Ternary-Search-based Scheme to Measure Link Available-bandwidth in Wired Networks

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***Abstract*—Accurate measurement of available bandwidth (ABW) is an important parameter to analyze network performance. Active measurement is an attractive approach as it provides controllability and flexibility to perform network measurement and monitoring. However, active measurement can affect both the data traffic and the measurement process itself if a significant amount of probe traffic is injected into the network. Furthermore, measurement must be completed in short time to effectively monitor the network state. In this paper, we propose a fast ABW measurement scheme that generates a small amount of probe traffic to achieve an acceptable measurement accuracy. The proposed scheme achieves an accuracy comparable to that of popular existing schemes. We present a performance study of the proposed scheme through ns2 simulation under different traffic conditions.**

***Index Terms*—Network measurement, active measurement, available bandwidth, ternary search, probing load.**

I. Introduction

End-to-end available-bandwidth (ABW) and link-capacity are two important parameters required to determine network condition for service providers to efficiently manage their resources and services. ABW is the unused link-capacity of a path at an instance of time, i.e., it is the difference between the link capacity and the amount of data traffic at particular period of time. Several ABW measurement schemes have been proposed [1]-[9]. Active measurement schemes send probe packets from a source node towards a destination node to estimate various network parameters. In these schemes, different probe packet characteristics, such as probe size, number of probes, and inter-probe gaps, etc. determine the features of the measurement process. However, active measurement schemes add extra traffic into the network, which may affect legitimate data traffic and the measurement accuracy [7]. So, it is desirable to perform ABW measurement in short period of time without injecting large amount of probe traffic.

In this paper, we propose an ABW measurement scheme that uses a ternary search algorithm [11], which converges in a short measurement time and with a small number of trails. This paper presents a performance study of the proposed scheme along with IGI [7] and Pathload [5] schemes in terms of different traffic conditions.

The remainder of this paper is organized as follows. Section II discusses about the existing ABW measurement schemes. Section III introduces the proposed ABW measurement scheme. Section IV presents the performance study of the proposed scheme. Section V presents our conclusions.

II. Related Work

Controllability of the active measurement process (e.g., rate and size of probe packets) makes it an attractive approach. Active measurement schemes send probe packets either as pairs or probe trains on a source-destination path and check the modification that the probe pairs or trains undergo to collect link-state information. These schemes can be further categorized into either probe-gap or probe-rate models. Probe-gap model schemes measure gap dispersion (i,e., change) value of a probe packet pair at the destination. e.g., cprobe [3], TOPP [4], IGI [7], spruce [9], and pathchirp [8]. Probe-rate model schemes compare the transmission rates of probe packets at source and destination for measurement. In this paper, we consider IGI and Pathlaod for comparisons with our proposed scheme.

IGI measures ABW of a path by sending out probe packets and determining the dispersion of probe packet pair gaps due to the interference of cross-traffic available on the path during measurement. It relies on a proportional dispersion of probe packets with respect to cross-traffic by ensuring joint queuing region (JQR) operation of the probe packet pairs on the smallest link-capacity of the path. It is called JQR operation when the first packet of a packet pair is available in the output queue of a node while the second packet arrives in the same queue. Note that IGI actually measures cross-traffic through gap model scheme and the ABW value is obtained by deducting this value from the smallest link-capacity of the path.

Pathload iteratively sends out probe packets towards the destination to determine the maximum probing rate over the measurement path until the sending rate at source and the receiving rate at destination are equal. Pathload uses a binary search algorithm [12] that adjusts the probing rate at each iteration. During the probing process, it compares one-way delays of the probe packets at the destination instead of their inter-probe gaps. Pathload shows that probe packets have non-increasing delays when the probing rates at source and destination are smaller than the ABW of the path under measurement.

