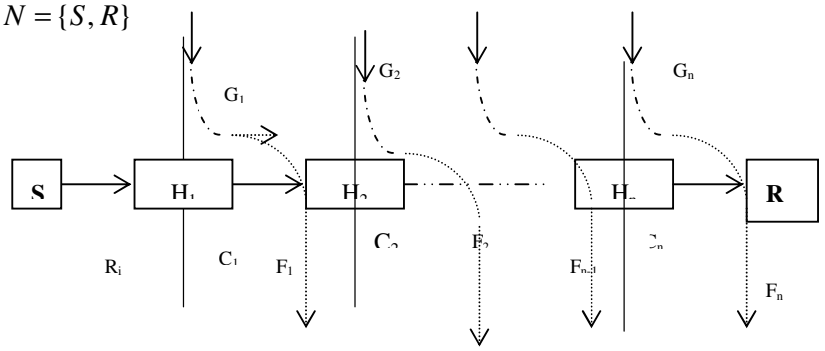

Figure 2: **The rate of different flows as they pass through the Network Path.** *S and R are the probe source and destination. C_i is the Capacity and F_i is the flow rate of the Probe Traffic at link i on the path, and G_i is the Aggregated Cross Traffic*.

A network path consist two individual traffics: cross traffic –competing traffic; and probe traffic. Thus, utilization of a network path or link at any point in time can be viewed as a single aggregated stream (cross traffic). Consider a path P as shown in Figure 2, each link with capacity C_i and utilization U_i, such that $0<U_i<1$, the unused capacity (available bandwidth A_{bw}) is $A_{bwi}=C_i - G_i$ and where $Gi=U_iC_i$. The aggregated competing traffic (G) arriving during any interval t is U_iC_it as stated by Jacobson fluid assumption. Assuming a packet pair of size L (in byte) is sent from S at a constant rate R_i. The time spacing between the first packet and the second packet becomes $t=L/R_i$. The aggregated cross traffic that arrives at the link i during the interval (0,t) is U_iC_it (ie. $G_t=U_iC_it$) and the total amount of traffic that arrives at the link in the same interval t is $L+ U_iC_i(L+G_t)$. On the other hand, maximum amount of traffic the link can transmit in the same interval (0,t) is C_it. When $R_i > A_{bw}$, the link receives more traffic than it can service i.e. $L+ U_iC_it > C_it$. The extra arriving traffic (NP) accumulates at the links buffer at the rate $R_i - A_{bw}$.

$$NP = (R_i - A_{bw})t \qquad (7)$$

For a single link path, when this situation occurs (i.e $R_i > A_{bw}$), the measured rate R_o of the packet at the receiver becomes $R_o=(R_i/(R_i+G))C$ where path capacity is C. There are two methods to determine the probing rate (R_i) is greater than available bandwidth - one

way delay or lower output rate (R_o) [2]. Using higher probing as the starting point the following propositions can be made:

Proposition 1:

Case $R_i < A_{bw}$: In this case, . $L + U_iC_it \leq C_it$, packet P is processed before P+1 arrives in the queue. i.e $R_i=R_o$ (since the path capacity can take off the traffic all at once.)

Case $R_i > A_{bw}$: It is assumed that there is a proportional sharing of links on the path P between cross traffic and probe traffic. If E_i is the entering rate to link i and X_i is the exit rate of link i, for a multihop path, the following relationship can be obtained.

$$X_i = [E_i/(E_i + G_i)] * C_i \quad \text{if } E_i > A_{bwi} \text{ or } X_i = E_i \quad \text{if } E_i \leq A_{bw} \qquad (8)$$

In general, for multihop path, the rate R_o at the receiver R is a cascaded effect of all the C_i and A_{bwi} along the path as shown above.

Proposition 2:

The case ($R_i > A_{bw}$) leads to the final receiving rate R_o being bounded by A_{bw} as upper limit and the input rate, R_i, as lower limit ($R_i > R_o \geq A_{bw}$). With this, the delay at the sender T_i is less than the delay at the receiver T_r i.e. $T_r > T_i$ where $T_r = T_i + T_h$. We describe T_h as overhead in delay backlogged by extra traffic that accumulates at the link. For a multihop path, T_h is an accumulation of delay of all the congestible links in the path and T_h is largest at the last congestible link where congestible link refers to any link where rate of input into the link is greater than the link A_{bw}.

