# On Modeling Round-Trip Time Dynamics of the Internet using System Identification

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# Background

- The end-to-end packet delay dynamics
  - Affects the QoS(Quality of Service)
  - Enables us to design an efficient congestion control mechanism
- Delay-based approach for congestion control
  - Packet loss can be prevented

# Model the packet delay dynamics

- Queuing theory
  - Assumes stationarity of the network
  - Allows us to obtain the average packet delay and the average packet loss probability
  - It is difficult to analyze the dynamic behavior of the network

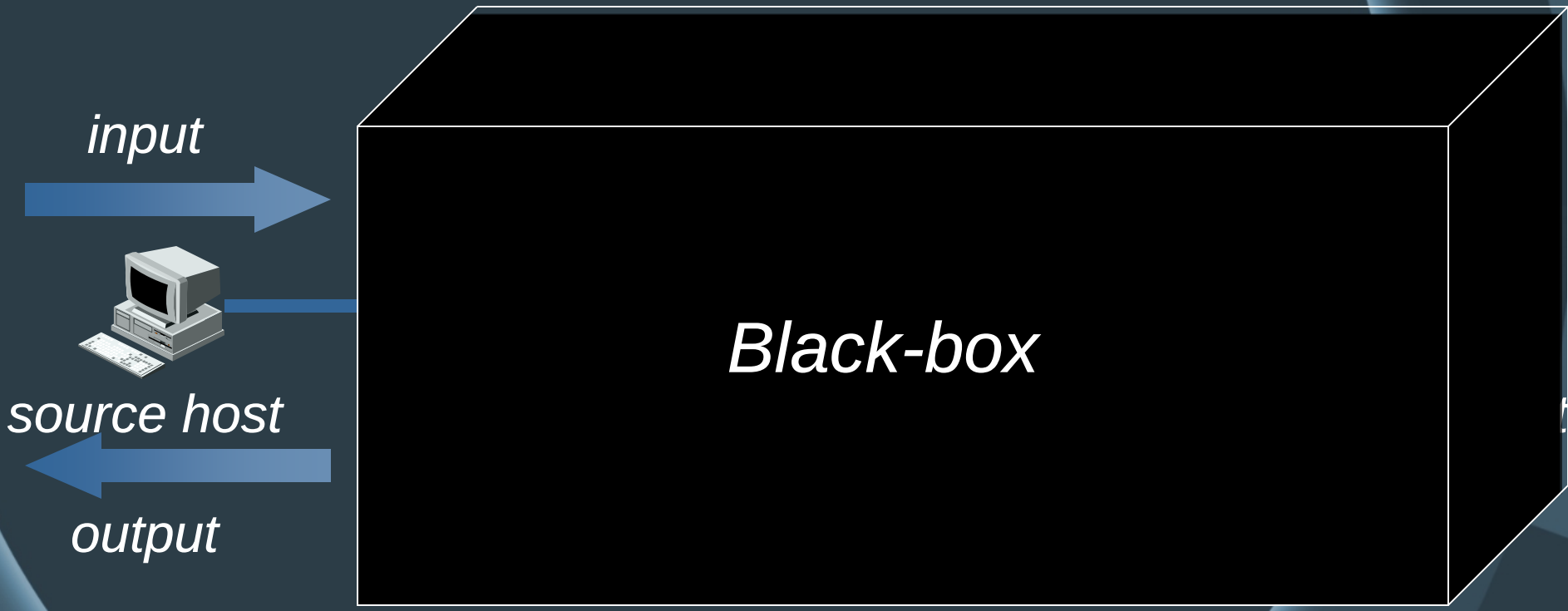
