Intrusiveness-aware Estimation for High Quantiles of a Packet Delay Distribution

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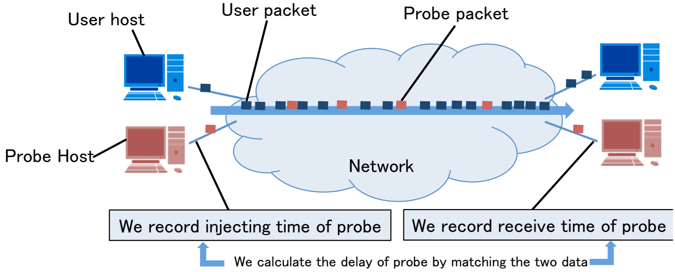
Importance of Active Measurement

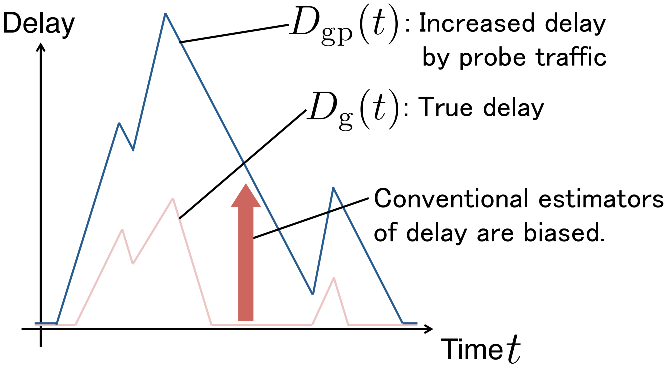
- Real-time applications have been widely spread. (e.g. audio/video conferencing and IP telephony)
- Large end-to-end delay lowers the quality of real-time applications.
- It is often necessary to accurately estimate end-to-end delay and evaluate path quality.

- Active measurement is one representative measurement technique for end-to-end delay.



Fundamental Problem and Objective

- A problem with active measurement is that probe traffic increases network delay.

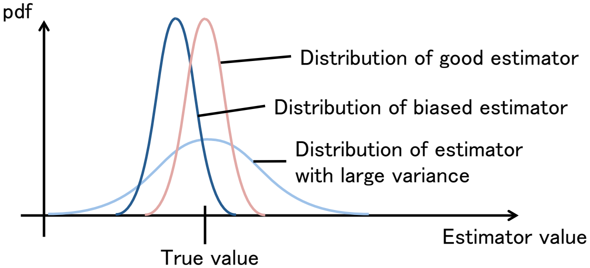


Objective

- To estimate the delay of a network without probe packets from the delay of that same network with probe packets.

What is an Acculate Estimator?

- An accurate estimator must have a smaller variance and a smaller bias.



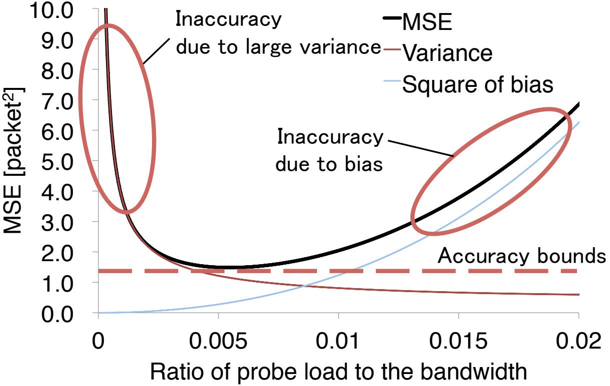
- We evaluate estimators by using Mean Square Error (MSE).

$$(\text{MSE}) = \underbrace{\text{Var}[\hat{P}]}_{\text{Variance}} + \{\underbrace{\text{E}[\hat{P}] - P^*}_{\text{Bias}}\}^2 = \text{E}[(\hat{P} - P^*)^2] \quad (1)$$

$\hat{P}$: Estimator $\qquad$ P^* : True value

Bounds of Conventional Estimator

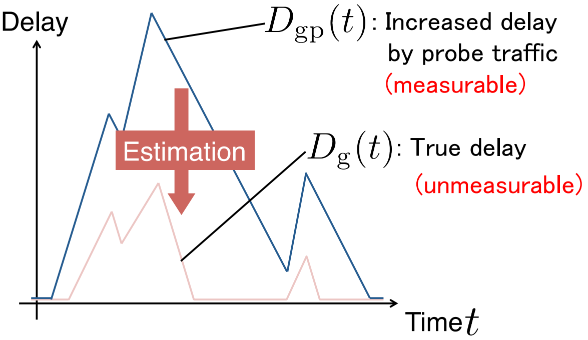
- We calculated MSE of conventional estimator for the mean number of packets in M/M/1.