III. Proposed Schemes

The proposed ABW measurement scheme is based on the probe-rate model, which iteratively sends probe trains (i.e., sequence of probe packets) at specific rate over the end-to-end path and estimates changes in the of probe trains transmission time at the destination. Here, the transmission time of a probe train at the destination is calculated as the time difference between the first and last probe packets. Change in transmission time of the probe train is affected by the ABW of the path during the measurement period. If the probe transmission rate is lower than or equal to the ABW, the probe train does not experience changes in its transmission time. We adopted the ternary search algorithm in the proposed scheme to find the ABW. This search algorithm sends two probe trains at two different transmission rates, during each iteration. These two probing rate values are one third and two thirds of the difference between the minimum and maximum probe rate limits of the ternary search algorithm. This search algorithm speeds up the search time.

1) Measurement Algorithm: Figure 1 shows a flow chart that describes the ABW measurement scheme. In this scheme, the source node shoots two probe trains towards the destination at two different transmission rates, i.e., *g-rate* and *h-rate*. The source node computes the cumulative gaps of the trains at the destination, i.e., *g_outgap* and *h_outgap*, upon receiving the replies of the probes, and compares them with the initial cumulative gap at the source, i.e., *g_ingap* and *h_ingap*, respectively. The source updates the probing rates in the following iterations based on the change of *g_increment* (i.e., *g_increment* = *g_outgap* - *g_ingap*) and *h_increment* (i.e., *h_outgap* - *h_ingap*). The measurement process terminates by providing an ABW value when either *g_increment* or *h_increment* undergoes a change between 1% and 1.5% or when the *g-rate* and *h-rate* difference is smaller than or equal to 1.5 Mb/s. Here the selected minimum measurable ABW is 0.5 Mb/s. This minimum is selected according to the complexity to comply with the termination condition of the search scheme and in function of the expected link capacity. We adopt 2.5% of the link capacity (e.g. 20 Mbp/s) as the minimum ABW value for the considered simulations examples. The maximum value is defined by the link capacity of the path.

IV. Performance Study

The proposed scheme along with IGI and Pathload were simulated in the ns2 network simulator [13] using different traffic types and load conditions. Figure 2(a) shows the single-hop scenario used in our simulation. The proposed schemes were also tested in two multiple-hop scenarios as shown in Figure 2(b). The multiple-hop scenario has more than one cross-traffic sources on different nodes. This cross traffic on different links can create a bottleneck link in any part of the network.

