Design of Probe Intervals to Improve Accuracy of CoMPACT Monitor

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Background (1)

Change of recent network

- Various applications appear and provide new services including telephony and live video
- The traffic of each flow exhibits various characteristics
- Various applications require the various quality of service (QoS)
- It is necessary to guarantee the reliability to the network used on business

In order to meet such varied requirements for network control, the measurement technology to produce per-flow QoS information is needed.
(e.g. for each user, application, or organization)

- In this paper, we focus the one-way delay for each flow

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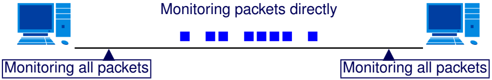
- Conventional means of measuring one-way delay can be classified into passive and active measurements

Passive measurement

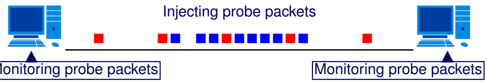


- It monitors the target packets directly by capturing the packets
  - It is used to measure the volume of traffic, one-way delay, round-trip time (RTT), loss, etc.
- It can get accurate one-way delay for each flow
  - One-point monitoring to measure volume of traffic can be conducted very easily
- Two-point monitoring to measure one-way delay lacks scalability

Background (3)

- Conventional means of measuring one-way delay can be classified into passive and active measurements

Active measurement



- It monitors QoS by injecting probe packets into a network path and monitoring them
- It can be used to measure one-way delay, RTT, loss, etc.
- It is easy for the end user to carry out
- Injection of enormous probe packet debase network performance
- the one-way delay data obtained by active measurement does not represent the per-flow one-way delay, but only one-way delay of the probe packets

Background (4)

Traditional methods

- Passive measurement has a scalability problem
- Active measurement can not measure per-flow one-way delay

In large-scale network, we can NOT get per-flow one-way delay by using traditional methods.

The objective (1)

We have proposed change-of-measure-based passive/active monitoring (CoMPACT monitor) that achieves scalable measurement of one-way delay distribution for each flow.

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Study of F.Baccelli

- Study about inter-probe time for active measurement
- Suboptimal probing in terms of accuracy was proposed

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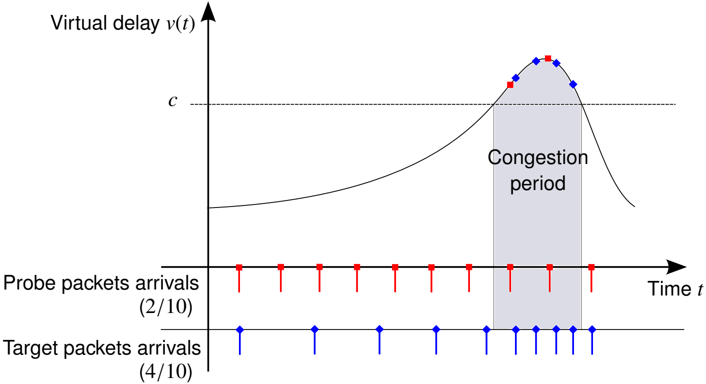
In our study, we have applied this suboptimal probing to CoMPACT monitor and tried to improve CoMPACT monitor in accuracy.

CoMPACT Monitor (1)

- If arrival timing is different, packet delay is different



- In probe packets, 2 packets of 10 packets arrive in congestion period
- In target packets, 4 packets of 10 packets arrive in congestion period
- CoMPACT monitor transfers probe packets delay into target packets delay according to density of target packets

CoMPACT Monitor (2)

- Estimator of one-way delay distribution by CoMPACT monitor
- It estimates the probability for target packet delay to exceed c

  m : The number of probe packets
  T_n : Arrival time of nth probe packet
  $v(t)$: Sample path of virtual one-way delay
  $a(t)$: Sample path of volume of traffic of target flow

$$\underbrace{\frac{1}{m}\sum_{n=1}^{m} 1_{\{v(T_n)>c\}}}_{\substack{\text{Delay of}\\\text{probe packet}\\\text{(Active)}}} \underbrace{\frac{a(T_n)}{\sum_{l=1}^{m} a(T_l)/m}}_{\substack{\text{Weight for}\\\text{translation}\\\text{(Passive)}}}$$

- The traffic $a(t)$ is obtained by one-point passive measurement
- Passive measurement to measure traffic has NOT scalability problem
- Note that $v(t)$ and $a(t)$ are both sample paths in this estimator

Suboptimal Probing (1)

- Intervals with an exponential distribution have been widely used as probe packets arrivals
  (Probing method according to PASTA property)
- This is the only appropriate method if we can not ignore the effect of probe packets

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Assumption

- We can ignore the effect of probe packets

- PASTA-based probing is NOT the only method
- Some other probing method can estimate true value
  (e.g. Intervals with a uniform or Gamma distribution etc.)

Suboptimal Probing (2)

Assumption

- The autocovariance function of the target process is convex

- Periodic-probing achieves minimum variance of the estimator
- A lower variance is connected with accuracy
- If the autocovariance function is convex strictly, periodic-probing is optimal in accuracy

However, the autocovariance function is not convex strictly. Therefore, a phase-lock phenomenon occurs and the estimator may converge on a false value when the cycle of the target process corresponds to the cycle of the probe packet.

