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Influence of Packet Reordering on Concurrent Multipath Transmissions for Transport Virtualization

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NICT National Institute of Information and Communications Technology

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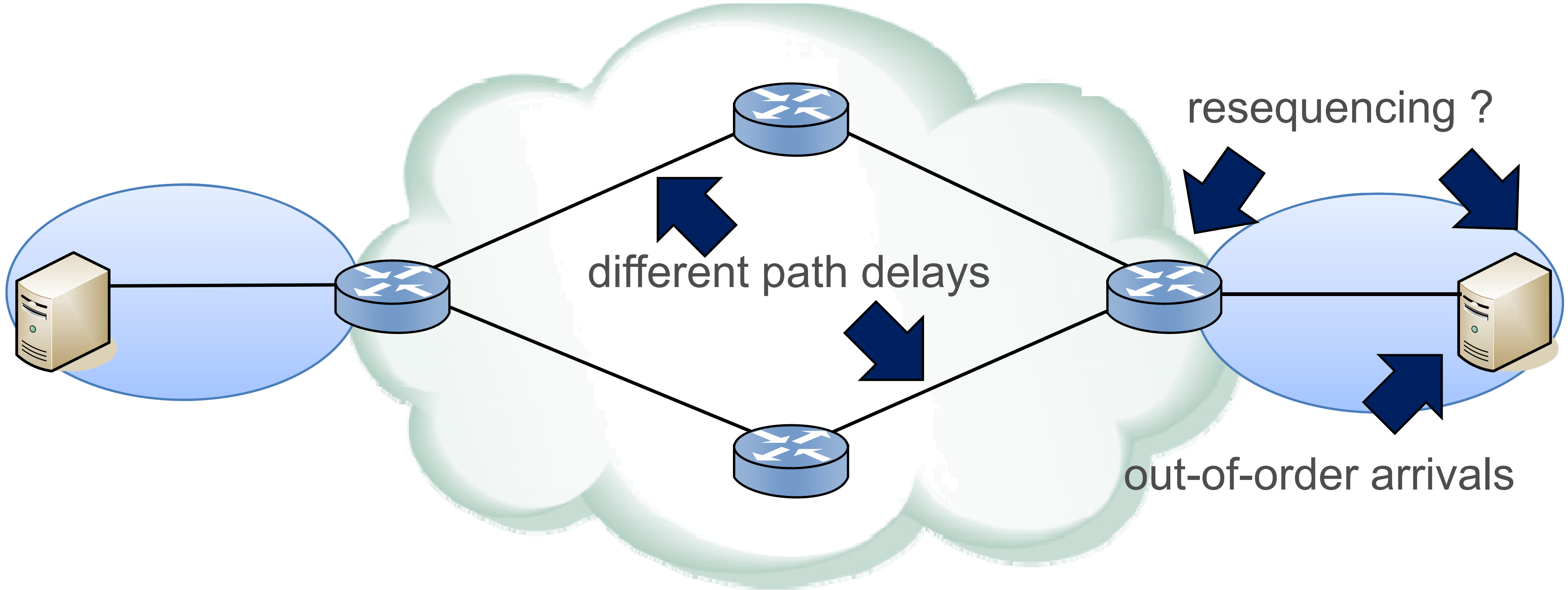
Motivation

- Resource Pooling: Multipath-Transmissions
  - Resilience
  - High capacity (e.g. videostreaming)



  - But: packets arrive out of order at the destination
  - Resequencing necessary

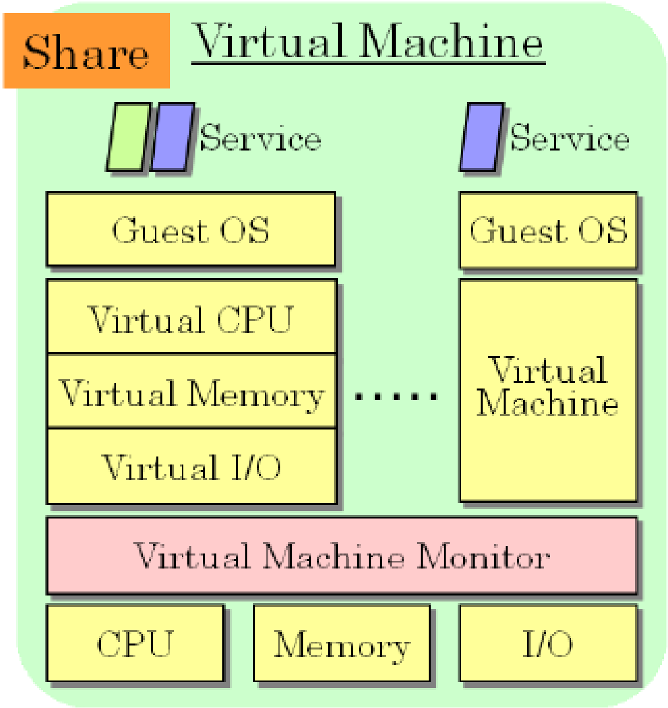
Agenda

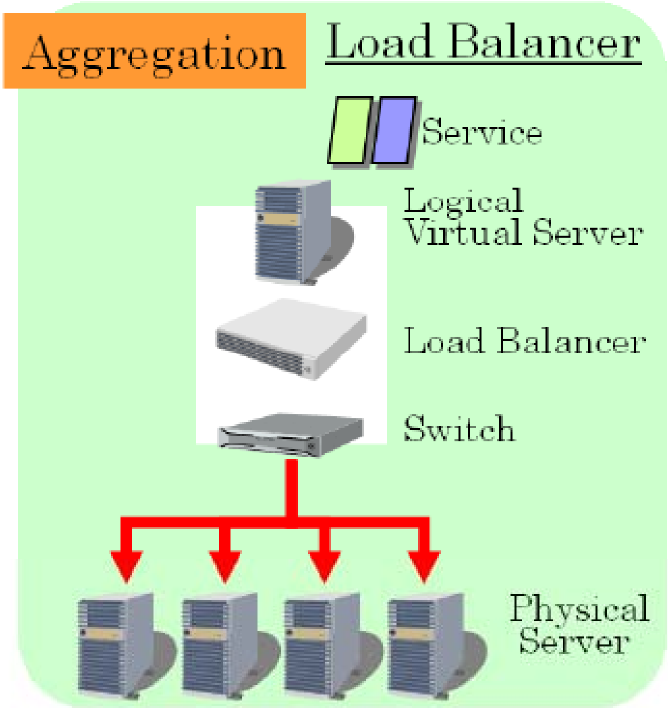
- Virtualization
  - Transport virtualization
  - Concurrent multipath transfer as implementation of transport virtualization
- System model
  - Transmission model
  - Simulation setup
  - Delay model for a single path
- Results
- Conclusion