Bandwidth :	155.52 Mbps	Traffic load :	90% of bandwidth
Packet size :	Exponential distribution with mean 600 byte	Measurement period :	1.0 [sec]

INTEST: INTrusiveness-aware ESTimation

To transcend that bound, we propose INTrusiveness-aware ESTimation (INTEST), an approach that modifies for delays increased by probe packets for networks.

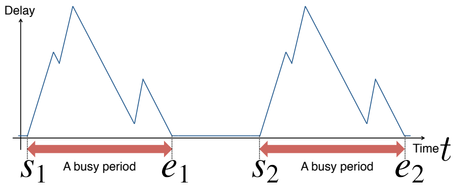


- We can know increment of delay using the information of the number of probe packets.

INTEST: INTrusiveness-aware ESTimation (2)

- For busy period $[s_j, e_j)$, delay $D_{\mathrm{gp}}(T_i)$ experienced by a probe packet can be expressed by the following:

$$D_{\mathrm{gp}}(T_i) = D_{\mathrm{gp}}(T_{i-1}) + \frac{X_{\mathrm{gp}}(T_i, T_{i-1})}{c} - (T_i - T_{i-1}), \quad (s_j \le T_i \le T_{i-1} \le e_j)$$



T_i :	Time of an arrival of ith probe packet
c :	Bandwidth [bps]
$X_{\mathrm{gp}}(t_0, t_1)$:	traffic in a period $[t_0, t_1)$ [bit]

- Bussy periods can be estimated by probe delay.
- Based on the above equation, we can modify the inclement of delay since the traffic of probe packets in $X_{\mathrm{gp}}(T_i, T_{i-1})$ is known.

INTEST: INTrusiveness-aware ESTimation (3)

- We can estimate the true delay by the following recurrence equation.

Decreasing the increased delay by probe traffic

Busy case and idle case

$$\hat{D}_{\mathrm{g}}(T_i) = \begin{cases} \max\left(\hat{D}_{\mathrm{g}}(T_{i-1}) + D_{\mathrm{gp}}(T_i) - D_{\mathrm{gp}}(T_{i-1}) - \dfrac{x^{\mathrm{p}}_{i-1}}{\hat{c}}, \hat{d}\right), & \hat{s}_j \le T_i \le \hat{e}_j \\ D_{\mathrm{gp}}(T_i), & \text{otherwise.} \end{cases}$$

$\hat{D}_{\mathrm{g}}(T_i)$: The delay of the network without probe packets at time T_i

x^{p}_i : The size of ith probe packets [bit]

$\hat{s}_j$: jth smallest element of $\{T_i \mid D_{\mathrm{gp}}(T_{i-1}) \le d + \delta < D_{\mathrm{gp}}(T_i)\}$

$\hat{e}_j$: jth smallest element of $\{T_i \mid D_{\mathrm{gp}}(T_{i-1}) \ge d + \delta > D_{\mathrm{gp}}(T_i)\}$

- $\hat{s}_j$ and $\hat{e}_j$ are estimators of start and end time of a busy period, respectively.