Another approach should be taken

We use ***system identification***

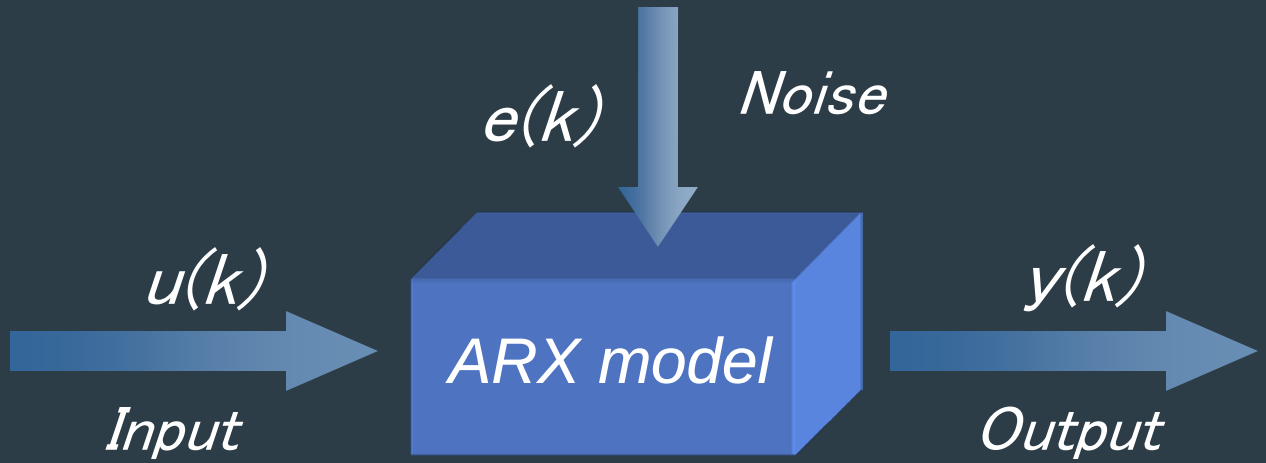
# Objective

- Model a SISO system describing the packet delay dynamics
  - Treat the network as a black-box
  - Model the packet delay dynamics based on ARX model
  - Collect the input and output data
  - Determine the coefficients of the ARX model using system identification
  - Investigate how accurately the ARX model can represent the round-trip time dynamics

# Black-box modeling



# ARX (Auto-Regressive eXogenous) model



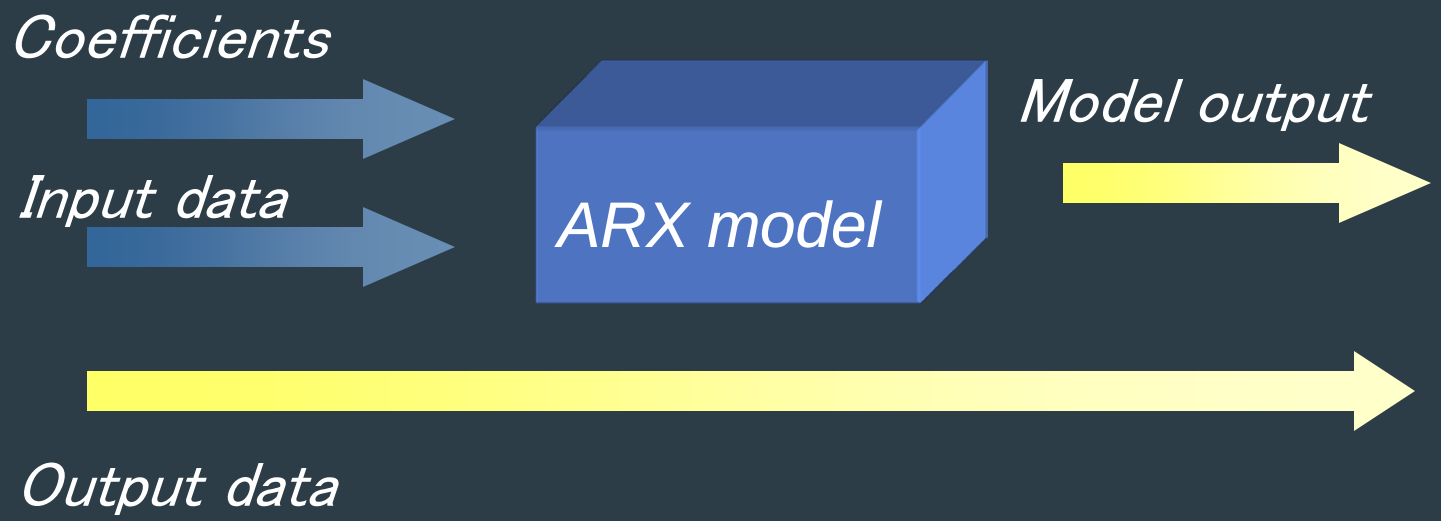

$$y(k) = -a_1 y(k-1) - ..... - a_{n_a} y(k-n_a)$$
$$+ b_1 u(k-1) + ..... + b_{n_b} u(k-n_b) + e(k)$$