VIRTUALIZATION

Virtualization

- Virtualization is a technology that abstracts physical resources to generate logical resources
  - Share type of Virtualization (one physical, multiple logical)
  - Aggregation type of Virtualization (multiple physical, one logical)



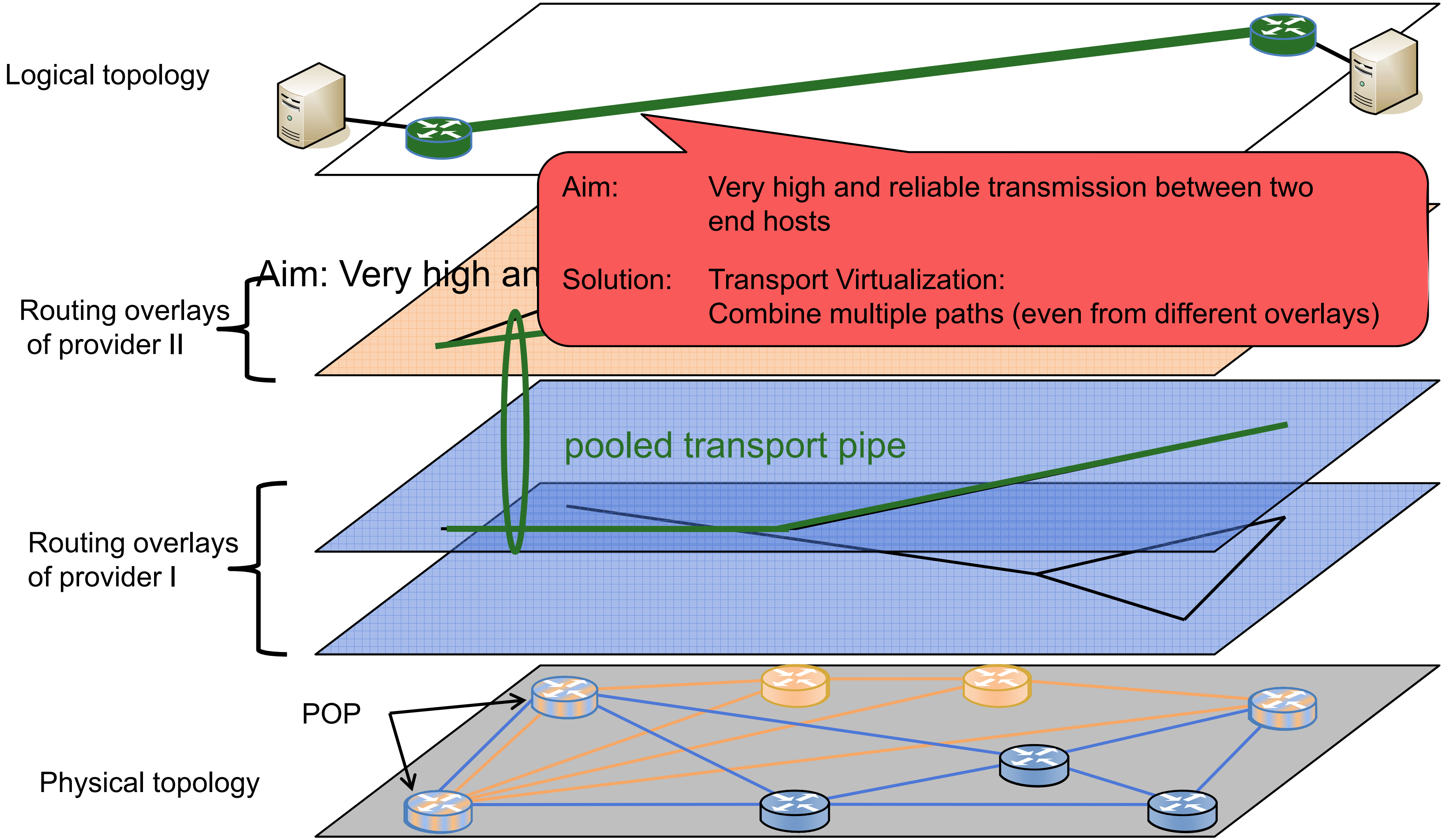


Transport Virtualization (TV)

- Transport Virtualization (Tutschku, Nakao, Zinner, Tran-Gia 2008): abstraction concept for data transport resources
  - Physical location of transport resource doesn't matter
  - Achieved by: abstract data transport resources
    - combined from one or more physical/overlay transport resources, e.g. wave length or MPLS path, an overlay link, or an IP forwarding capability (even in different administrative domains)
    - physical resources can be used preclusive or concurrently

- Advantages of TV:
  - Increased reliability (don’t rely on a single path)
  - Higher capacity (parallel use of links)

Concurrent Multi-Path Transfer



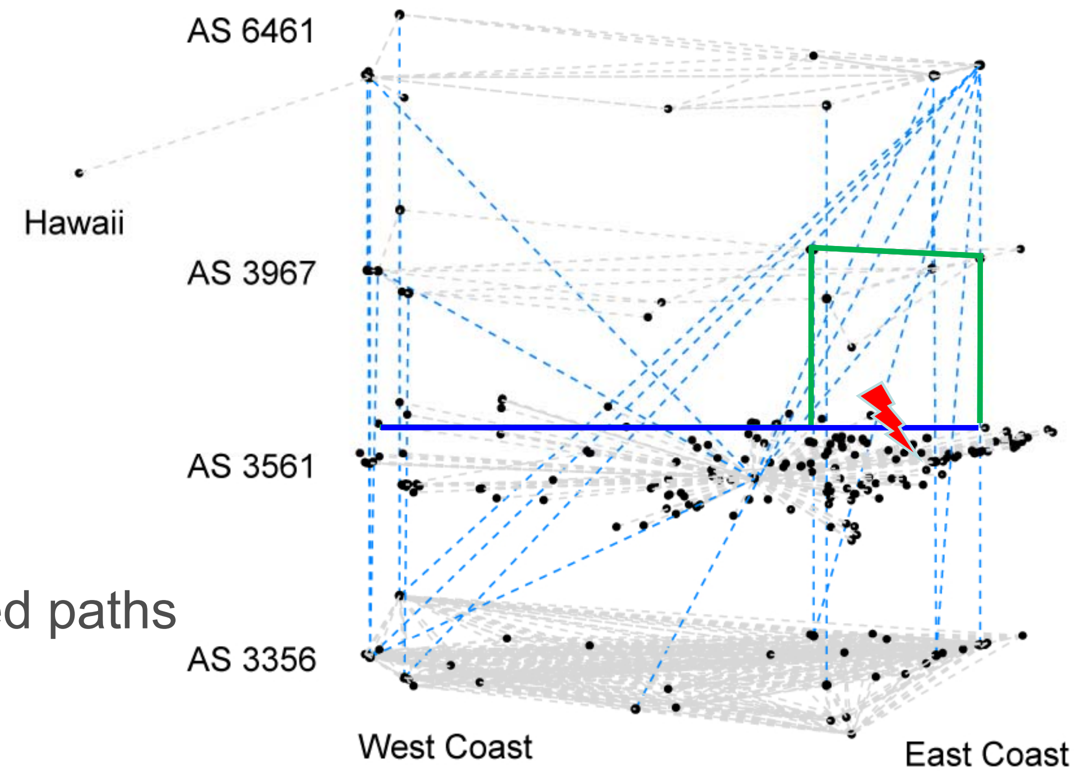
Aim: Very high and reliable transmission between two end hosts

