Accurate Measurement Technique of Packet Loss Rate in Parallel Flow Monitoring

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***Abstract*—In our previous research, we have proposed a parallel flow monitoring method in which the end-to-end delay is accurately measured. The method increases delay samples of a target flow by utilizing the observation results of other flows sharing the source/destination with the target flow. In this paper, we extend this method to loss measurement, and enable it to fully utilize information of all flows including flows with different source and destination. Through NS-3 simulations, we confirmed that the proposed method reduces error of loss rate estimations by 57.5% on average.**

***Index Terms*—Active Measurement, Packet Loss Rate, Parallel Measurement, Probe Packet, QoS Monitoring**

I. INTRODUCTION

As a measurement technique of end-to-end metrics (e.g. delay, loss rate, etc.) for networks, an active measurement in which probe packets are injected into a network is commonly used, and various measurement tools for active measurements have been proposed in prior works [1]–[3]. In the modern Internet, a large delay (that exceeds 150 [ms] as mentioned in ITU-T Recommendation G.114 [4]) or packet loss are rare events. Hence, it is difficult to capture such rare events using a limited number of the probe packets on the path, and they are still hard to measure. While most of prior works utilize only one probe flow for a measurement of one path in a parallel path monitoring, we have proposed a parallel flow monitoring method in which delay on a flow is accurately measured by utilizing the observation results of flows sharing the source/destination [5], [6].

Based on the delay measurement method in reference [5], we propose a loss measurement method that fully utilizes flows, including flows with different source and destination in this paper. We extend the delay measurement method to loss measurement with a weighted loss estimator. In the proposed method, when a loss rate on a path of a target probe flow is estimated, information regarding lost probe packets of the other probe flows is utilized. Even if a target probe flow fails to catch loss events, the proposed method can estimate the loss rate on the path of the target probe flow since another probe flow may catch loss events. Therefore, the proposed method transcends a fundamental accuracy bound of conventional active measurement of loss rate.

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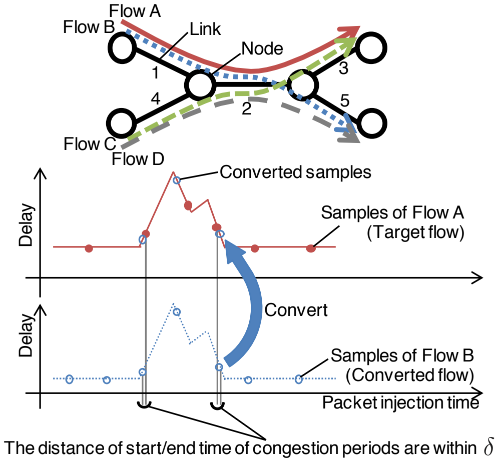

Fig. 1. Conversion of samples in parallel flow monitoring.

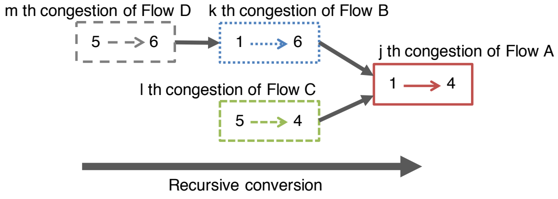

Fig. 2. An example of a dependency tree for a recursive conversion.

II. ASSUMPTIONS

In this paper, we assume that most of loss events are caused by a buffer overflow in interfaces included in links with congestions. Propagation delay can be regarded as a constant for a path while queueing delay dynamically changes reflecting traffic status. Inevitably, loss events highly depend on queueing delay. We assume that links with large queueing delay, i.e. links with many loss events, are sparse among all links in a network, and a ratio of periods with large queueing delay on a link to the other periods is small.

III. PARALLEL FLOW MONITORING FOR DELAY

Since we assume sparsity of congested links, queueing delay processes within a congestion period on multiple paths that have common links frequently overlap, and the samples within the congestion periods can be converted (see Fig. 1).

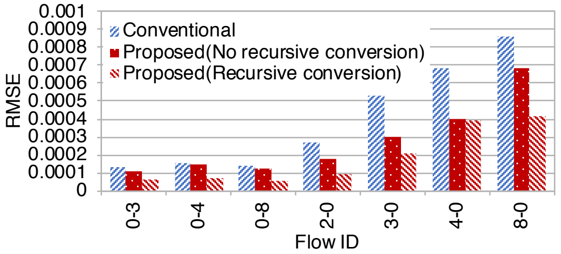

Fig. 3. RMSE of a loss rate estimation.