*Determine the coefficients using system identification*

# Flow for modeling (determine the coefficients)


1. Collect the input and output data
2. Apply these data to the ARX model
3. Determine the coefficients of the ARX model using system identification

# Flow for modeling (investigate the model accuracy)




- Compare the model output and the output data
- Investigate the effects of the model orders and the number of samples

# Measurement method (TCP)

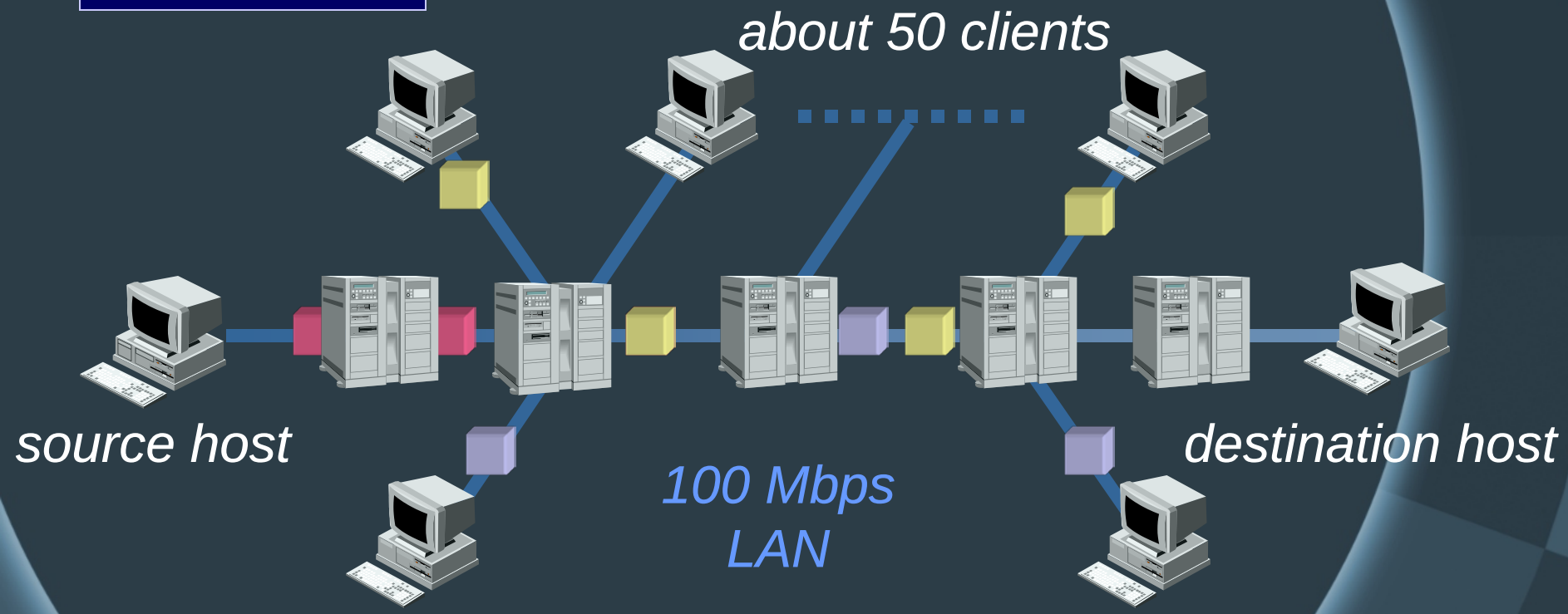
- Limitation for system identification purposes
  - The input contains all frequencies
  - The input is independent on the output
- TCP (Transmission Control Protocol)
  - ACK-based protocol
    - Easy to measure the round-trip time
  - Feedback-based protocol
    - The input is dependent on the output