Solution: Transport Virtualization:
Combine multiple paths (even from different overlays)

Diversity in Multi-Provider Environment

- High diversity w.r.t. paths:
  - Four North-american nation-wide ISPs Tier1: M. Liljenstam et al., 2003)

→ Multiple routes for increased resilience are (theoretically) available

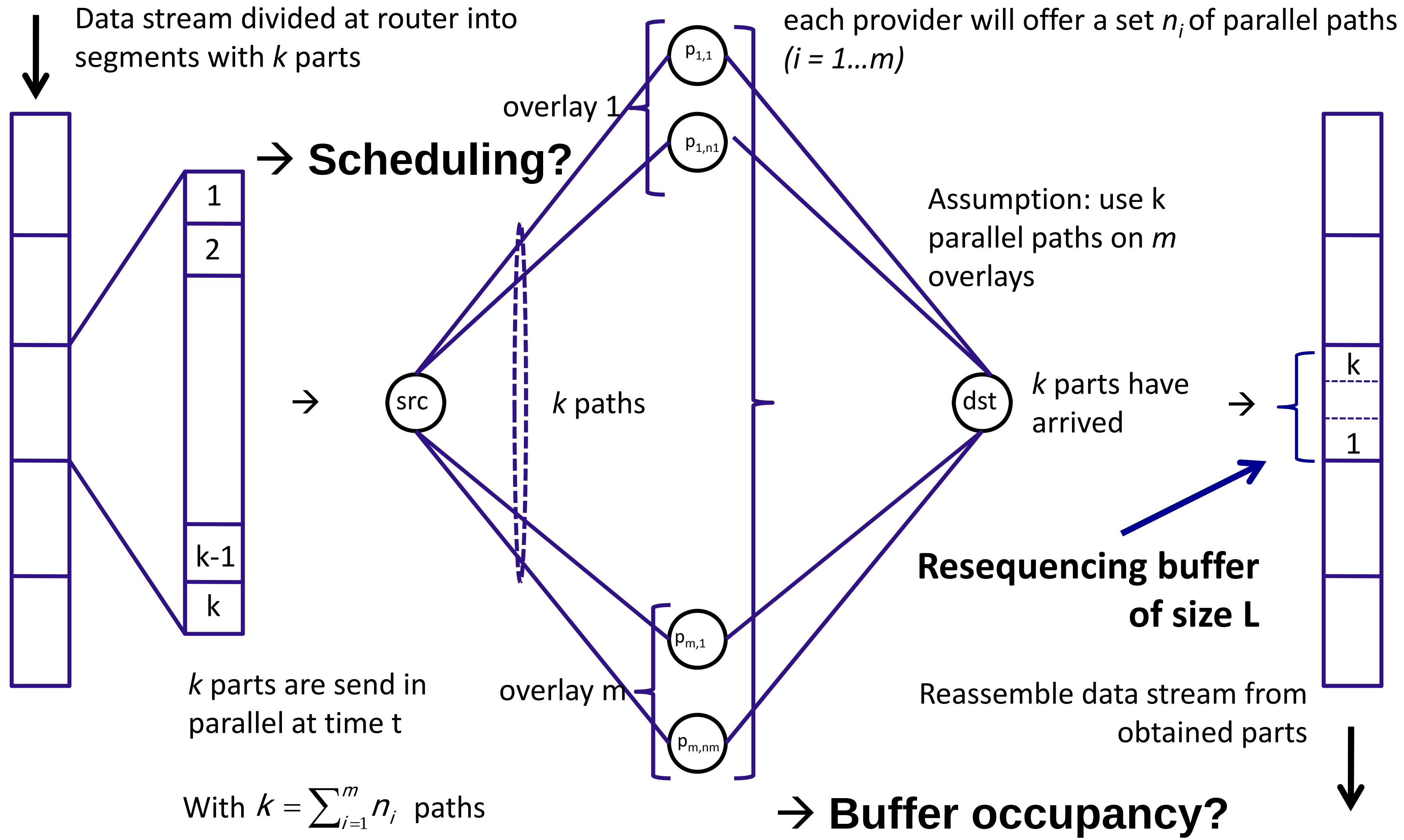


- Moreover: For 25% of the used paths shorter paths exist (TIV; Measurements in PlanetLab by S. Banerjee et al., 2004)