Proposition 3:

When ($R_i > A_{bw}$) then the next probing rate can be generated by proportionally decreasing the initial sending rate based on the overhead T_h experienced along the path. Hence the new probing rate can be taken as:

$$R_i = R_i \left(1 - T_h/T_r\right) \qquad (9)$$

This is assumed to have knocked out part of delay caused by extra traffic of the former probing rate. Thus, this can be iterated until $T_i=T_r$ i.e. $T_h=0$. At this point the first value of R_i at which $R_i = R_o$ is the A_{bw}

3.2 An Iterative Algorithm

An iterative algorithm to measure Available Bandwidth from Host-to-Host can be constructed based on propositions 2 and 3.

```
{
/* initialisation*/
Pair_Length =  Number_of_Pairs;
Packet_size=PACKET_SIZE;
R^max = Get_Pre_Bandwidth_Estimation();
Ri= R^max;
Probe_Num=0;
/* iteration to measure Abw*/
Do{
        Probe_Num=+1;
        Sending_rate=Ri;
        Send_Probing_Packet(Probe_Num,Pair_Length,Packet_size,Sending_Rate);
```

```
        Output_Rate=Get_Receiver_Rate();
                T_i= Packet_size / Sending_rate;
                T_r= Packet_size / Output_rate;
                If!( T_i = T_r) then
                Ri=Ri*(1-T_h/T_r)
} while (Sending_rate=Output_rate);
/* Assign Available Bandwidth*/
        Abw = Sending_rate;
```

4.0 Model Validation

The model requires interactions between the end points; as a result, there are two phases: the first at the sender and the second at the receiver. The first phase is an active probing phase where probing packet pairs are injected into the network. The second phase measures the output rate from the dispersion of the probing packets and notifies the sender where necessary analyses are being carried out. It has also been found that large probe packets result in more accurate estimates [10]. Therefore, the MTU (1500bytes) size is a suitable probe packet size. Using longer packet length helps in providing more predictable A_{bw} estimate and with reduction in the number of probing phases ([10]. To get an average traffic load and at the same time to make it less intrusive, a length of 30 packet pairs is to be used.

4.1 Simulation Model

The simulation consists of two Gigabit Ethernets connected over 5 hops (boxes) as demonstrated in topology shown in Figure 3. The path consists of two congestible links placed one after the other. The essence is to eliminate the hazardous assumption that there is only one congestible link along a path [3]. Cross traffic is generated at each link using CBR traffic source. The propagation delay along the path is 50msec and the links are sufficiently buffered to avoid packet losses.

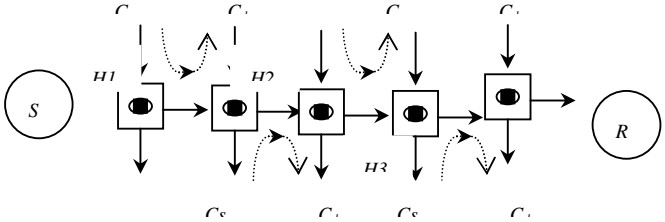

Figure 3**: Simulation Configuration** S *and R are the probing source and destination; C_s and C_d are the source and destination nodes for the competing traffic while the boxes represent Routers along the path.*

For comparative analysis which further justifies this algorithm has shorter measurement latency, we simulated a scenario simulated by [3] with two congestible links [(10,30%),

(34,91%)] and two non-tight links. The results are presented in Table 2 (Path A_{bw} =3Mbps))

Table 1: The measured Available Bandwidth along a Path with varying utilization

configuration	Abw (Mbps)	Measured Abw (Mbps)	% Error
[100,(20,40%),(10,40%),(12,60%),(20,40%),100]	4.8	4.801	0.0208
[100,(20,40%),(10,40%),(12,80%),(20,40%),100]	2.4	2.43	1.25
[100,(20,40%),(10,40%),(12,40%),(20,40%),100]	6.0	6.004	0.067
[100,(20,40%),(10,60%),(12,60%),(20,40%),100]	4.0	4.015	0.375
[100,(20,40%),(10,80%),(12,60%),(20,40%),100]	2.0	2.034	1.7

Table 2: Comparing the number of iteration in TOPP and Proposed Model

	Estimated Available Bandwidth (Mbps)	No of Iterations
TOPP	3.26	100
Proposed Model	3.15	32

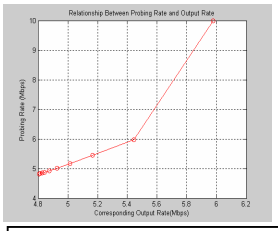

Figure 4: Graph Showing Probing Rate and the Resulting Corresponding Output Rate

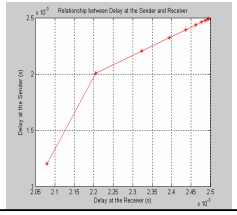

Figure 5: Graph Showing Delay at the Sender and the Delay at the Receiver

Various simulations model would have been tested to further justify this claim but TOPP algorithm is mathematically complex and computationally intensive.

4.1.1 Effect of Cross Traffic on the Number of Probing

It was observed that increase in utilization of the tight link increases the number of number of probing required to get an estimate.The results obtained are shown figure 6 and it shows an increasing trend in number of probing as utilization of the tight link increases. Hence, it can be asserted that the higher the utilization of the tight link, the more the probing that is needed but lesser than those reported in [3].