# Measurement method (UDP and ICMP)

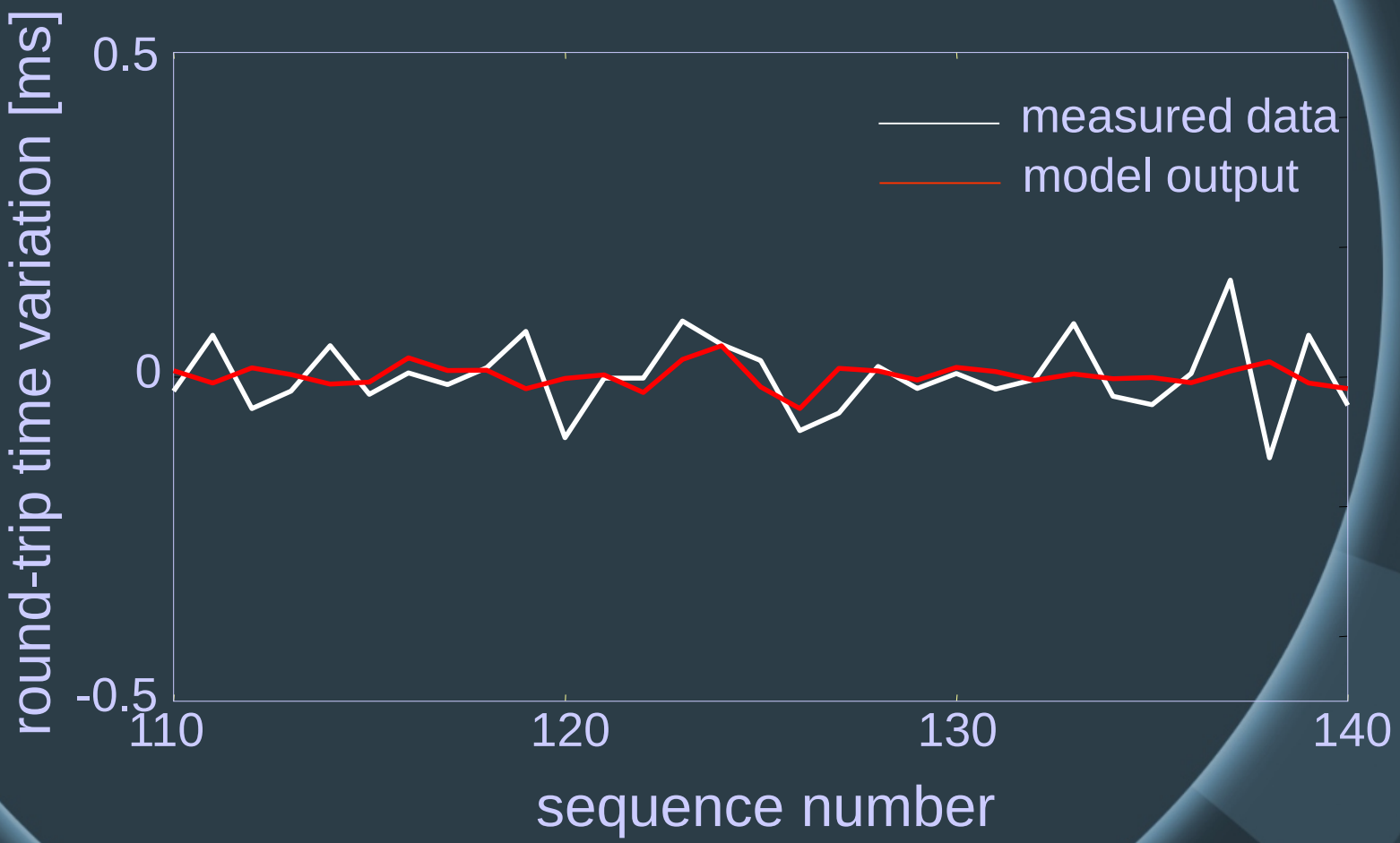
- UDP (User Datagram Protocol)
  - No feedback-based protocol
    - The input can be freely controlled
  - One-way protocol
    - The destination host must perform some procedure
- ICMP (Internet Control Message Protocol)
  - No feedback-based protocol
    - The input can be freely controlled
  - Two-way protocol
    - Easy to measure the round-trip time