→ Better paths exist; capacity is readily available

MODELING

Transmission Model



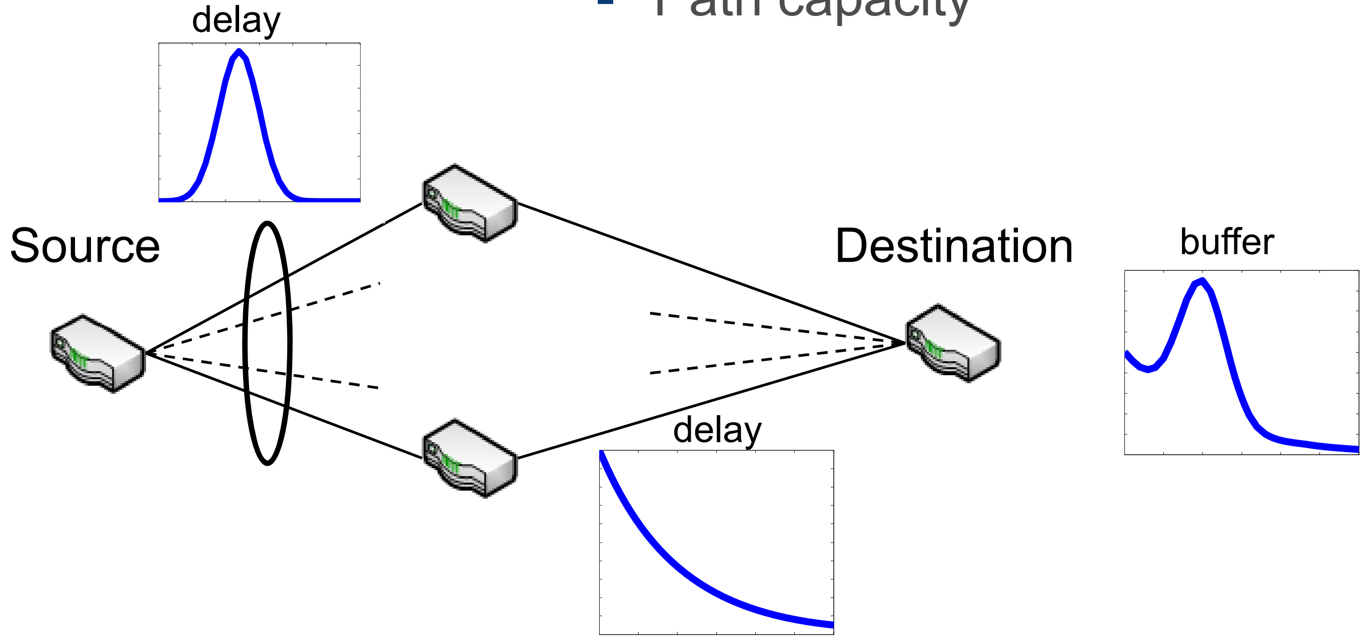
Simulative vs. Analytical Approach

- Related approach by Nebat and Sidi 2006: „Parallel downloads for streaming applications: a resequencing analysis“
  - Analytical approach
  - Enables computation of re-sequencing buffer occupancy in case of round-robin scheduling
  - Adapted methodology to transmission model, performed scenario studies (current work)

- Our approach here:
  - Simulation
  - Enables computation of resequencing buffer occupancy
  - Different scheduling methods can be investigated
  - Validation of the analytical approach possible

Simulation Experiment

- Input:
  - Number of paths
  - Scheduling
  - Path delay distributions
  - Path capacity

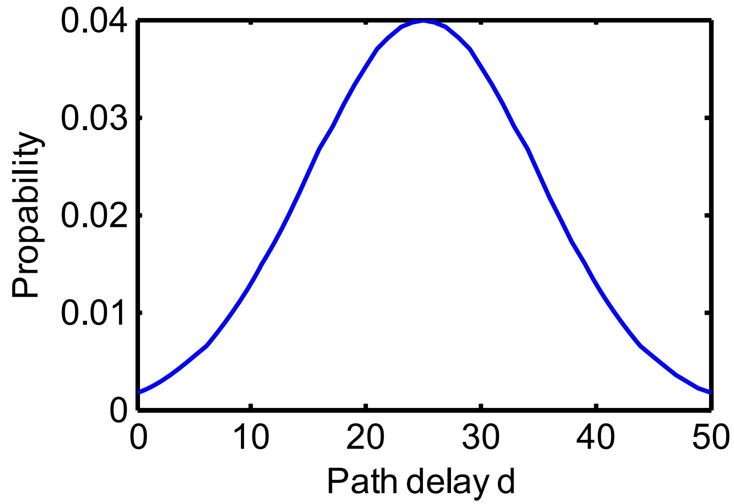


- Output: Resequencing buffer occupancy distribution

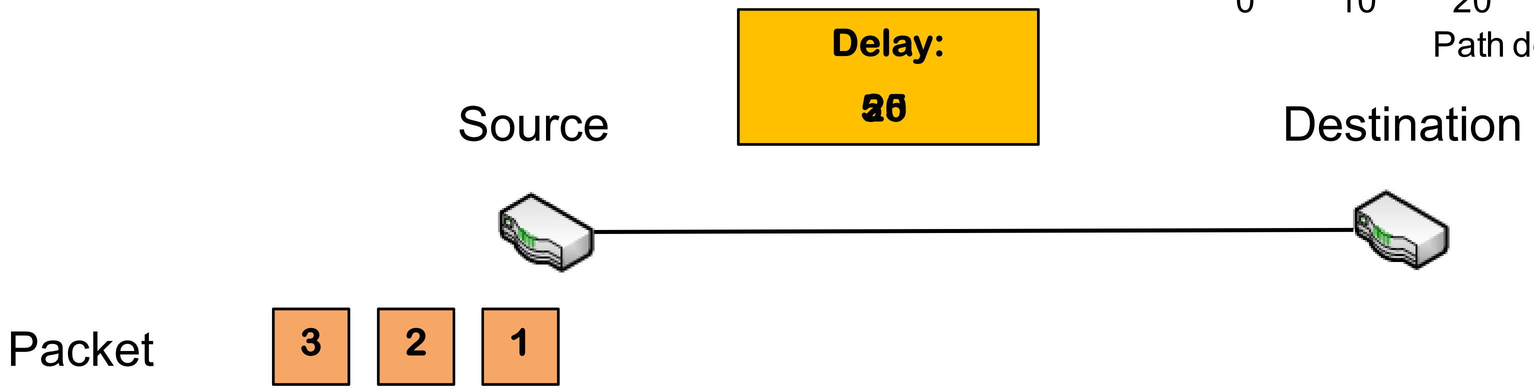
➔Random delay generation w.r.t. the path delay distributions