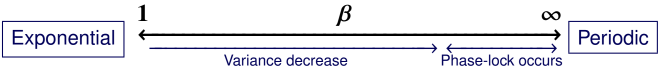
- Periodic-probing is not actually optimal
- There is the tradeoff between PASTA-based probing and periodic-probing

Suboptimal Probing (3)

- To solve the tradeoff, intervals with the parameterized Gamma distribution is proposed
- When $\beta = 1$, it corresponds to exponential distribution
- When $\beta \to \infty$, it converges on determinate value

Property of this Gamma-probing

- This Gamma-probing links PASTA-based probing with periodic-probing continuously.



- Variance decreases with increase of β
- Phase-lock occurs when β is so large value
- We can get a suboptimal probing if we tune appropriate β

The application of Gamma-probing to CoMPACT monitor (1)

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- We discuss the application of Gamma-probing to CoMPACT monitor
- Both of them estimate some averages of process which represent network state by using sampling of probe packets
- The significant issue in this application is in the difference between objects to measure
- We should carefully investigate the characteristics of CoMPACT monitor and Gamma-probing

Theory of Gamma-probing

- The target process is stationary and ergodic stochastic process
- The accuracy improvement is guaranteed only when we estimate the ensemble mean of stationary stochastic process

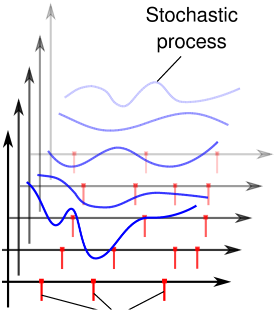
Theory of CoMPACT monitor

- We assume neither stationarity nor ergodicity for the target process
- We measure the time average of sample path by CoMPACT monitor

The application of Gamma-probing to CoMPACT monitor (2)

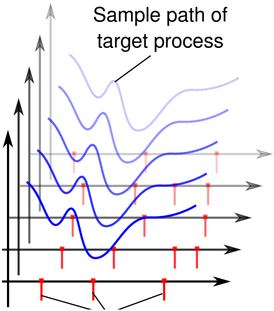
- This difference appears in discussion of variance of estimator (namely discussion of accuracy)

Theory of Gamma-probing



The variance of estimator depends on both stochastic variations of target process and sampling timing.

Theory of CoMPACT monitor



The variance of estimator depends on only stochastic variations of sampling timing.

The application of Gamma-probing to CoMPACT monitor (3)

- Variance of estimator in each theory is expressed as follows

Theory of Gamma-probing

- We should treat target process as stochastic process $Y(t)$
- Variance of estimator can be divided into two parts: variance and covariance part
- The variance part does not depend on β
- The covariance part decreases monotonously as β increases

$$\mathrm{Var}[\hat{p}] = \underbrace{\frac{1}{m}\mathrm{Var}[Y(0)]}_{\text{The variance part}} + \underbrace{\frac{2}{m^2}\sum_{n\neq l}\int R(\tau) f_{|n-l|}(\tau)\mathrm{d}\tau}_{\text{The covariance part}}$$

m : The number of probe packets

$Y(t)$: Target stochastic process

$R(\tau)$: The autocovariance function of target stochastic process

$f_n(t)$: Probability density function of arrival time of nth probe packet

The application of Gamma-probing to CoMPACT monitor (4)

- Variance of estimator in each theory is expressed as follows

Theory of CoMPACT monitor

- We should treat target process as sample path $y(t)$
- The covariance part tends to decrease with increase of β as well as the case of Gamma-probing
- The variance part depends on β, too
- We should discuss the relation between variance part and β

$$\mathrm{Var}[\hat{p}] = \underbrace{\frac{1}{m^2}\sum_{n=1}^{m}\mathrm{Var}[y(T_n)]}_{\text{The variance part}} + \underbrace{\frac{2}{m^2}\sum_{n\neq l}\mathrm{Cov}(y(T_n), y(T_l))}_{\text{The covariance part}}$$

m : The number of probe packets

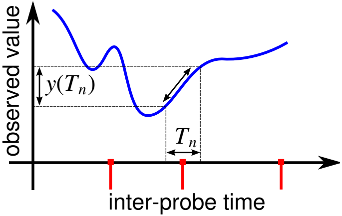
$y(t)$: Sample path of target process

T_n : Arrival time of nth probe packet

The application of Gamma-probing to CoMPACT monitor (5)

