Measurement-Based Modeling of Internet Round-Trip Time Dynamics using System Identification

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Research Background

sender — receiver

- If characteristic of packet transmission delay is known...
  - Can improve QoS (Quality of Services)
  - Can realize efficient congestion control
- Dynamics of packet transmission delay
  - How packet transmission delay is affected by packet transmission rate

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Research Objectives

- Model dynamics of packet transmission delay
  - View network as a black box
  - Measure input and output to network
  - Estimate model parameters by system identification
- Validate model accuracy
  - Using two validation methods
  - Comparison with simulation (time domain)
  - Comparison with spectral analysis result (frequency domain)

Black-Box Modeling

sender
input
output

black box
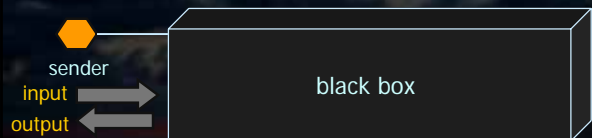
- Definition of input and output

  input → packet transmission rate

  output ← round-trip time

ARX Auto-Regressive eXogenous Model

$e(k)$ noise (effect of other traffic, etc)

$u(k)$ input (transmission rate)

ARX model

$y(k)$ output (round-trip time)
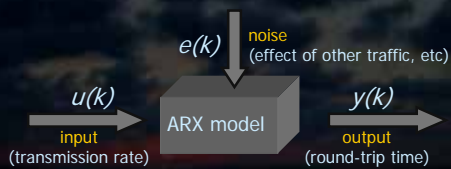
$$y(k) = -\,a_1\,y(k-1) - \dots - a_{n_a}\,y(k-n_a)$$
$$+ b_1 u(k-1) + \dots + b_{n_b} u(k-n_b) + e(k)$$

Determined by system identification

Modeling Procedure

input data
output data
→ ARX model →
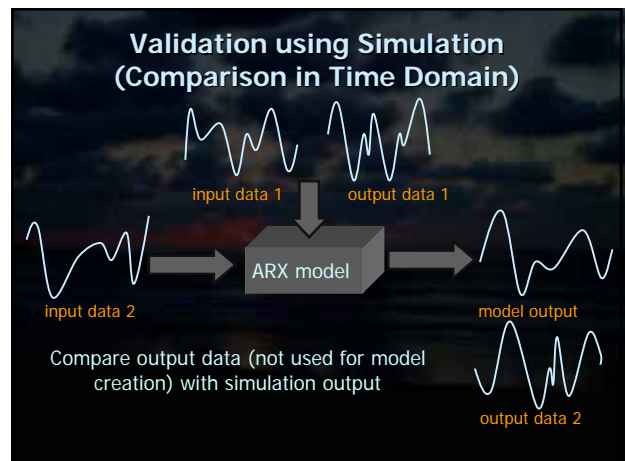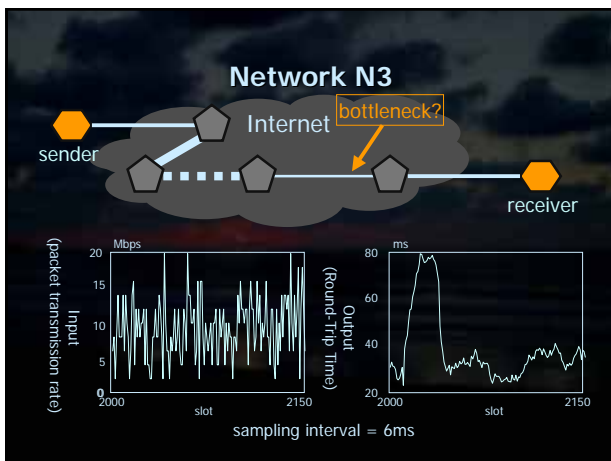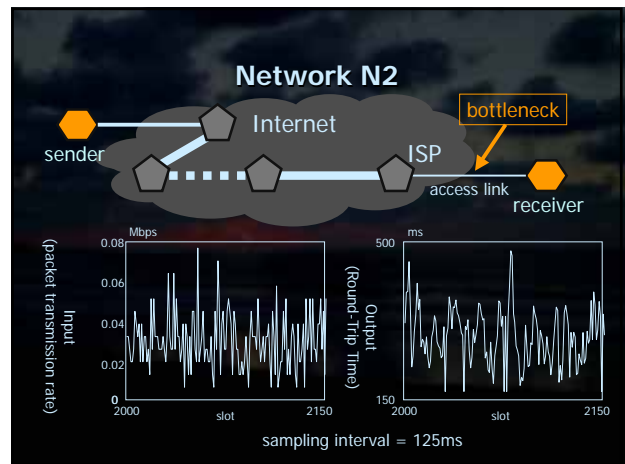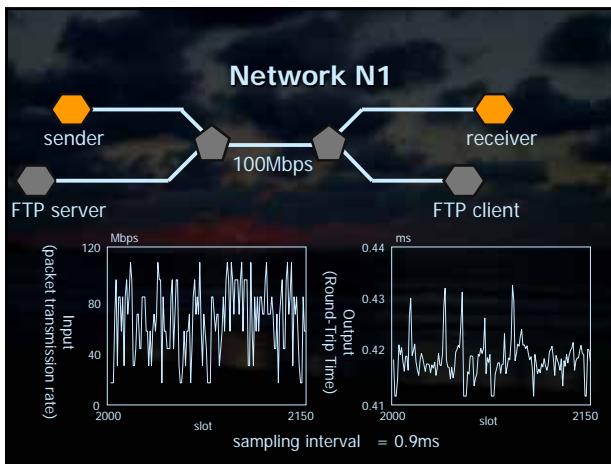model parameters