# Network configurations

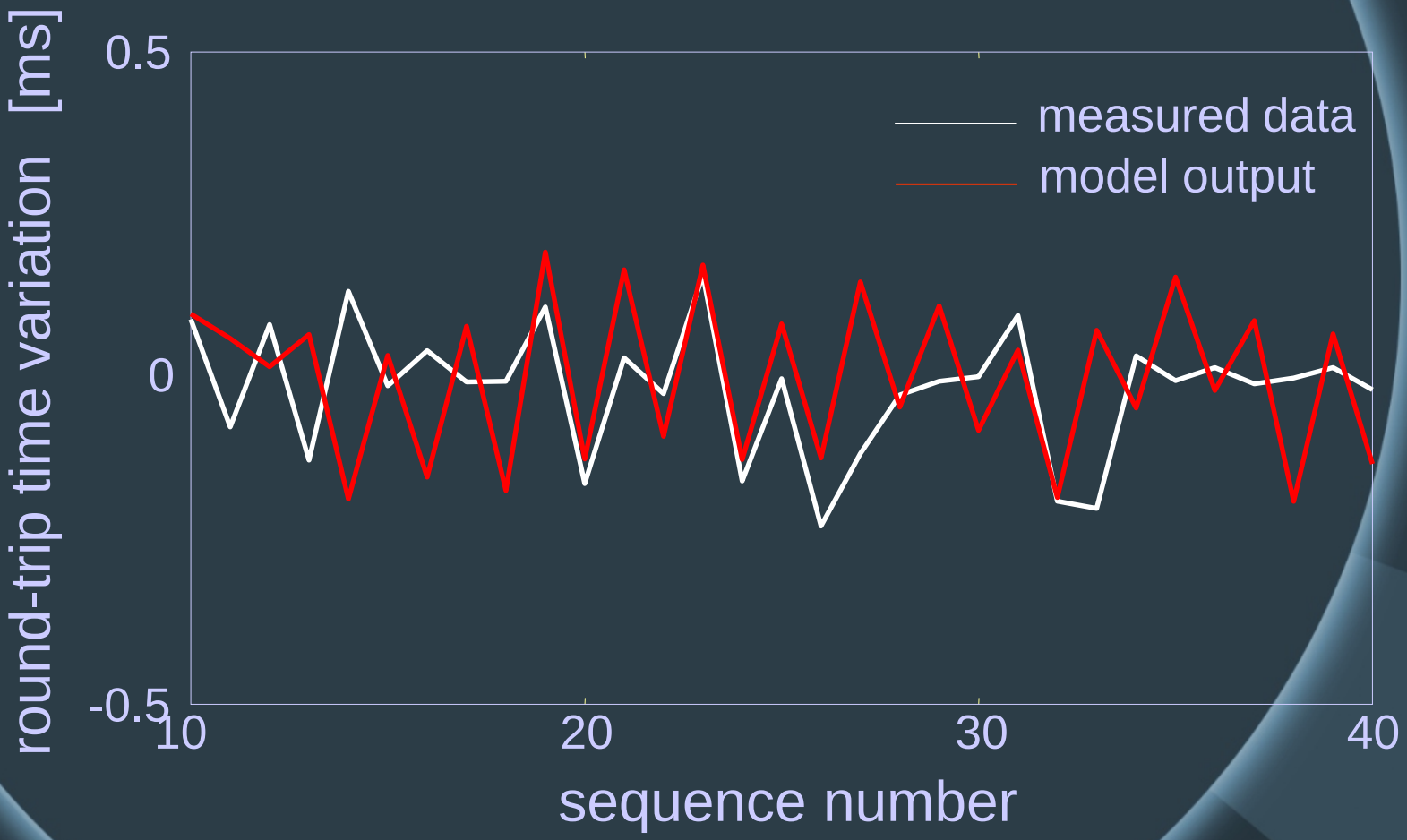
Network N2