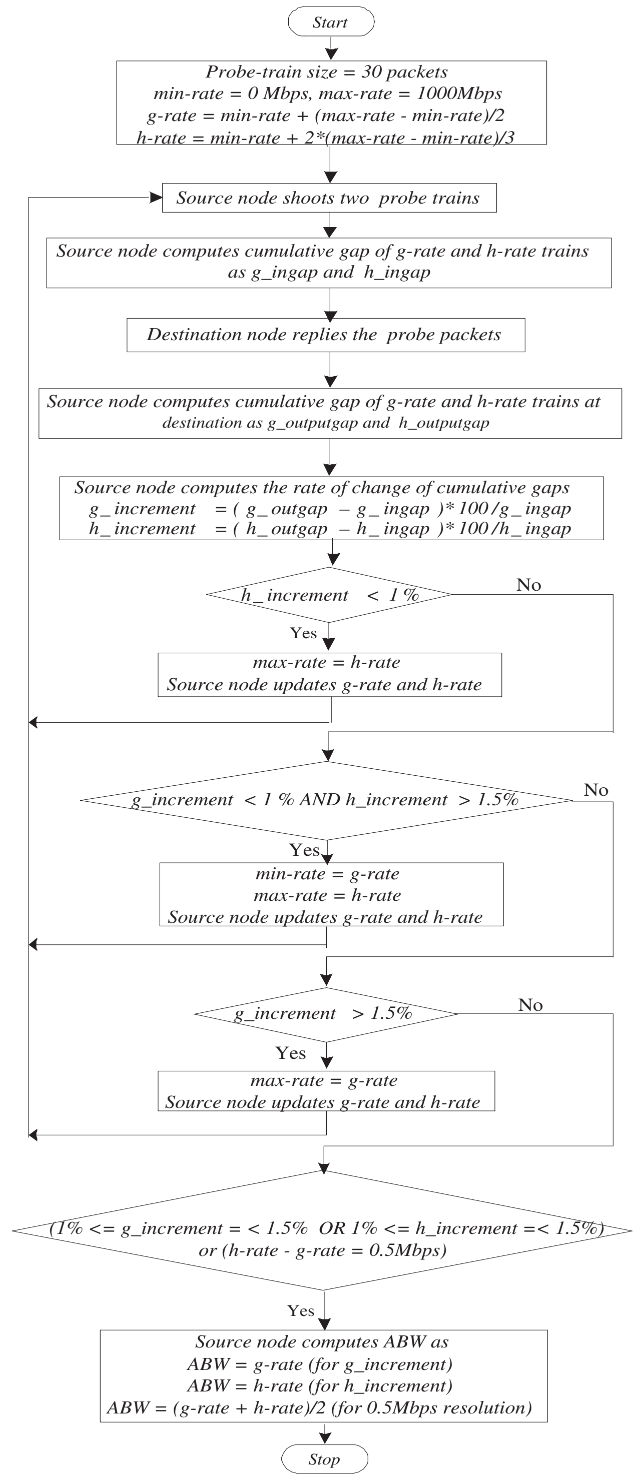

Fig. 1. Proposed ABW measurement algorithm.

A. Measurement Accuracy with Traffic Load

Figure 3 shows an accuracy comparison graph of IGI, Pathload, and the proposed scheme on the single-hop scenario in Figure 2(a) with 200 Mb/s of link capacity for each link and constant bit rate (CBR) traffic. The graph contains average

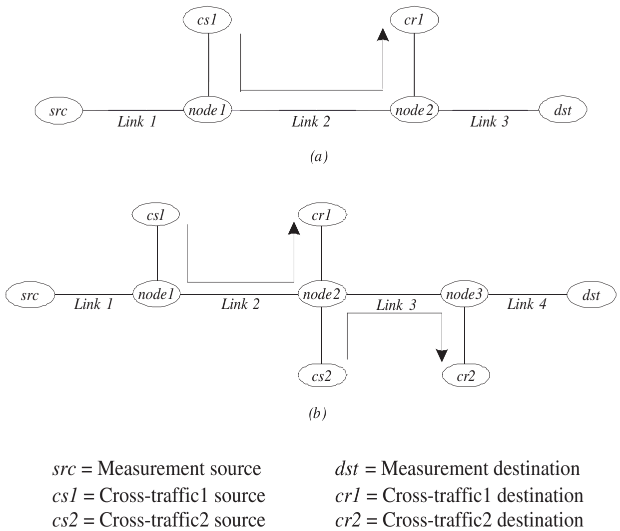

Fig. 2. (a) Single-hop topology, and (b) multiple-hop topology.

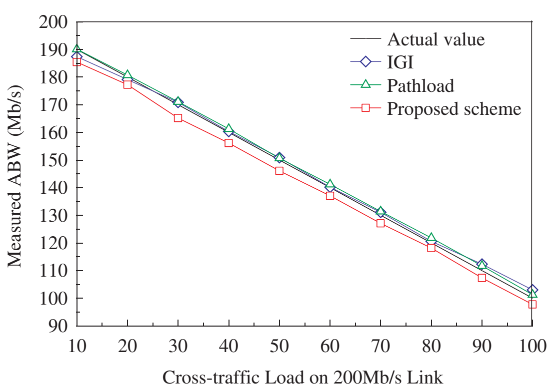

Fig. 3. Accuracy comparison of ABW measurement schemes with traffic load.

values from 25 measurements for each ABW point. The simulation results for the proposed scheme show an error (i.e., percentage error in reference of the actual value, which is calculated as the ratio of the difference between the actual value and the measured value and the actual value) equal to or smaller than 3% in every case. Even though IGI and Pathload have higher accuracy (i.e., smaller error) than the proposed scheme, the accuracy of the proposed scheme is comparable.

Table I shows the ABW measurement results of the proposed scheme for the multiple-hop scenario in Figure 2(b) using CBR traffic. We tested this scenario with different combinations of cross-traffic load values under a high load condition, e.g., 70% cross-traffic load. Still, the proposed scheme has an error below 10% in all load conditions. As an example, for an ABW of 16 Mb/s, the measured output is 15 Mb/s. This is an error of 6.25%.