Random Delay Generation - Example

- Gaussian path delay $\mu = 25, \sigma = 10$

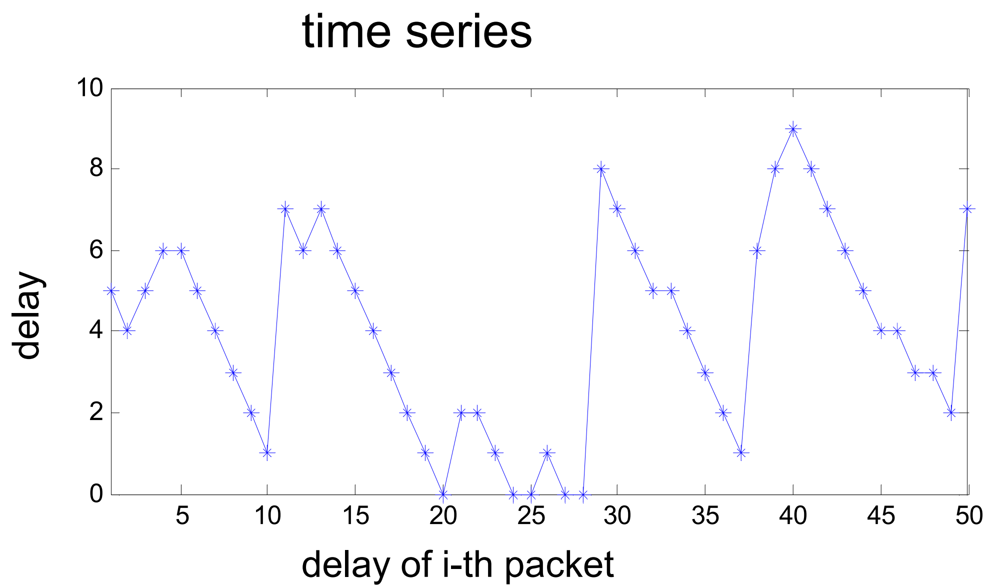


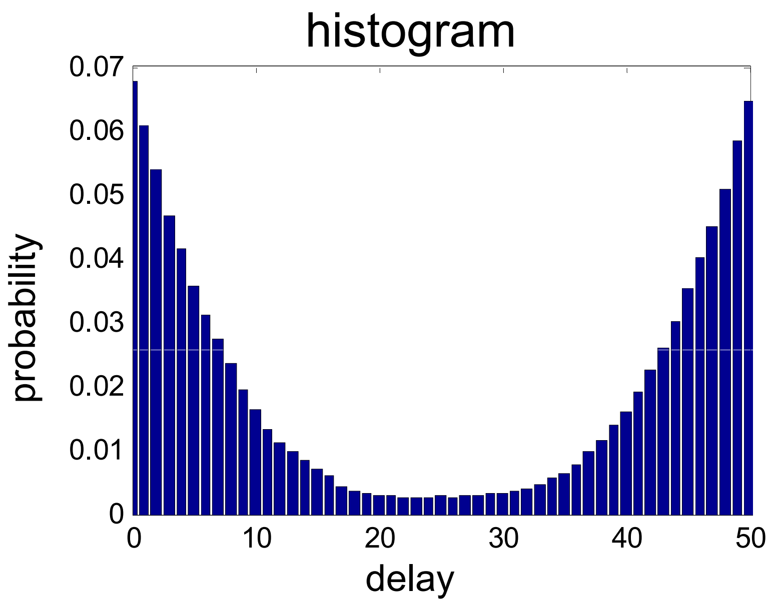
- Example: Path delay randomly draw, packet interdeparture every time unit



- Packet reordering on a single path occurs
- But: typically packets can not overtake each other !

Path Model



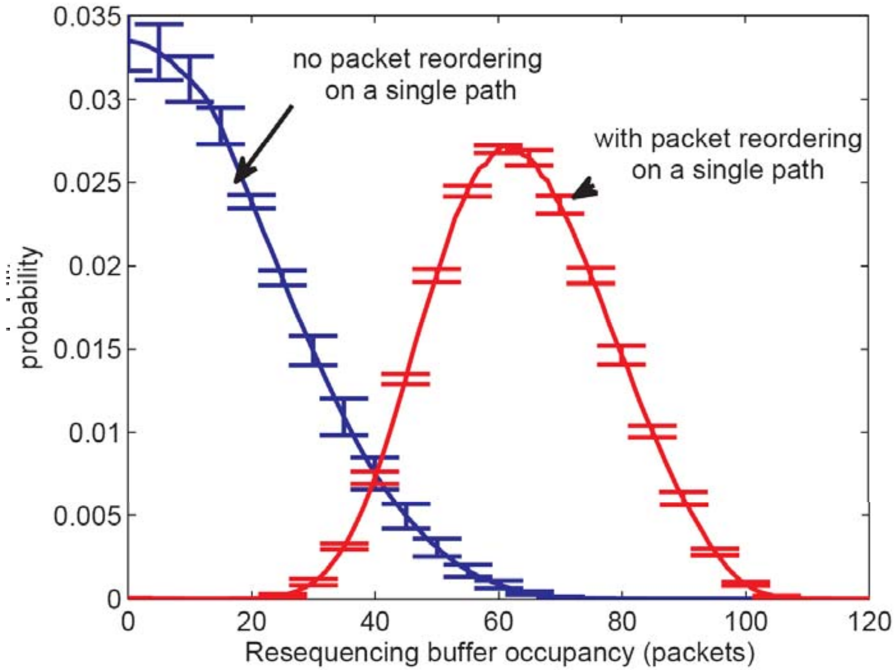


- Constraint: packets do not overtake each other on a single path, i.e. current delay ≥ previous delay – interdeparture time

$$d_i = f(d_{i-1}) \geq \begin{cases} d_{i-1} - 1, & d_{i-1} > 1 \\ 0 & d_{i-1} \leq 1 \end{cases}$$

Example

- Resequencing buffer occupancy (two paths):
  - Overtaking packets on a single path
  - No overtaking

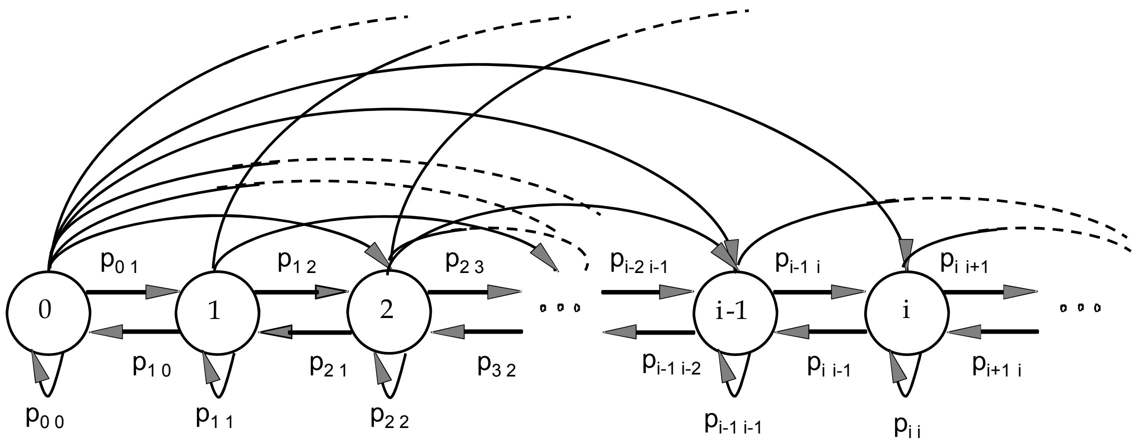


➔ Computed buffer occupancy much higher in case of overtaking

- How to achieve in order transmission on a single path?