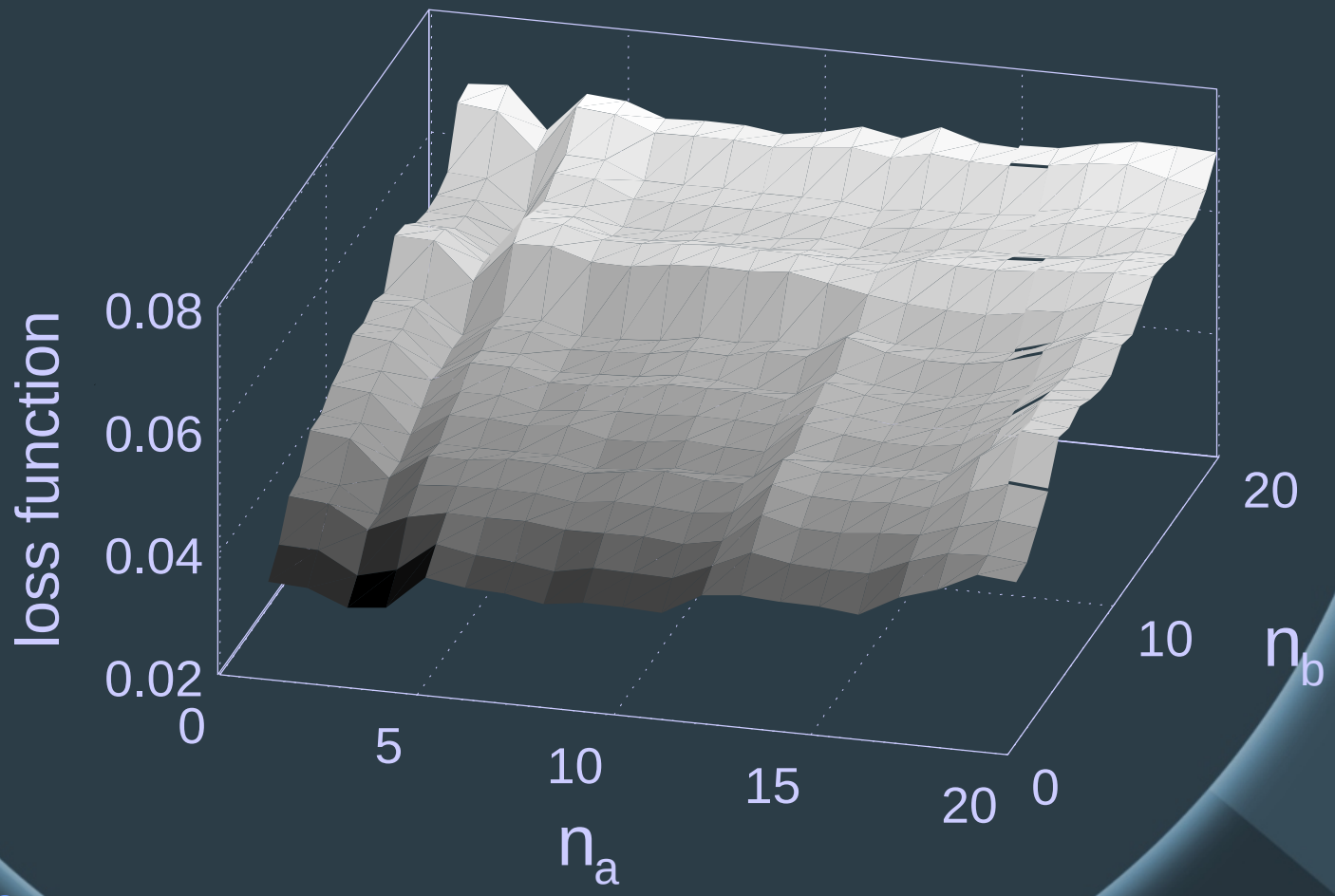
# Network N1 (without background traffic)



