Error Analysis of An Estimation Method Using RTT for Available Bandwidth of A Bottleneck Link

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I. INTRODUCTION

The Internet real-time applications grow rapidly. Available bandwidth estimation methods by the end host have been studied such as Pathload[1] and pathChirp[2]. These methods parameterize probe packets volume and observe the delay variation to estimate available bandwidth. In these methods, probe packets give heavy overhead loads on the network.

The authors proposed a new available bandwidth estimation method based on RTT [3]. The estimation errors consist of sampling errors and errors caused by the probe packets size for our proposed method.

In this paper, the sampling errors are analyzed by using inferential statistics. The errors caused by the probe packets size are also analyzed.

II. NEW AVAILABLE BANDWIDTH ESTIMATION METHOD USING RTT FOR A BOTTLENECK LINK

A. *Bandwidth utilization estimaiton*

The bandwidth utilization estimation plays a primary role in the proposed method.

The proposed method uses frequencies of minimum *RTT*s to estimate bandwidth utilization. The bandwidth utilization of a bottleneck link is estimated by observing the variation of *RTT*. Variation of RTT is generated mainly at the bottleneck link. The bandwidth utilization is determined by the ratio of number of minimum RTTs and total number of *RTT*s.

An example of measured *RTT* with bandwidth utilization of 0.5 is shown in Figure 1.

Minimum *RTT*s are defined as smaller *RTT*s than the specified threshold value, as shown as data points below the dashed line in this figure. The number of minimum *RTT* for link 1, RTT_1, is defined as in the following.

$$number of\ minimum RTT_1 = 1 - \frac{number of\ minimum RTT}{total\ number of\ RTT} \quad (1)$$

The equation gives bandwidth utilization of a single link configuration.

B. *Application to multi-hop links*

Bandwidth utilization estimation using the frequencies of minimum *RTTs* described in the previous section deals with a single hop network. This section describes the extension of single hop network to multi-hop networks.

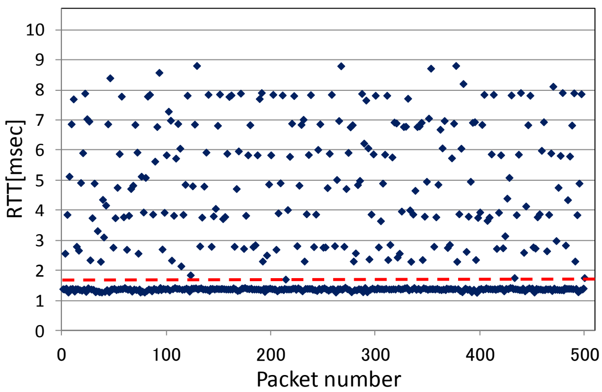

Figure 1. An example of RTT with the bandwidth utilization of 0.5

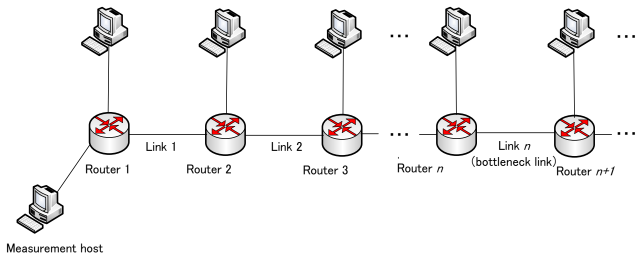

Figure 2. Network configuration

A multi-hop network configuration is shown in Figure 2. Link *n* is assumed to be a bottleneck link. The *number of minimum* RTT_n of link *n* observed at a measurement host is represented by the following

$$number\ of\ minimum RTT_n = \sum_{i=1}^{n} u_i \prod_{j=1}^{i-1} \left(1 - u_{j-1}\right) \quad (2)$$

where u_n is bandwidth utilization of the link *n*. The bandwidth utilization of link *n* is estimated by using measured *number of minimum* RTT_{n-1} and *number of minimum* RTT_n.

C. *Physical bandwidth capacity estimation*

Physical bandwidth capacity is estimated by using the difference between two bandwidth utilizations. The measurement host measures bandwidth utilization with the additional network load L_A, after the measurement host measures bandwidth utilization of link *n*. Physical bandwidth

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capacity C_n for a bottleneck link, link n, is given by the following

$$C_n = \frac{L_A}{u_n(L_A) - u_n(L_0)} \tag{3}$$

where C_n is bandwidth capacity of the bottleneck link n, L_A is additional network load, $u_n(L_0)$ is measured bandwidth utilization with no additional network load, and $u_n(L_A)$ is measured bandwidth utilization with an additional network loads L_A .