system identification
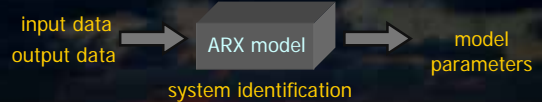
1. Measure input and output data
2. Determine ARX model parameters from measured input and output data
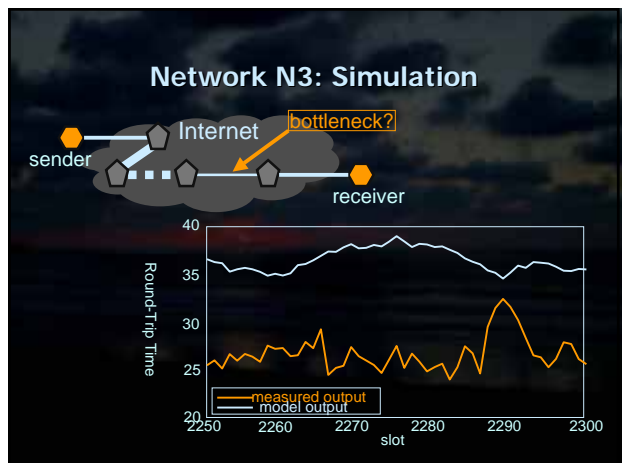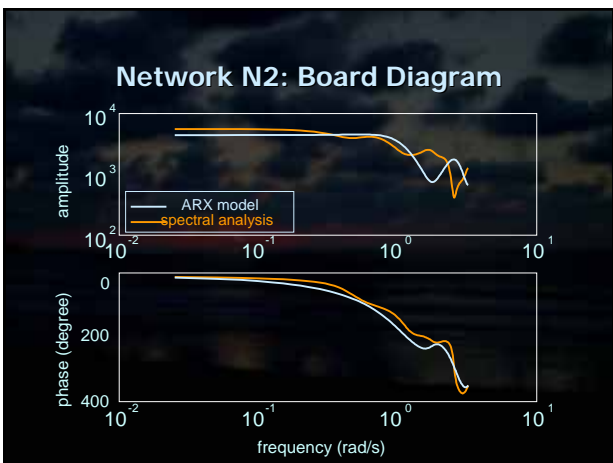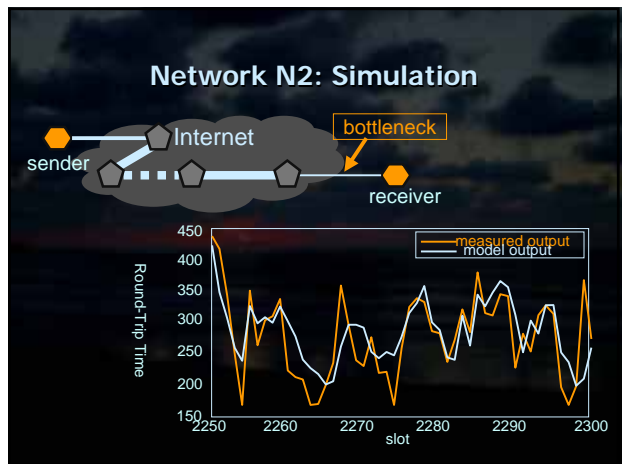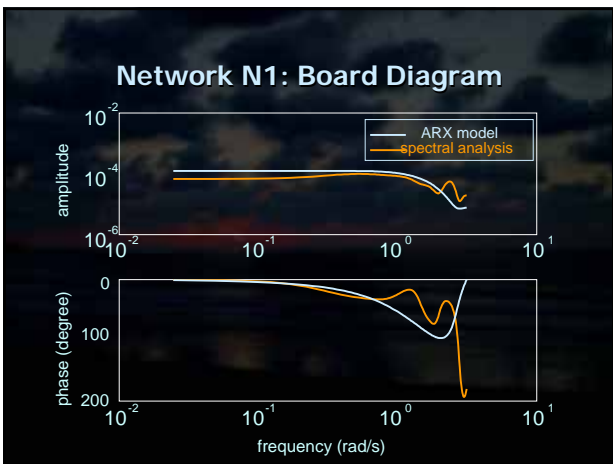3. Validate accuracy of ARX model obtained