Markov Chain Model

- Markov-chain for modeling the delay d
- States are the delay d
- State-transition propability $p_{i\,j}$ between two departures



- Solution of the matrix equation d·P=d (fixpoint equation)

Solution with Linear Programming

Algorithm 1 Determine the transition matrix

Maximize

$$f(P) = \sum_{i=0}^{n} \sum_{j=0}^{n} p_{i,j}$$

Subject to

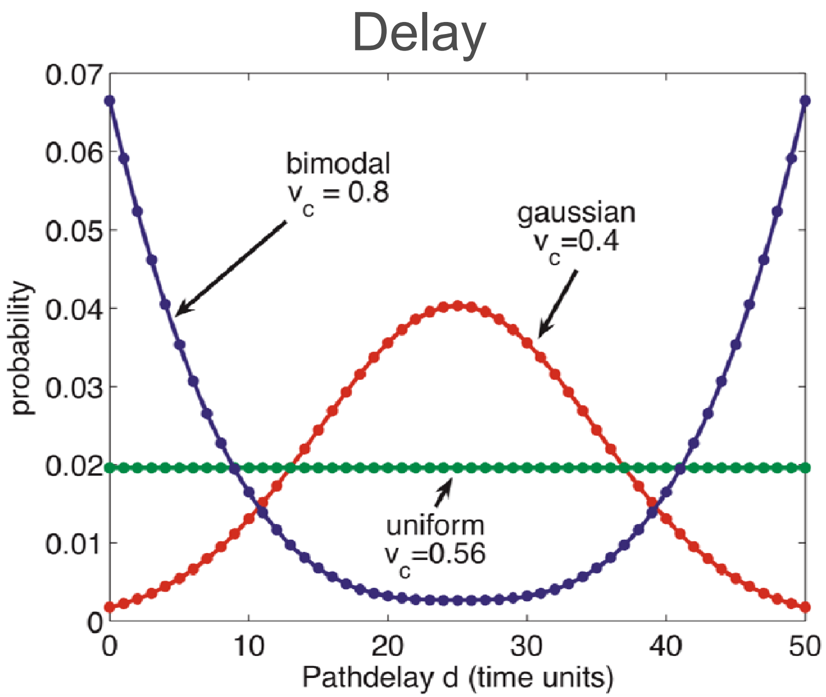
$$\begin{aligned}
\sum_{i=0}^{n} p_{i,j} \cdot x_i &= x_j \quad \forall j; \\
\sum_{j=0}^{n} p_{i,j} &= 1 \quad \forall i \\
p_{i,j} &= 0, \quad i < j - 2; \\
0 < p_{i,j} &< 1, \quad j - 1 < i < j \\
c_1 < p_{i,j} &< c_2, \quad i = j \\
0 < p_{i,j} &< 1, \quad i > j
\end{aligned}$$

$$\begin{pmatrix}
p_{0,0} & p_{0,1} & p_{0,2} & \cdots & p_{0,n-1} & p_{0,n} \\
p_{1,0} & p_{1,1} & p_{1,2} & \cdots & p_{1,n-1} & p_{1,n} \\
0 & p_{2,1} & p_{2,2} & \cdots & p_{2,n-1} & p_{2,n} \\
0 & 0 & p_{3,2} & \cdots & p_{3,n-1} & p_{3,n} \\
\vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\
0 & 0 & 0 & 0 & p_{n,n-1} & p_{n,n}
\end{pmatrix}$$

RESULTS

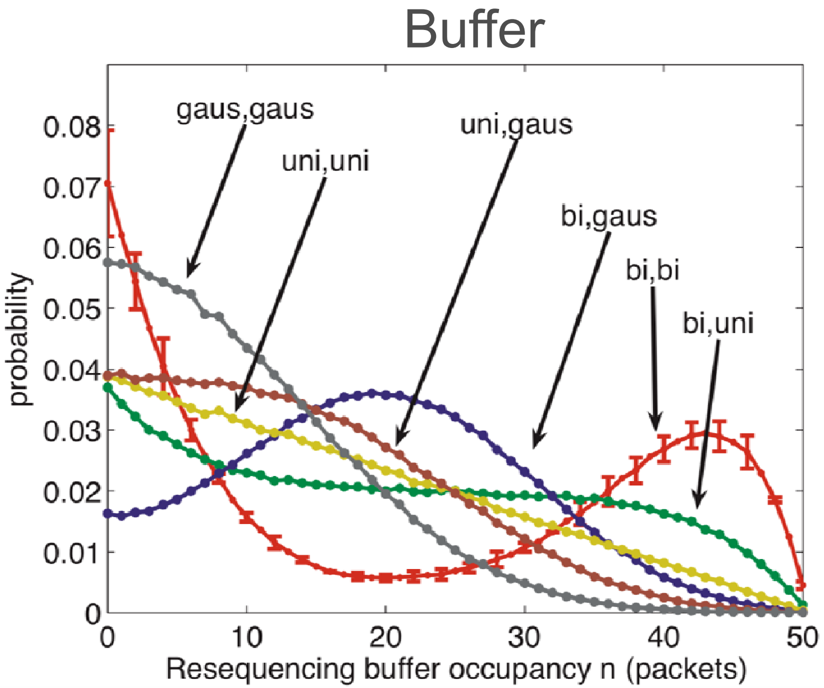
Impact of Type of Delay Distribution (i)

- Types of distributions:
  - Uniform: artificial behavior
  - Truncated gaussian: mathematical tractability
  - Bimodal: Two modes of a path
- Investigation of different influence factors