In the method in reference [5], when congestion periods of two flows whose start and end times are respectively almost the same (i.e., they are closer than a constant probe interval δ), the samples within the congestion periods of each flow are mutually converted. A congestion period is observed as consecutive samples that are larger than a threshold x_{th}. The jth congestion periods on the path of Flow A can be observed by $X_{\mathrm{A},j}$.

IV. PARALLEL FLOW MONITORING FOR LOSS RATE

The proposed method achieves accurate loss rate measurements by converting samples of loss events. First of all, samples $L_{\mathrm{A},j}$ of loss events between first and last samples are recorded with $X_{\mathrm{A},j}$. Based on the method in reference [5], samples $X_{\mathrm{A},j}$ for delay are converted each other, thereby obtaining samples $\mathcal{X}_{\mathrm{A},j}$ which includes converted samples. When the samples $X_{\mathrm{A},j}$ are converted to the kth congestion period on the path of Flow B, samples $L_{\mathrm{A},j}$ of loss events are also converted to samples of loss events within the kth congestion period on the path of Flow B. As a result, the samples $\mathcal{L}_{\mathrm{B},k}$ which includes converted samples within the kth congestion period on the path of Flow B are updated to $\mathcal{L}_{\mathrm{B},k} \cup L_{\mathrm{A},k}$. Note that $\mathcal{X}_{\mathrm{A},j}$ and $\mathcal{L}_{\mathrm{A},j}$ includes converted samples from other flows while $X_{\mathrm{A},j}$ and $L_{\mathrm{A},j}$ represent original samples of Flow A.

To provide an unbiased estimator of loss rate on each path, samples should be weighted since the samples of loss events in the proposed method are biased on a time-space, while most of conventional loss measurements using active probes assume that probe packets are uniformly distributed. The weight of a sample s is given as $|X_{\mathrm{A},j} \cup L_{\mathrm{A},j}|/|\mathcal{X}_{\mathrm{A},j} \cup \mathcal{L}_{\mathrm{A},j}|$ for $s \in \mathcal{L}_{\mathrm{A},j}$. $\sum_s |X_{\mathrm{A}} \cup L_{\mathrm{A}}|/|X_{\mathrm{A}}|$ provides an estimator of loss rate on the path of Flow A.

By repeatedly converting samples obtained from each probe flow, the proposed method utilizes information of all probe flows that include flows with different source and destination. Even if both source and destination are different, flows that share a part of paths includes information of the target flow. By checking whether conversion of samples is possible for all pairs of congestion periods of all probe flows, trees that represent dependency of each conversion are generated for each congestion period (see Fig. 2). The proposed method recursively converts from the leaves to the root of the tree. The computational complexity of the conversion process of the proposed method is $O(NL)$ for each congestion, where N and L denote the number of flows and the maximum number of samples in a congestion, respectively.

V. EVALUATIONS

We perform ns-3 [7] simulations to confirm that the number of captured loss events increase and accuracy of a loss rate estimation is improved. The network we simulated resembles Internet2 topology [8] with 9 nodes and 13 links whose capacities are 15.552 [Mbps]. 3 types of traffic (Poisson, exponential ON-OFF, and periodical probe traffic) stream between all pairs of 9 nodes. Queue management in each interface of nodes is drop-tail policy, and the maximum queue size is set to 1024. A buffer overflow can occur due to temporal capacity shortage when multiple ON-OFF traffic join together at an interface. The simulation time is 1005 [s] and we only use the data from 5 [s] to 1005 [s]. The threshold x_{th} is set to 0.01 [s].

We evaluate an accuracy of a loss rate estimation of the proposed method. The simulation was repeated 10 times by changing the phase of the probe packet injection time. Root Mean Squared Errors (RMSE) of loss rate measurements are calculated, and the result is shown in Fig. 3. In no recursive conversion of Fig. 3, only samples of flows that has the same source/destination with a target probe flow are converted. We can confirm that RMSE of each probe flow is reduced by the proposed method. The proposed method without recursive conversion provides 31.3% reduction of RMSE on average. Since the proposed method with recursive conversion achieves 57.5% reduction of RMSE on average, it can be confirmed that recursive conversion achieves further improvement in accuracy.

VI. CONCLUSIONS

We proposed a loss measurement method that fully utilizes flows, including flows with different source and destination in this paper. The proposed method is based on the delay measurement method in reference [5]. Through simulations on ns-3 simulator, we confirmed that the proposed method can reduce estimation errors by 57.5% on average.

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