TABLE I
ABW MEASUREMENT USING A MULTIPLE-HOP TOPOLOGY.

Topology: 2.(b), Probe packet size: 800B, Iterations: 25				
Link (1,2,3,4) (Mb/s)	Load (Link2) (Mb/s)	Load (Link3) (Mb/s)	Actual ABW (Mb/s)	Measured ABW (Mb/s)
20	1	1	19	17.0
20	1	2	18	16.5
20	1	3	17	16.0
20	2	3	17	16.0
20	4	2	16	15.0
20	4	3	16	15.0
20	5	3	15	14.0
20	5	4	15	14.0
20	6	4	14	13.0
20	5	6	14	13.0
20	5	7	13	13.0
20	10	3	10	10.0
20	4	10	10	10.0
20	11	5	9	9.0
20	13	12	7	7.0
20	14	10	6	6.0
20	15	4	5	5.0
20	16	10	4	4.0

1) Effect of Probing Load: We studied the effect of probing load on the ABW measurement using the single-hop scenario in Figure 2(a). We simulated the ABW schemes with three different probe-train lengths that induce different amount of probing loads on the measurement path. Each of the schemes were run for one measurement iteration to produce the measurement results.

Figure 4 shows the accuracy comparison of IGI, Pathload and the proposed scheme with 30-packet, 60-packet, and 100-packet probe trains. From these graphs, it seems that the ABW measurement overestimates the measurement with larger probe trains considering the outcomes of the proposed scheme. However, the measurement accuracies of all the schemes are smaller than or equal to 3% in every case. Pathload implementation uses a probe-train length of 100 packets while IGI uses 60 packets. IGI has shown that Pathload always overestimates ABW measurement as compared to IGI in Internet experiment and this is been attributed to the larger amount of probing load induced by Pathload. Hence, our simulation experiment states the similar fact that probing load can significantly affect the measurement process in TCP traffic environment on small ABW paths.

2) Measurement Accuracy with Multipe Traffic Flows: We simulated the effect of multiple traffic flows on the ABW measurement accuracy. We used 60-packet probe-train for all the schemes and similar single-hop topology as shown in Figure 2(a) except that the load on *Link 2* is the sum of the multiple flows (e.g., 2, 3, and 5 flows) on the measurement path in contrast with the single traffic flow scenario. According to Figures 5(a) and (b), the ABW measurement does not seem to be affected by a multi-source load condition. However, IGI and the proposed scheme results in Figures 5(a) and 5(c), respectively, show an error of up to 4.13% in the measurement with a larger number of flows.

3) Measurement Accuracy with Bursty Traffic: We also investigated the performance of ABW schemes with bursty traffic model in single-hop scenario as shown in Figure 2(a). Each scheme uses a probe-train length of 60 packets. In this

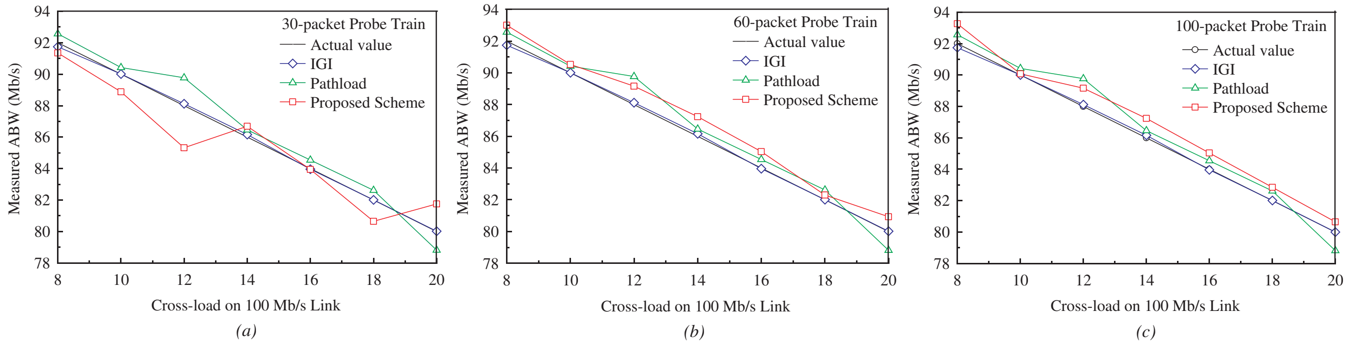

Fig. 4. Accuracy comparison ABW measurement schemes with (a) 30-packet probe train, (b) 60-packet probe train, and (c) 100-packet probe train loads.

