Analysis on the Fluctuation Magnitude in Probe Interval for Active Measurement

Kohei Watabe Masaki Aida

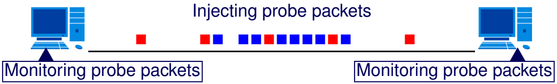
Graduate School of System Design,
Tokyo Metropolitan University

Apr. 11, 2011

Background and Related work

- The Internet is composed of multiple networks that are managed by different ISPs.
- It is difficult to gather the QoS information from multiple ISPs.
- We need a way of measuring, from outside the Internet, the QoS of end-to-end connections.

Active measurement



- It is an end-to-end measurement technique.
- It can estimate the QoS of a network path.
- From the delay and loss experienced by probe packets, it can estimate delay, loss, etc.
- It is easy for the end user to perform.

Background and Related work (2)

Tokyo Metropolitan University

Kohei Watabe

Exponential distribution is widely used as probe packet intervals for active measurement. This probing policy bases on PASTA property.
(i.e. packet injection is a Poisson process.)

- Work by Baccelli et al gave an important suggestion.
  - There are many other distributions that can provide appropriate measurement if we assume the effect of probe packets is insignificant.
  - Periodic-probing with fixed interval is the optimal probing policy if we focus only on variance of estimator under some assumption.
  - It is not the best policy since the phase-lock phenomenon due to synchronization against the network performance may occur.

Background and Related work (3)

Tokyo Metropolitan University

Kohei Watabe

- To solve the problem, Baccelli et al proposed a new probing policy named Gamma-probing.
- The probing policy gives probe intervals that obey the parameterized Gamma distribution.

The property of Gamma-probing

Gamma-probing provides multiple selections lying between traditional probing and periodic-probing through parameter.

Exponential ← 1 — Parameter — ∞ → Periodic

Variance improves → ← phase-lock occurs →

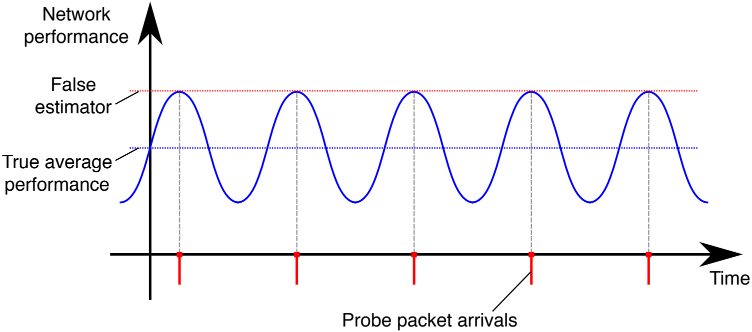
- It was not indicated how to decide upon the optimal parameter.
- A remaining issue is how to decide the optimal probing policy while taking the phase-lock phenomenon into consideration.

Evaluation of the Phase-lock Phenomenon

Aim of our study

We want to get the method to specify the optimal probing policy corresponding to the property of the target network.

- First, we should consider the factor of phase-lock phenomenon.
- Phase-lock phenomenon is caused by synchronization between probe packet injection and the network performance.



Evaluation of the Phase-lock Phenomenon (2)

Tokyo Metropolitan University

Kohei Watabe

- In other words, the cause of phase-lock phenomenon is a periodicity of the network performance.

Even if there is no special periodicity of the network performance in terms of long-time average, there is a possibility that the phase-lock phenomenon occurs.

Actual measurement period on finite period

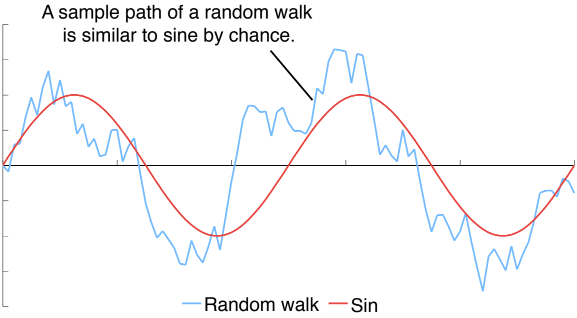
- In actual measurement, we measure a single sample path of the network performance on finite period.
- A specific periodicity may be present by chance.
- This accidental periodicity causes phase-lock phenomenon.

Evaluation of the Phase-lock Phenomenon (3)

Tokyo Metropolitan University

Kohei Watabe

- Even if a process has no special periodicity, accidental periodicity can be generated.



- The accuracy will become bad if the network performance contains strong periodicity that can synchronizes with the probe.
- Conversely, if it does not contain such periodicity so much, the accuracy will be quite good.
- The effect of phase-lock phenomenon is instability of accuracy.