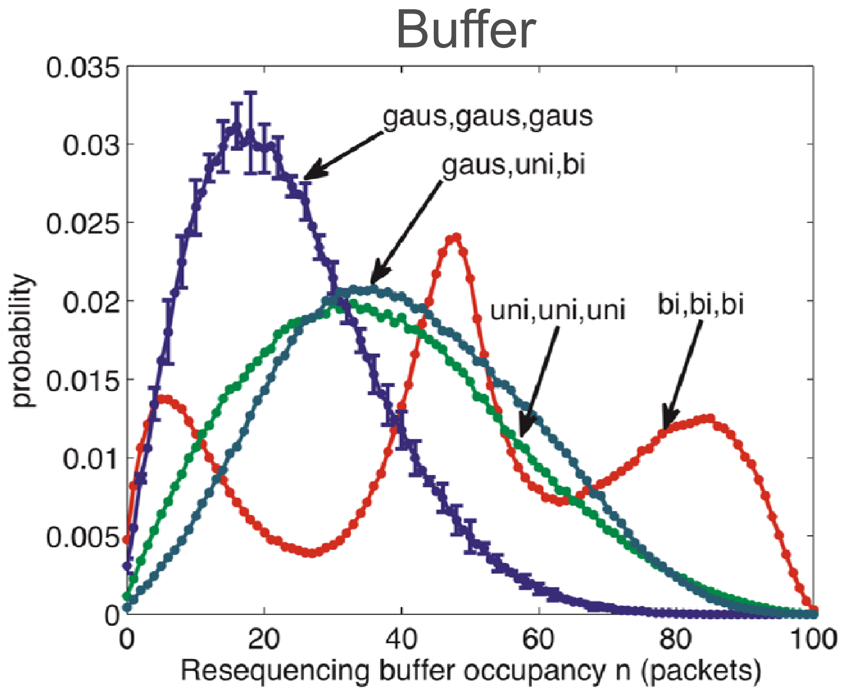


Impact of Type of Delay Distribution (ii)

Two synchronous, equal capacity paths



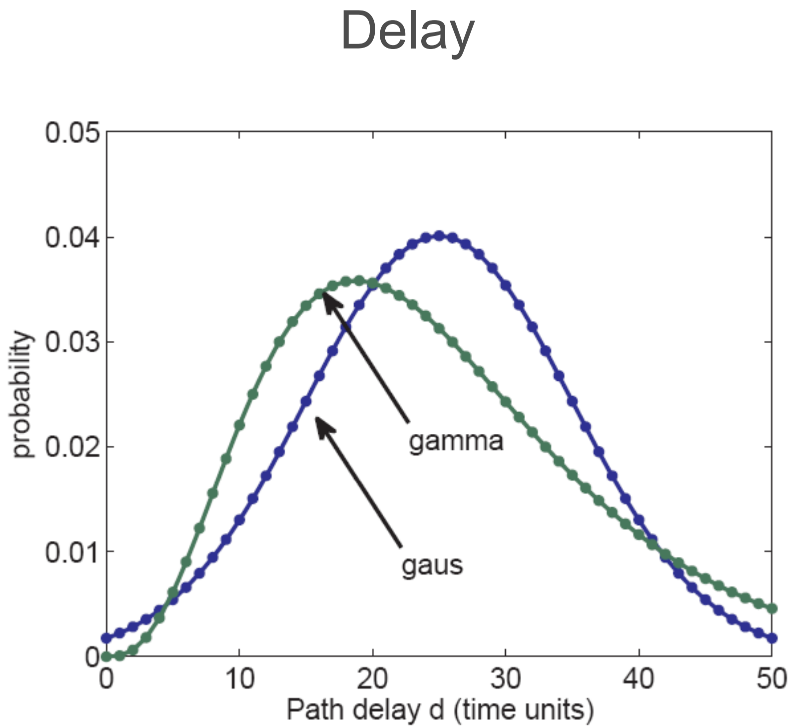
Three synchronous, equal capacity paths



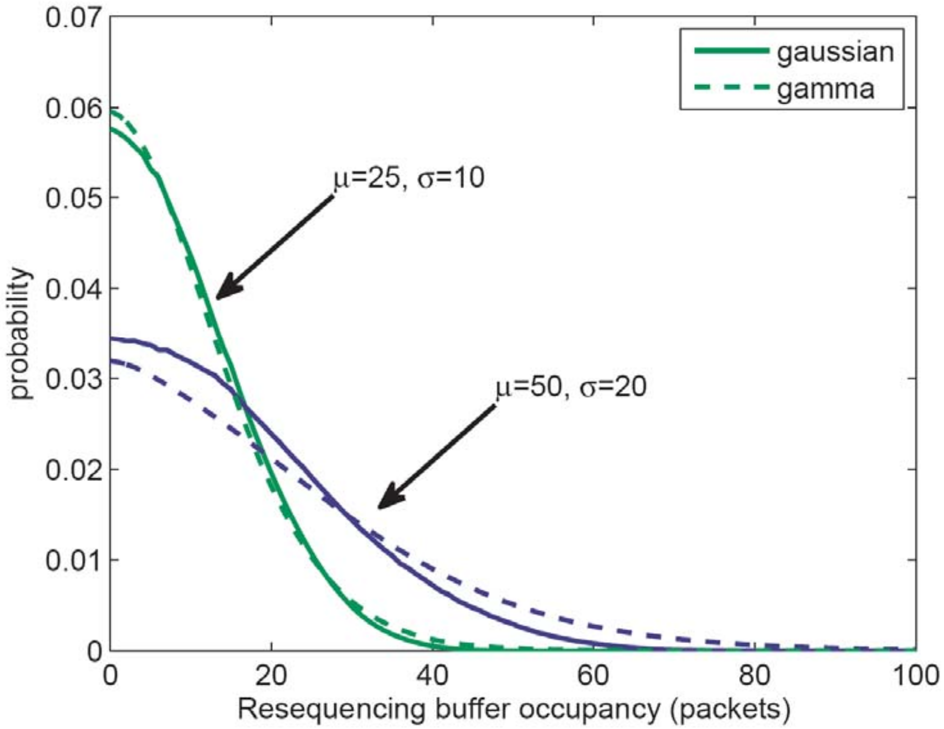
➔Highly non-linear → careful and complex path selection

Similar Path Distributions (i)

- Types of distributions:
  - Gaussian: realistic approximation
  - Gamma: similar to gaussian distribution
- Different skewness:
  - Measure for asymmetry of a probability function
    $$\nu = \frac{\mu_3}{\sigma^3}$$
  - Gaussian: $\nu = 0$
  - Gamma: $\nu > 0$



Similar Path Distributions (ii)