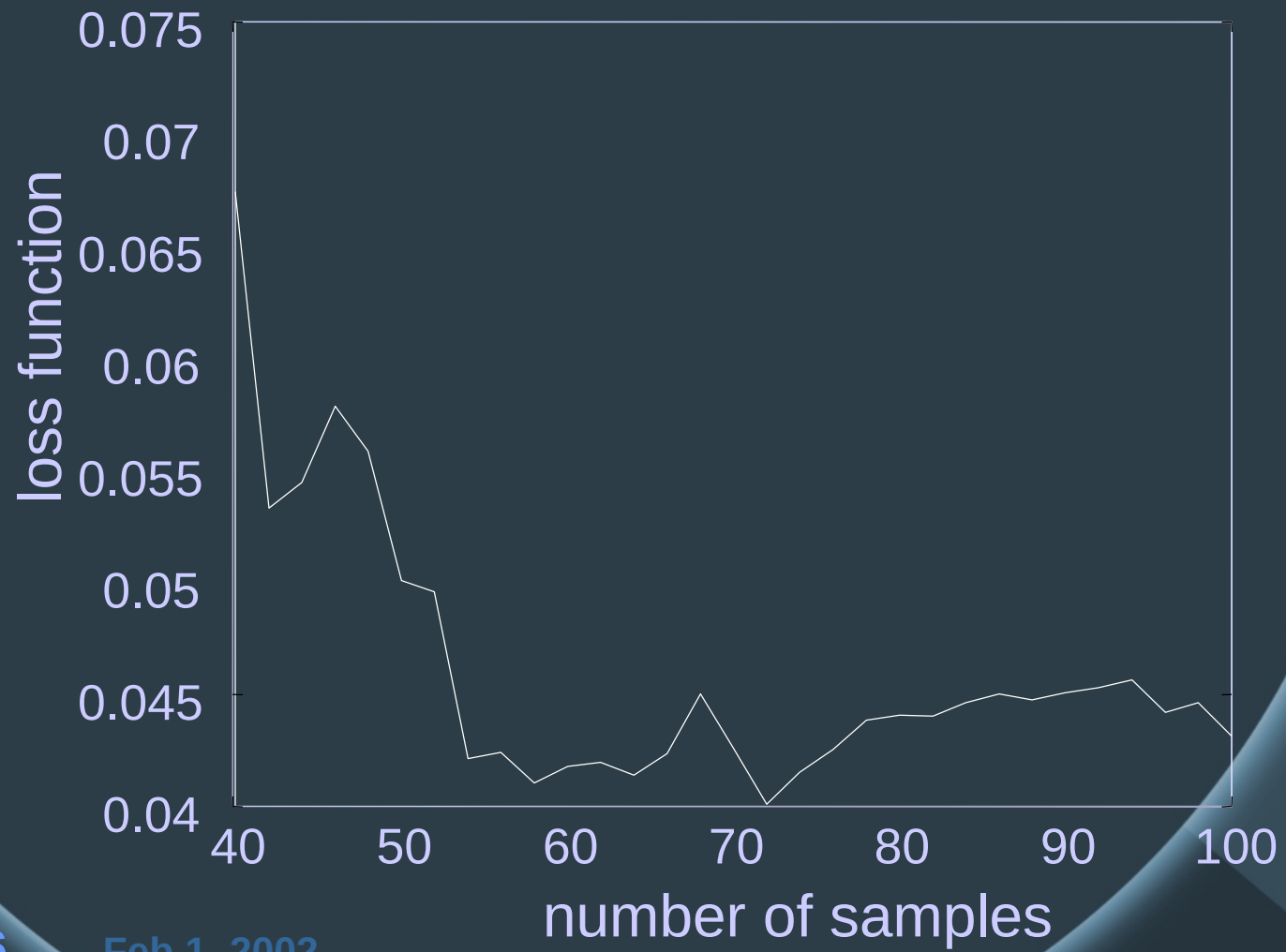
# Network N2 (with background traffic)



# Choice of model orders



# Choice of the number of samples



# Conclusion and Future work

- Conclusion
  - The ARX model can capture the round-trip time when the network moderately congested
  - The ARX model fails to capture when the network is not congested or the measured round-trip time is noisy
- Future work
  - Model the packet delay dynamics of various network