Evaluation in M/M/1

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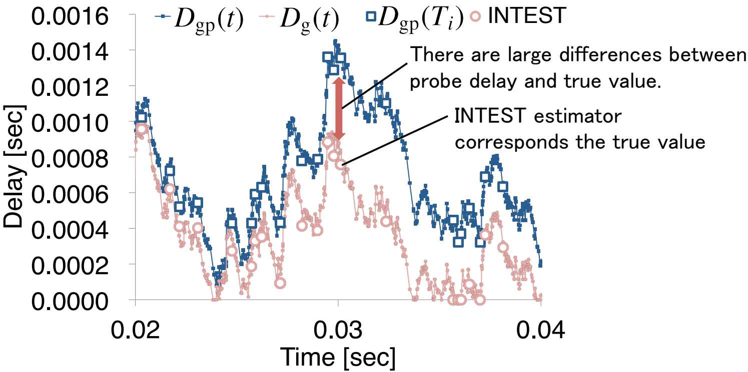
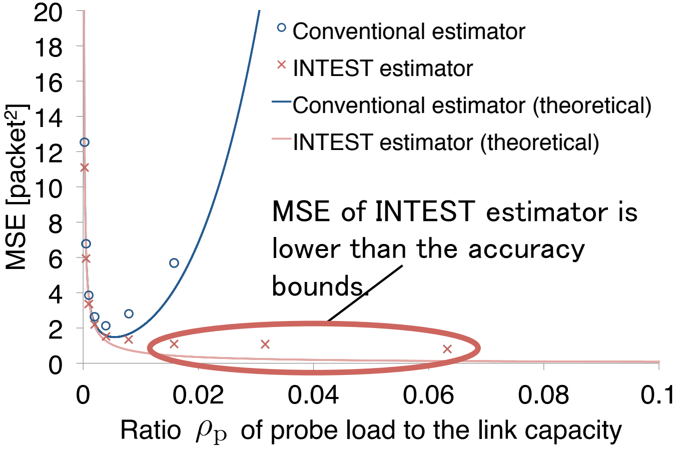
- We estimated the number of the packets in the router modeled by M/M/1.



Bandwidth :	155.52 Mbps	Target traffic rate :	90% of bandwidth
Packet size :	It follows the exponential distribution with mean 600 byte	Probe rate :	About 3.16% of bandwidth
		Threshold δ :	7.5 packet

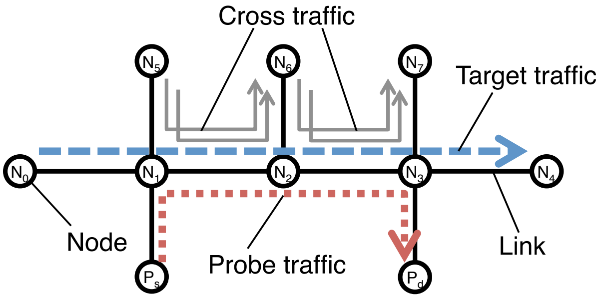
Evaluation in M/M/1 (2)

- We calculated the MSE by repeating the simulation 5000 times.
- INTEST can achieves acculate estimation though the conventional estimator has a accuracy bounds.



Evaluation through ns-3 Simulations

- We performed INTEST in ns-3 simulation.



Bandwidth of N_1-N_2 and N_2-N_3 :	15.552 Mbps
Bandwidth of the other links :	62.208 Mbps
Probe packet size :	64 byte
Packet size of the other traffic :	600 byte
Target traffic rate :	10% of the bottleneck bandwidth
Cross traffic pattern :	ON-OFF process in which ON/OFF period follows exponential distribution with mean 0.5 sec
Cross traffic rate :	8 Mbps

Evaluation through ns-3 Simulations (2)

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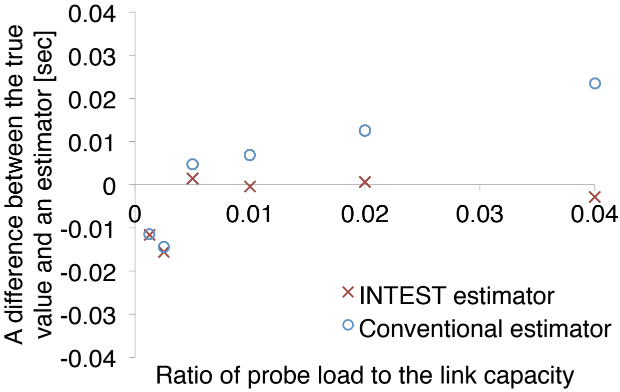
- We evaluated the bias when we estimated 95%-quantile of delay.
- We obtained a similar result to the M/M/1 result.



Conclusion and future works

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In this paper, we demonstrated that there exists a fundamental accuracy bound to conventional active measurement of delay and proposed INTEST that estimates the delay of a network without probe packets from the delay of that same network with probe packets.

- INTEST modify the increased delay by the load imposed by probe traffic.
- Performing simulations of M/M/1 and ns-3, we demonstrated that INTEST provides unbiased and small variance estimation.

Future works

- Evaluation of INTEST on a real network.
- To extend it to packet loss estimation and to wireless networks.

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Thank you for your kind attention.