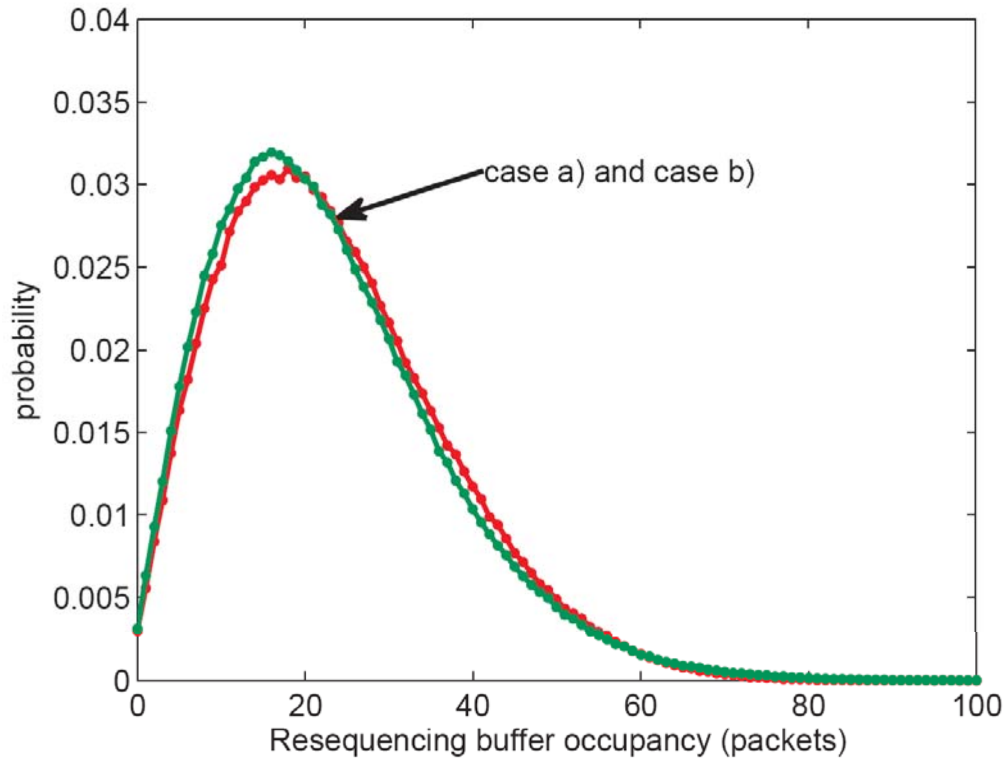
➔ Resequencing buffer occupancy slightly different (different skewness of the input path delay distributions)

➔ Similar behavior of the two distribution classes

Path Selection in Case of 3 Paths

- Different truncated gaussian path delay:
  - $\mu = 50, \sigma = 10$
  - $\mu = 25, \sigma = 10$

- Homogeneous selection of paths:
  - a) $3 \bullet \{\mu = 50, \sigma = 10\}$
  - b) $3 \bullet \{\mu = 25, \sigma = 10\}$

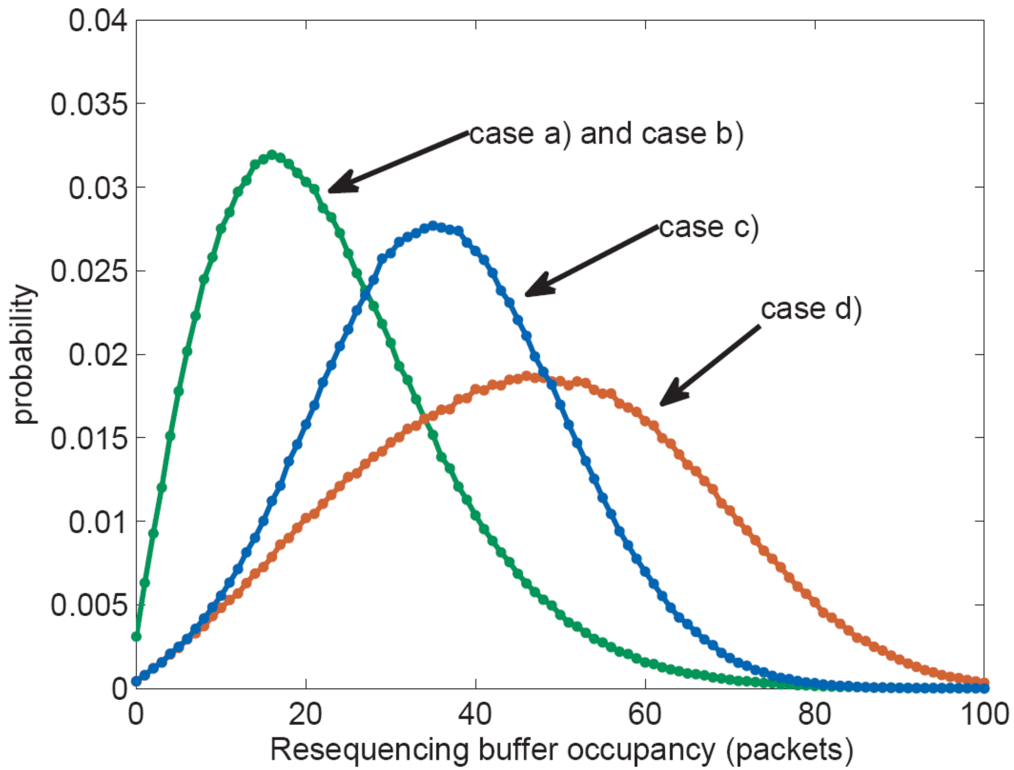


➔ Minor influence of mean path delay on buffer occupancy

➔ High influence of delay variation on buffer occupancy

Path Selection in Case of 3 Paths

- Homogeneous selection of paths:
  - a) $3 \bullet \{\mu = 50, \sigma = 10\}$
  - b) $3 \bullet \{\mu = 25, \sigma = 10\}$
- Heterogeneous selection of paths:
  - c) $2 \bullet \{\mu = 50, \sigma = 10\}$
    $1 \bullet \{\mu = 25, \sigma = 10\}$
  - d) $1 \bullet \{\mu = 50, \sigma = 10\}$
    $2 \bullet \{\mu = 25, \sigma = 10\}$



➔ System performs well for paths with equal characteristics

➔ Mixed path selection: Faster paths increase buffer occupancy

Conclusion

- Transport Virtualization improves capacity and reliability
- Simulative approach for investigating the resequencing buffer:
  - Number of paths, different path delays, scheduling, capacity,…
  - Evaluation of path selection strategies possible
- Case-Study of the resequencing buffer occupancy:
  - Complex path selection
  - Analysis based on mean values is insufficient
- Further Work:
  - Extend LP by adding additional constraints (e.g. jitter,…)
  - Investigation of correlated delay peaks possible (coughing of a router, congestion)
  - Include packet loss, TCP, E2E delay….