4.1.2 Relationship between Probing Rate and the Latency of Probe Traffic

Each probing stream consists of 30 packet pairs. The average latency of each probing stream is calculated for the number of probing involved. Figure 7 shows the relationship between the probing rates and the average latency.

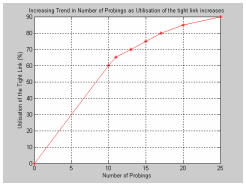

Figure 6: Graph showing increasing trend in number of probing as utilization of the tight link increases

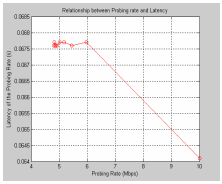

Figure 7: The relationship between Latency and Probing Rate

5.0 CONCLUSION AND FURTHER WORKS

This paper has focused on estimation of available bandwidth, A_{bw} from Host-to-Host on a network path. The result has shown clearly that probing packets is a useful technique with which end-hosts can estimate bandwidth characteristics of a network path. The key idea of the model is that if $R_i > A_{bw}$ then $R_o<R_i$ and $R_o \geq A_{bw}$, and if R_i is successively decreased based on proportion of extra delay experience along the path, the first value of R_i at which $R_i=R_o$ is the available bandwidth ($R_i \approx A_{bw}$). The model has also proved that A_{bw} on a path can be obtained with very few probing using the algorithm proposed. The model is less intrusive and does not require any privilege to obtain bandwidth information from routers, except cooperation of two end hosts, thus, users can use it to monitor available bandwidth periodically as the case may be. In our future works, we are working towards applying available bandwidth as a parameter to dynamically transport control congestion on the Internet and optimality in routing.

REFERENCES

[1] DOVROLIS, C. AND JAIN, M. (2003), "End to end Available Bandwidth: Measurement Methodology, Dynamics and Relation with TCP throughput" in IEEE/ACM Transactions in Networking, 11:4, pages 537-549.

[2] JAIN, M. AND DOVROLIS, C. (2004), "Ten Fallacies and Pitfalls on End-to-End Available Bandwidth Estimation", In the Proceedings of the ACM Internet Measurements Conference (IMC' 04).

[3]MELANDER, B., BJORKMSAN, M. AND GUNNINGBERG, P. (2002), "Regression Based Available Bandwidth Measurement", in International Symposium on Performance Evaluation of Computer Telecom.System.

[4]PRASAD, R.S., MURRAY, M., DOVROLIS, C., AND CLAFFY, K.C. (2003),"Bandwidth Estimation: Metrics, Measurement Techniques and Tools" in IEEE Network, 17:6.

[5]DOVROLIS, C., RAMANATHAN, P. AND MOORE, D. (2001), “What Do Packet Dispersion Techniques Measure?”, in proceedings of IEEE INFOCOM, pages 905-914.

[6]DOWNEY, A. (1999), “Using Pathchar to Estimate Internet link Characteristics” in proceeding of ACM SIGCOMM 29:4, pages 241-250.

[7]JACOBSON, V. (1997), “Pathchar: A tool to infer characteristics of Internet paths: ftp://ftp.ee.lbl.gov/pathchar/.

[8]JACOBSON, V. (1998), “Congestion Avoidance Control”, in proceeding of ACM SIGCOMM, pages 314-329.

[9]DOVROLIS, C., RAMATHAN, P. AND MOORE, D. (2004), “Packet Dispersion Techniques and Capacity Estimation Methodology”, in IEEE /ACM Transactions in Networking.

[10]NINGNING H. AND STEENKISTE, P. (2003) “Evaluation and Characterization of Available Bandwidth Probing Techniques”, in IEEE Journal on Selected Areas in Communication, 21: 6

[11]RIBEIRO, V., COATES, M., RIEDI, R., SARVOTHAM, S., HENDRICKS, B., AND BARANIUK, R., (2000) ”
Multifractal Cross-Traffic Estimation," in Proceedings ITC Specialist Seminar on IP Traffic Measurement, Modeling, and Management

[12]RIBEIRO, V, RIEDI, R, BARANIUK, B., NAVRATIL J, & COTTRELL, L., (2003)
“pathChirp: Efficient Available Bandwidth Estimation for Network Paths," in Proceedings of Passive and Active Measurements (PAM) workshop.

[13] STRAUSS, J., KATABI, D., AND KAASHOEK, F., (2003) ”A measurement study of available bandwidth estimation tools," in Proceedings of ACM SIGCOMM conference on Internet measurement.

[14]AKELLA, A., SESHAN, S., AND SHAIKH, A., (2003) “An empirical evaluation of wide-area internet bottlenecks," in Proceedings of ACM SIGCOMM conference on Internet measurement