Queuing Theory vs. System Identification

	queuing theory	system identification
modeling approach	white box	black box
dynamics	cannot model	can model
control theory applicability	no	yes
statistical characteristic	can model	cannot model
model information	required	not required
model accuracy	good	?

Network Configurations

- Build model in three network configurations
  - Complexity of network topology
  - Effect of noise (e.g., background traffic)
  - Location of bottleneck link
- N1: LAN
  - Simple network topology
- N2: WAN
  - Complex network topology
  - Access link is bottleneck
- N3: WAN
  - Complex network topology
  - Access link is not bottleneck

Network N1

sender — 100Mbps — receiver
FTP server — FTP client

Input (packet transmission rate) — Mbps
Output (Round-Trip Time) — ms

sampling interval = 0.9ms

Network N2

sender — Internet — ISP — receiver
bottleneck
access link

Input (packet transmission rate) — Mbps
Output (Round-Trip Time) — ms

sampling interval = 125ms

Network N3

sender — Internet — bottleneck? — receiver

Input (packet transmission rate) — Mbps
Output (Round-Trip Time) — ms

sampling interval = 6ms

Validation using Simulation (Comparison in Time Domain)

input data 1   output data 1
input data 2 → ARX model → model output
output data 2

Compare output data (not used for model creation) with simulation output

2

Validation using Board Diagram (Comparison in Frequency Domain)

$\sin(\omega t)$ → unknown → $A\sin(\omega t + \varphi)$

A gain φ phase

ARX model → obtain frequency characteristic from ARX model

input data / output data → estimate frequency characteristic using spectral analysis

Compare frequency characteristics of ARX model and one estimated using spectral analysis

Network N1: Simulation

sender — FTP server — 100Mbps — receiver — FTP client

Network N1: Board Diagram

Network N2: Simulation

sender — Internet — bottleneck — receiver

Network N2: Board Diagram

Network N3: Simulation

sender — Internet — bottleneck? — receiver

Network N3: Board Diagram

Conclusion

- Model dynamics of packet transmission delay
  - View network as a black box
  - Measure input and output data
  - Determine model parameters by system identification
- Validate model accuracy
  - Simulation (comparison in time domain)
  - Bode diagram (comparison in frequency domain)
- Show effectiveness of black-box modeling
  - When network is not so noisy

Future Works

- More accurate modeling of packet transmission delay
  - Model structures
    - Parametric model
    - Non-parametric model
  - Linearity
    - Linear model
    - Non-linear model
  - Noise assumption
    - white noise
    - colored noise
- Design a delay-based congestion control using control theory
- More info: http://www.anarg.jp/