D. Available bandwidth estimation taking into accounttraffic load in return path traffic

The above estimation assumes no traffic in return path, which does not happen in the real situation. This section describes available bandwidth estimation taking into account return path traffic.

Forward path traffic and return path traffic are separated by using the parameters which were used to estimate the physical bandwidth capacity C_n. Measured bandwidth utilization $u_n(L_0)$ with no additional network load is given by the following equation

$$u_n(L_0) = u_{nfw} + u_{nbw}(1 - u_{nfw}) \tag{4}$$

where u_{nfw} is bandwidth utilization of forward direction, u_{nbw} is bandwidth utilization of backward direction of link n. Measured bandwidth utilization of link n, $u_n(L_A)$, with network load L_A is given by the following equation

$$u_n(L_A) = u_{nfw} + L_A + u_{nbw}(1 - u_{nfw} - L_A) \tag{5}$$

The bandwidth utilization of forward direction of link n, u_{nfw} , is estimated by the following

$$u_{nfw} = \frac{u_n(L_A) - u_n(L_0) + L_A / C(u_n(L_0) - 1)}{u_n(L_A) - u_n(L_0)} \tag{6}$$

The available bandwidth of the link n, $A_{n,}$ is given by the following

$$A_n = C_n(1 - u_{nfw}) \tag{7}$$

where C_n is physical bandwidth capacity of the link n, u_{nfw} is bandwidth utilization of forward direction of link n. The flowchart of the proposed method is shown in Figure 3.

V. ERROR ANALYSIS FOR THE PROPOSED METHOD

The estimation errors consist of sampling errors and errors caused by the probe packets size. The sampling errors are analyzed by using inferential statistics. The errors caused by the probe packets size are also analyzed. The analytical values were compared with experimental values. The experimental values are obtained for the experimental network with seven hop configuration [3].

The estimation error is defined as in the following

$$Esitimation\ error \triangleq \frac{Eestimated\ available\ bandwidth - Theoritical\ available\ bandwidth}{Physical\ bandwidth\ capacity}$$

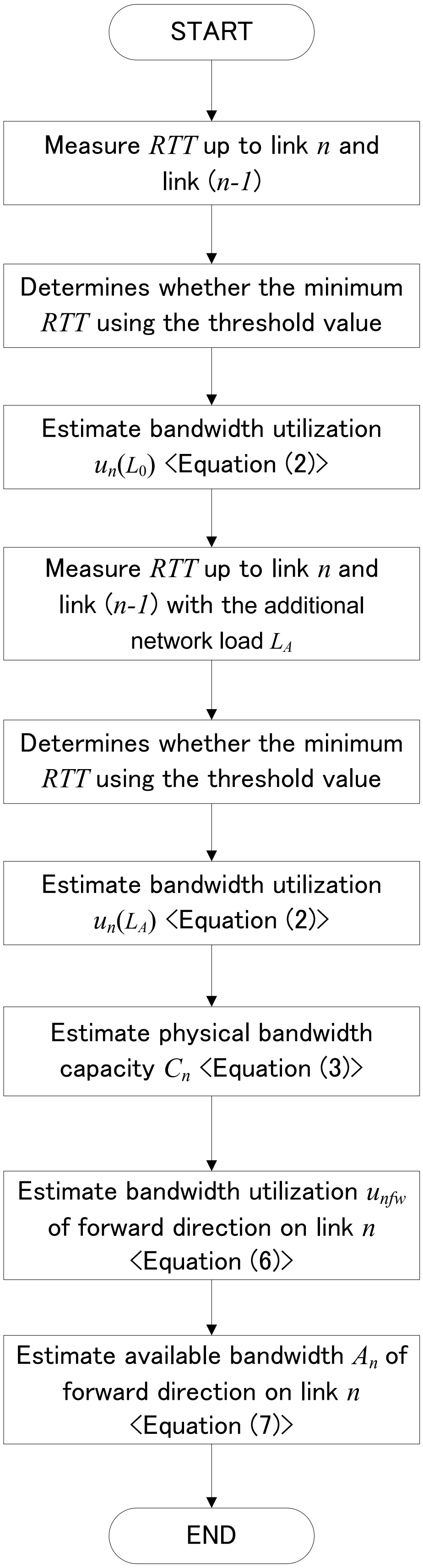

Figure 3. Flowchart of the proposed available bandwidth estimation method

A. *Sampling Errors*

This section analyses sampling errors of the proposed method using inferential statistics.

