Noise-assisted Traffic Distribution over Multi-path Ad Hoc Routing

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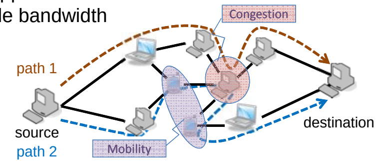
Outline

- Motivation
- Research overview
  - Attractor Perturbation (AP)
- Proposal: noise-assisted traffic distribution
  - AP parameters mapping
  - Research objective: total packet delay minimization
  - Solution to minimization problem using AP
- Evaluation: verification of AP
  - Numerical
  - Single-path simulation
- Work in progress
  - Evaluation of traffic distribution over multi-path routing

Motivation

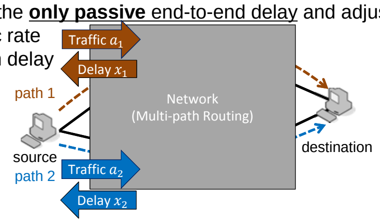
- In ad hoc network, there are unstable paths, due to
  - continuous topology change (caused by mobility, etc.)
  - network congestion, etc.
- Multi-path approach has been used to increase robustness and available bandwidth



- However, existing traffic distribution approaches require **active** resource estimation, e.g., available bandwidth, number of flows, etc. to perform load balancing
  - resulting in complication and high overhead

Research Overview

- Instead of tracking the complex resource information of each path to distribute traffic, we aim to
  - consider the network as a black box,
  - observe the **only passive** end-to-end delay and adjust the traffic rate based on delay statistics



- Ability to estimate the effect of traffic rate change is required
  - Attractor Perturbation concept is used

Attractor Perturbation (AP)

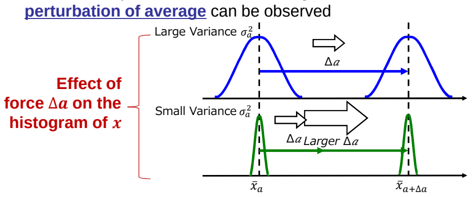
From an observation in cell biology [10] :

Given an *observable variable* x, which could be influenced by *parameter* a, when applying Δa (called *force*) to the system, the average of x is perturbed as follows:

perturbation of average: $\bar{x}_{a+\Delta a} - \bar{x}_a$ = b (constant coefficient) Δa (controllable force) σ_a^2 (observed variance)

$$\bar{x}_{a+\Delta a} - \bar{x}_a = b\,\Delta a\,\sigma_a^2$$

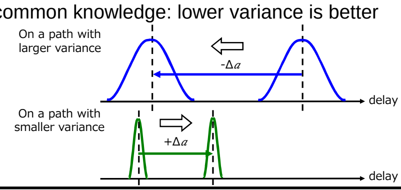
The above equation shows that the larger the variance is, the larger perturbation of average can be observed



[10] K. Sato et al., "On the Relation between Fluctuation and Response in Biological Systems," Proc. Nat'l. Academy Sci. USA, vol. 100, Nov. 2003, pp. 14086–90.

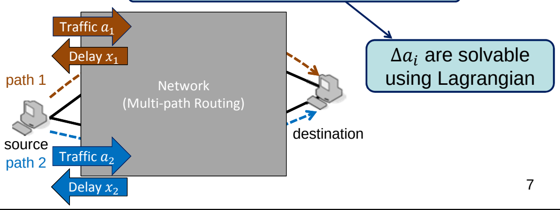
Traffic Distribution over Multi-path

- Mapping parameters to the traffic distribution problem (per path basis)
  - x is the observed per-packet end-to-end delay
  - a is the traffic rate (amount of traffic on the path)
- Objective: minimize the total end-to-end delay of all packets by shifting the traffic from paths with higher variance to paths with lower one
  - from AP: lower variance paths can tolerate more traffic
  - common knowledge: lower variance is better



Minimization Problem

- Total delay $=\sum_{\text{all path } i}$ (amount of traffic × average delay)
  $=\sum_i a_i \bar{x}_i$
- Average delay of path i after traffic rate change
  $\bar{x}_i' = \bar{x}_i + b_i \Delta a_i \sigma_i^2$
- Total delay after traffic rate change $=\sum_i (a_i + \Delta a_i)\bar{x}_i'$
- Objective: Minimize $\sum_i (a_i + \Delta a_i)\bar{x}_i'$ s.t. $\sum_i \Delta a_i = 0$



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Implementation

<u>Every interval τ DO:</u>

CALCULATE average and variance of end-to-end delay

SOLVE the minimization problem

IF $\sum_i a_i \bar{x}_i - \sum_i (a_i + \Delta a_i)\bar{x}_i' > \epsilon$ THEN *(improvement threshold ϵ)*

  IF $\forall i (\Delta a_i \leq k)$ THEN

    PERFORM traffic re-distribution

  ELSE

    $\forall i \left(\Delta a_i' = \Delta a_i * \frac{k}{\max_j \Delta a_j}\right)$

    PERFORM traffic re-distribution with normalized $\Delta a_i'$

    (gradually re-distributing traffic in small steps)

  ENDIF

ENDIF

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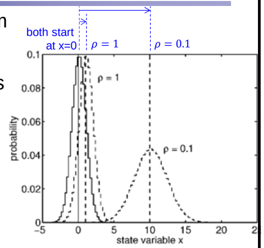
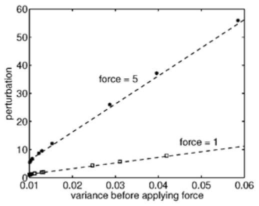
Numerical Evaluation of AP

- Considering an attractor system with $\frac{dx}{dt} = -\rho(x - x_0) + \eta \quad +\Delta a$
  - Same amount of force yields different amount of effect according to ρ





  - Results from multiple runs with random ρ show linear relationship between average difference and variance

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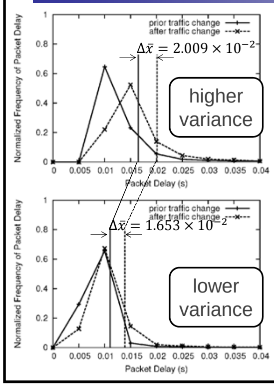
Simulation of Single Path AP



- 25 nodes, uniformly distributed in $10^3 \times 10^3$ m^2 area
- Traffic: 1 CBR session + 4 Poisson background traffic sessions
- Underlying routing protocol: MARAS
- Simulation length is 1000 s
  - CBR starting with 10 packets/s rate
  - At 500 s, a force is applied by changing the rate to 20 packets/s
- It can be seen that
  - Average delay can be influenced by changing the traffic rate
  - Perturbation is larger in the case of higher variance

AP is valid in both numerical and simulation-based evaluation

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Conclusion and Future Work

- Attractor perturbation (AP):
  - is a biologically-inspired concept
  - simplifies control mechanism
  - only uses average and variance of the observed variable
- Verification results
  - AP is visible in both numerical and simulation-based evaluation
- Work in progress
  - Simulation of AP-based traffic distribution over multi-path ad hoc routing

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Thank you for your attention

Q&A