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

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Outline

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• 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 \( \alpha \), when applying \( \Delta \alpha \) (called force) to the system, the average of \( x \) is perturbed as follows:

\[
\bar{x} = \bar{x} + \text{constant coefficient} \times \Delta \alpha \times \text{observed variance}
\]

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

Effect of force \( \Delta \alpha \) on the histogram of \( x \)

Traffic Distribution over Multi-path

• Mapping parameters to the traffic distribution problem
  – \( x \) is the observed per-packet end-to-end delay
  – \( \alpha \) 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 $\sum_{\text{all path } i} (\text{amount of traffic} \times \text{average delay})$
- Average delay of path $i$ after traffic rate change $x_i' = x_i + h_i \Delta a_i x_i^2$
- Total delay after traffic rate change $\sum_i (a_i + \Delta a_i)x_i^2$
- Objective: Minimize $\sum (a_i + \Delta a_i)x_i^2$, s.t. $\sum \Delta a_i = 0$

$\Delta a_i$ are solvable using Lagrangian

Implementation

Every interval $\tau$ DO:
- CALCULATE average and variance of end-to-end delay
- SOLVE the minimization problem
- IF $\sum \Delta a_i > \varepsilon$ THEN (improvement threshold $\varepsilon$)
  - PERFORM traffic re-distribution
- ELSE
  - PERFORM traffic re-distribution with normalized $\Delta a_i$
    (gradually re-distributing traffic in small steps)
- ENDIF

Numerical Evaluation of AP

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

- Results from multiple runs with random $\rho$ show linear relationship between average difference and variance

Simulation of Single Path AP

- 25 nodes, uniformly distributed in $10^5 \times 10^5 \text{m}^2$
- 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

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

Thank you for your attention

Q&A