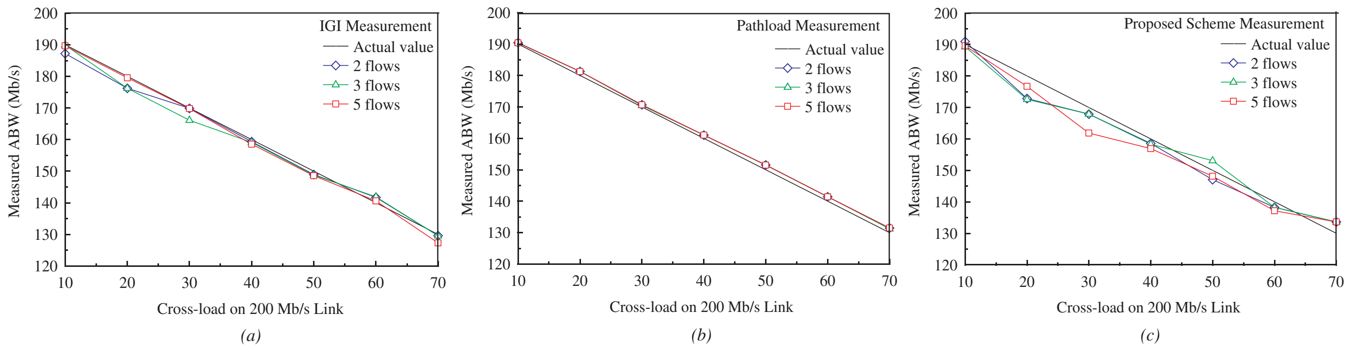

Fig. 5. Accuracy comparison of (a) IGI, (b) Pathload, and (c) the proposed scheme with different number of traffic load flows.

simulation, a Pareto traffic model with a burst and idle times of 200 ms and 100 ms, respectively, is used. The graphs in Figure 6 has similar performance as that of Figure 3 except that the propose scheme lightly overestimates the measurement.

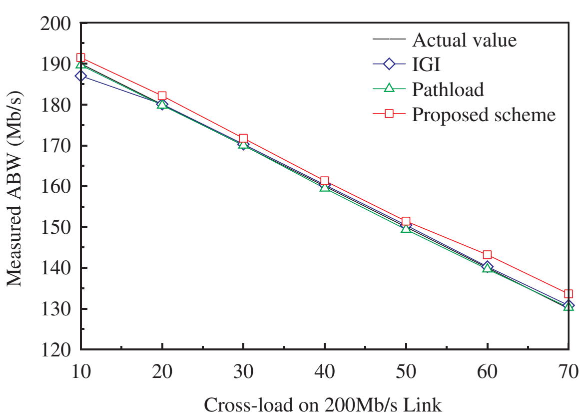

Fig. 6. Accuracy comparison of ABW mesurement schemes with bursty traffic load.

B. Measurement Time and Probe Load

We estimated both the measurement time and injected load of the proposed scheme and compared them to those of IGI, which is considered as one of the fastest existing ABW measurement schemes [7], [9]. For a fair comparison, both schemes used 60 800B probe packets per train and the simulation is ended after one measurement of similar termination conditions (i.e., IGI and the proposed scheme terminate with 1% and from 1% to 1.5% variations, respectively). According to Figure 7(a), the average measurement time of the proposed scheme is 1.36 sec with a standard deviation of 0.35 sec. On the other hand, IGI has an average measurement time of 1.55 sec and standard deviation of 0.32 sec.