The available bandwidth estimation by the proposed method is interpreted as the estimation of number of unused slots out of the number of population. The population number is given by the total number of slots in the network bandwidth. The slot size is given by the probe packet size, which gives estimation resolution.

The sampling error e_s is given by the following equation.

$$e_s = \pm \rho \sqrt{\frac{N-n}{N-1} \times \frac{P(1-P)}{n}}$$

where n is number of samples, N is the number of population, P is population proportion, ρ is reliability coefficient. The reliability coefficient ρ is 1.96 when the reliability is 95%. The population proportion is to be estimated and unknown, and is replaced by the estimated proportion in calculation.

In the proposed method, the number of samples n is 126 [slots] (1 slot =probe packet size, 60 byte) and the number of population N is 20833 [slots per second].

B. *Experimental results Error caused by probe packet size*

An example of probe packets overlapping a tail of network load packet is shown in figure 4. Spaces in the bandwidth, unused bandwidths, are accurately observed up to one byte precision when the probe packet size is one byte. One byte probe packet is not realistic. The adopted probe packet size is sixty byte in the experimental evaluation. In the worst case, the heading one byte of a probe packet does not fit in a space, i.e., one byte at an tail of a traffic packet and the one byte at the probe packet head are congested, *RTT* of the probe packet is not regarded as a non-minimum *RTT*, even if the remaining fifty nine byte of the probe packet is not congested with a traffic packet. Similarly, up to 59 byte of a probe packet congestion with the traffic packet will lead to estimation errors. Only zero byte and 60 byte congestion will lead to accurate estimation. This type of estimation errors is named estimation errors caused by the packet size. This error can be avoided only if one byte probe packet is realized.

C. *Sampling errors and errors caused by the probe packet size*

The analytical results with analytical errors caused by sampling and packet size are plotted together with the estimation by the proposed method in Figure 5.

The errors for analytical values and estimation values by the proposed method are shown in Figure 6. The results show good coincidence with the experimental results.

VI. CONCLUSION

We proposed the estimation method for available bandwidth of a bottleneck link by using frequency of minimum RTTs.

The estimation errors consist of sampling errors and errors caused by the probe packets size for our proposed method. This paper analyzes the errors of the proposed

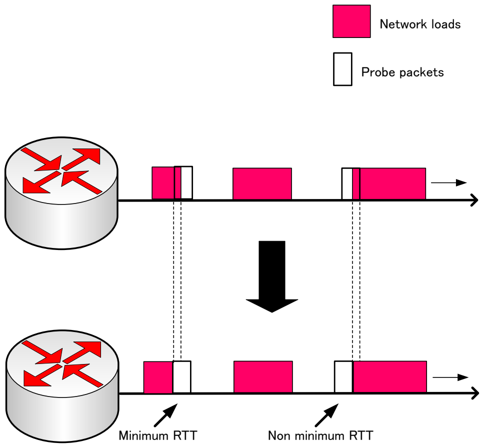

Figure 4. An example of probe packets overlapping a tail of network load packet

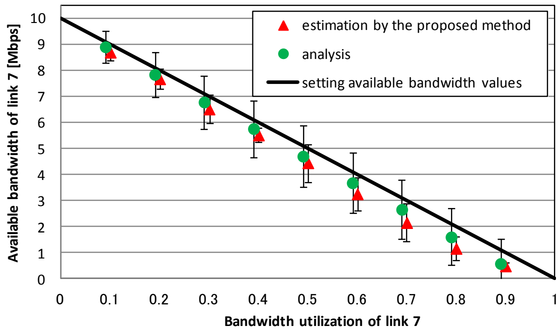

Figure 5. The analytical results with analytical errors caused by sampling and packet size and the estimation by the proposed method

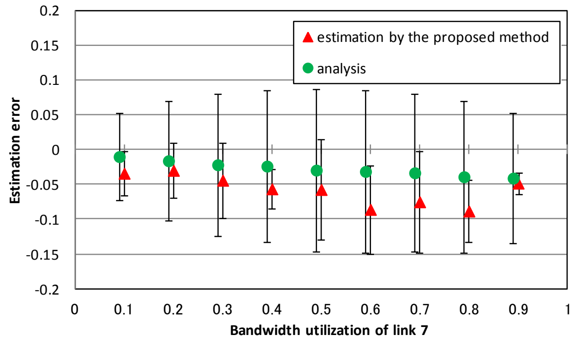

Figure 6. Errors in analytical results with sampling and packet size and those of the proposed method

method. It was clarified that the overall errors consist of the sampling errors and the errors caused by the probe packets size. The error analysis gives good coincidence with the experimental estimation.

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