Influence of Packet Reordering on Concurrent Multipath Transmissions for Transport Virtualization

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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 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. wavelength 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)

Logical topology
Routing overlays of provider II
Routing overlays of provider I
Physical topology
POPs

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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

Data stream divided at router into segments with \( k \) parts

\[ \rightarrow \text{Scheduling?} \]

Overlay 1

Each provider will offer a set \( n_i \) of parallel paths \((i = 1 \ldots m)\)

Assumption: use \( k \) parallel paths on \( m \) overlays

Overlay \( m \)

\( k \) parts are send in parallel at time \( t \)

With \( k = \sum_{i=1}^{m} n_i \) paths

\[ \rightarrow \text{Buffer occupancy?} \]

Reassembling buffer of size \( L \)

Reassemble data stream from obtained parts

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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

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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!
Constraint: packets do not overtake each other on a single path, i.e. current delay $\geq$ 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

  ![Graph showing buffer occupancy comparison]

  - 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 probability $p_{ij}$ between two departures

Solution of the matrix equation $d \cdot P = d$ (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

\[
 \sum_{i=0}^{n} p_{i,j} \cdot x_i = x_j \forall j;
\]

\[
 \sum_{j=0}^{n} p_{i,j} = 1 \forall i
\]

\[
 p_{i,j} = 0, \ i < j - 2;
\]

\[
 0 < p_{i,j} < 1, \ j - 1 < i < j
\]

\[
 c_1 < p_{i,j} < c_2, \ i = j
\]

\[
 0 < p_{i,j} < 1, \ i > j
\]
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: \( \nu > 0 \)
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) $3 \cdot \{\mu = 50, \sigma = 10\}$
  - b) $3 \cdot \{\mu = 25, \sigma = 10\}$

- Minor influence of mean path delay on buffer occupancy
- High influence of delay variation on buffer occupancy

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Path Selection in Case of 3 Paths

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

- Heterogeneous selection of paths:
  - c) \(2 \cdot \{\mu = 50, \sigma = 10\}, 1 \cdot \{\mu = 25, \sigma = 10\}\)
  - d) \(1 \cdot \{\mu = 50, \sigma = 10\}, 2 \cdot \{\mu = 25, \sigma = 10\}\)

- 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….