Evaluation of the Phase-lock Phenomenon (4)

- To assess the phase-lock phenomenon appropriately we must consider the accuracy of the target sample path.
- We can express the accuracy of the sample path as follows.

$$\mathrm{Var}\left[\hat{P}\,\middle|\,X(t)\right]$$

- The following two points are necessary for the optimal probing.
  1. Smaller expectation of $\mathrm{Var}\left[\hat{P}\,\middle|\,X(t)\right]$.
  2. Smaller variance of $\mathrm{Var}\left[\hat{P}\,\middle|\,X(t)\right]$.
- We define the probing policy that minimizes the following evaluation function as the optimal policy.

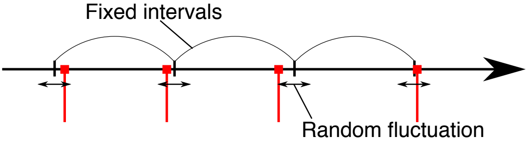
$$\underbrace{\mathrm{E}\left[\mathrm{Var}\left[\hat{P}\,\middle|\,X(t)\right]\right]}_{\text{Accuracy on average}} + \underbrace{\sqrt{\mathrm{Var}\left[\mathrm{Var}\left[\hat{P}\,\middle|\,X(t)\right]\right]}}_{\text{Instability of accuracy due to phase-lock phenomenon}}$$

$\hat{P}$: Estimator for active measurement.

$X(t)$: Network performance at time t.

Probing Policy with Fluctuations

- To avoid the phase-lock phenomenon, we propose the fluctuated intervals (which is an approach different from Gamma-probing).



- Our probing method gives the time of probe packet arrivals $\{T_i\}$ $(i = 1, 2, ..., m)$ as follows.

$$T_i = S + G_i - l \left\lfloor \frac{S + G_i}{l} \right\rfloor$$

T_i	: Arrival time of i th probe packet	m	: Number of the probe packets
l	: Length of measurement period	σ	: Fluctuation magnitude
S	: Random variables that follow uniform distribution $U(0, l)$		
G_i	: Random variables that follow normal distribution $N((i-1)l/m, \sigma^2)$		

- If $\sigma = 0$, $\{T_i\}$ corresponds to periodic-probing.
- $\hat{P} = \sum_{i=1}^{m} X(T_i)/m$ is an unbiased estimator for the time average.

Probing Policy with Fluctuations (2)

- By using our probing method and autocovariance function $r(\tau)$ of $X(t)$, the evaluation function is given by the following:

$$\mathrm{E}\left[\mathrm{Var}\left[\hat{P}\,\middle|\,X(t)\right]\right] + \sqrt{\mathrm{Var}\left[\mathrm{Var}\left[\hat{P}\,\middle|\,X(t)\right]\right]} \simeq \sum_{i=1}^{\infty}\frac{4}{l}w_i r_{C,i} + \sqrt{\sum_{i=1}^{\infty}\left\{\frac{4}{l}w_i r_{C,i}\right\}^2}$$

$$w_i = \begin{cases} \frac{1+(m-1)\mathrm{e}^{-\left(\frac{2\pi n}{l}\right)^2\sigma^2}}{m}, & i = mj\,(j=1,2,\dots) \\ \frac{1-\mathrm{e}^{-\left(\frac{2\pi n}{l}\right)^2\sigma^2}}{m}, & \text{otherwise} \end{cases}$$

$$r_{C,i} = \int_0^l \left(1-\frac{\tau}{l}\right)\cos\left(\frac{2\pi i}{l}\tau\right)r(\tau)\mathrm{d}\tau$$

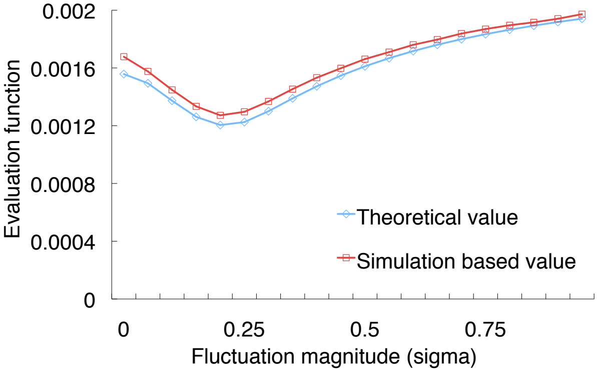
We can plot the evaluation function and can specify the optimal probing policy if we know the property of the target network $r(\tau)$.

Behavior of the Evaluation Function

Tokyo Metropolitan University

Kohei Watabe

- We executed Monte-Carlo simulations and calculated evaluation function directly.
  - We use the simple ON-OFF process as an example of $X(t)$.
- We can confirm that the above mentioned function corresponds to the simulation based function.



Conclusion

We defined an evaluation function which can well assess the phase-lock phenomenon, and we provided a method that can specify the optimal probing method.

- The result can apply to not only active measurement but also general sampling techniques.

Residual issues

- We confirmed the validity of our method through simple ON-OFF process.
- In the future, we should verify the validity on more realistic process.
  (e.g. queue length process of M/M/1 model, fractional Brownian motion etc.)

Tokyo Metropolitan University

Kohei Watabe

Thank you very much for your kind attention.