The relation between variance part and β

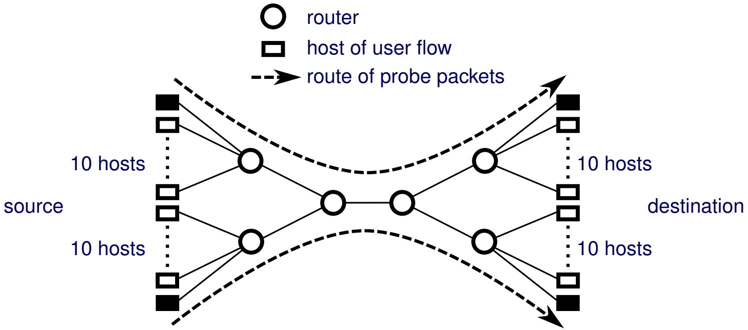
- Then variance of inter-probe time T_n decreases with increase of β in Gamma-probing
- The variance part decreases with increase of β since each observed value $y(T_n)$ is not varied



Both of the variance and covariance parts tend to decrease with increase of β. Therefore, we can also expect accuracy improvement with increase of β when Gamma-probing is applied to CoMPACT monitor.

Simulation Model (1)

- We investigated the effectiveness of Gamma-probing for CoMPACT monitor through simulations
  - There are 20 pairs of source and destination end hosts
  - Each source end host transfers packets by UDP to the corresponding destination end host as user flow
  - In addition, probe packet trains are streamed on the two routes to estimate one-way delay by CoMPACT monitor



Simulation Model (2)

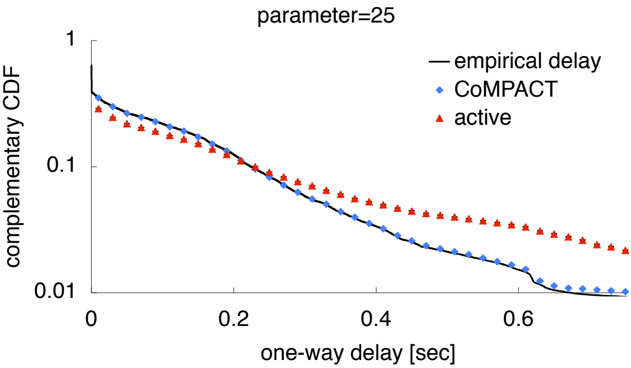
- User flows are given as ON/OFF processes and categorized into the 4 types
- Probe packet trains are categorized into the 5 types listed in the following table

Distribution of probe intervals	Parameter of Gamma distribution	Mean probe intervals
Exponential	$(\beta = 1)$	0.5 s
Gamma	$\beta = 5$	0.5 s
Gamma	$\beta = 25$	0.5 s
Gamma	$\beta = 125$	0.5 s
Periodic	$(\beta \to \infty)$	0.5 s

- Exponential is corresponding to traditional PASTA-based probing
- Note that parameters of Exponential and Periodic are parameters of the Gamma distribution corresponding to each probing

Estimation of one-way delay (1)

- We confirmed that we can estimate the empirical delay by CoMPACT monitor with Gamma-probing
  - Parameter β of Gamma-probing is 25



- For example, the rate of packets for delay to exceed 0.2 seconds is about 10 percent in this figure
  - We have plotted for other parameters and gotten similar results

Estimation of one-way delay (2)

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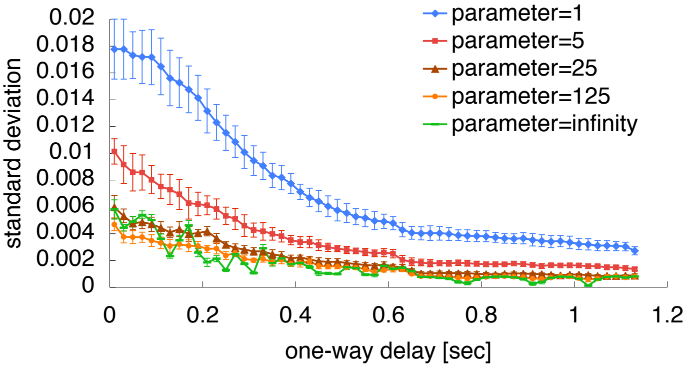
- We were able to confirm that the CoMPACT monitor with Gamma-probing gives good estimates
- We cannot judge the superiority or inferiority of any parameter
- To judge the superiority or inferiority of parameters, we should investigate variance of estimator

Variance of estimator (1)

- We show the standard deviation of estimator of the complementary CDF
  - A case of flow #1



- Parameter 1 correspond to traditional PASTA-based probing
- Parameter infinity correspond to periodic-probing

Variance of estimator (2)

- The standard deviation clearly decreases as β increases from $\beta = 1$ to $\beta = 125$
- The standard deviation of periodic-probing is larger than that for $\beta = 125$
- This reversal may be a sign of incorrectness due to the phase-lock phenomenon
- If we tune appropriate parameter β, we can get more accurate estimation than traditional PASTA-based probing

Conclusion

It was confirmed that the accuracy of estimating the complementary CDF of one-way delay can be improved by using Gamma-probing as part of applying CoMPACT monitor estimates.

- This means that Gamma-probing is able to apply to CoMPACT monitor that estimates the time average of sample path

Residual issues

- We should present the method to determine appropriate parameter β
- Application should be verified about not only one-way delay but also packet loss

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Thank you very much for your kind attention