Figure 7(b) shows the comparison of the number of measurement probes used by the proposed scheme and IGI in the same experiment. The graph shows that the proposed scheme generates a smaller number of probe packets than IGI to achieve comparable accuracy. In fact, the proposed scheme requires at least 984 fewer probe packets than IGI for every case. For example, the maximum difference is 1464 fewer probe packets for 60 Mb/s of ABW scenario by the proposed scheme.

Figure 7(c) shows the number of iterations required for different amount of ABW measurements in the proposed scheme. This figure can be used to describe the fluctuation in

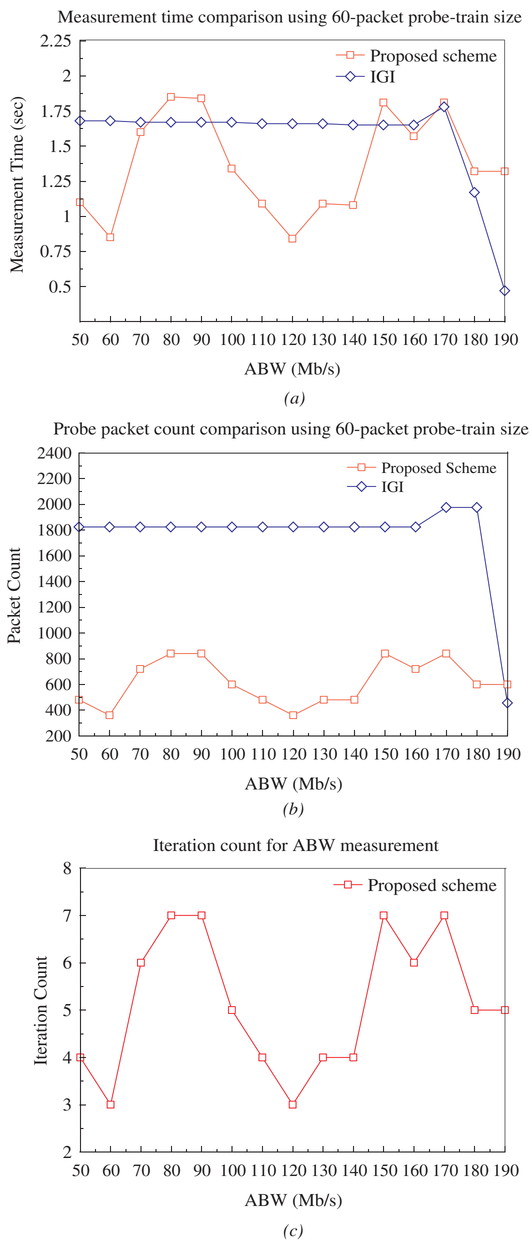

Fig. 7. (a) Measurement time of the proposed scheme and IGI, (b) probe load of the proposed scheme and IGI, and (c) iteration count of the proposed scheme.

the measurement time and probe load of the proposed scheme as shown in Figures 7(a) and 7(b). According to Figure 1, two probe trains with two different probing rates are sent during each iteration before obtaining the ABW of the measurement path. So, if the proposed scheme requires 7 iterations (e.g, ABW 80 Mb/s) instead of 6 iterations (e.g., ABW 70 Mb/s) for the ABW measurement, additional time and number of probe packets associated with the two probe trains are also added to the measurement time and the probe count, respectively. As the number of iterations required for ABW measurements varies with different ABW capacity of the path, the fluctuations in measurement time and probe count in Figures 7(a) and 7(b) are expected. We also tested the measurement time and probe load of the proposed scheme against Pathload. The smallest measurement time and probe count for Pathload are 17.09 sec and 10384 probe packets, respectively.

V. Conclusions

This paper presents a scheme to measure ABW based on the probe-rate model. This paper also presented a performance study of the proposed scheme in terms of probing load, traffic types and number of traffic flows and an accuracy comparison of the proposed scheme and other ABW measurement schemes. The ns2 simulation results of IGI, Pathload, and the proposed scheme show that all schemes have comparable accuracy under the tested load conditions. However, the proposed ABW measurement scheme, which uses a ternary search algorithm, measures ABW in shorter period of time and with low probing load.

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