A Wavelet-Based Approach to Detect Shared Congestion

Min Sik Kim
The University of Texas at Austin

Coauthors: Taekhyun Kim, YongJune Shin, Simon S. Lam, Edward J. Powers
Cooperative Congestion Control

- Better utilization of network resources

- Applications
  - Congestion Manager, path diversity
  - Improving overlay network topology
    - end system multicast, overlay routing, ...

- Identify flows sharing a bottleneck!
Previous Approaches to Detect Shared Congestion

- **Loss-based techniques**
  - Work with lossy links, drop-tail queues
  - Do *not* work with low loss rate, RED

- **Delay-based techniques**
  - More robust than loss-based ones

- **Limitation**
  - Require a *common endpoint*
Model

Observations on queueing delay
- Congested link: large fluctuations
- Non-congested link: stable
Basic Technique

\[
XCOR_{XY} = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n} (X_i - \bar{X})^2 \cdot \sum_{i=1}^{n} (Y_i - \bar{Y})^2}}
\]
Shared Congestion

$X_{src}$ $\rightarrow$ $X_{dst}$ $\leftarrow$ $X_{COR}$

$Y_{src}$ $\rightarrow$ $Y_{dst}$ $\leftarrow$ $Y_{COR}$

Queueing delay vs. time

$X_{COR}_{XY} = 1$
Independent Congestion

$X_{src}$ $X_{dst}$

$Y_{src}$ $Y_{dst}$

$XCOR_{XY} \approx 0$
1st Limitation of Basic Technique

Queueing Delay Variation
2nd Limitation of Basic Technique

Synchronization Offset
Outline

- Introduction
- Basic technique
- Limitations of the basic technique
- DCW: Delay correlation with Wavelet denoising
- Experimental results
- Summary
Queueing Delay Characteristics

- **Heavy traffic**: 2%–10% loss
- **Light traffic**: no loss
Wavelet Transform

Measured data $x(t)$

Wavelet basis $\psi_{i,j}(t) = 2^{-i/2}\psi(2^{-i}t - j)$

Scale

Translation

Wavelet coefficient at scale $i$ and translation $j$

$$X^i_j = \int_{-\infty}^{\infty} x(t)\psi_{i,j}(t) \, dt$$
Wavelet Denoising

- Soft thresholding
  - Threshold: $T$

\[
d_T(X) = \begin{cases} 
X - T & \text{if } X \geq T \\
X + T & \text{if } X \leq T \\
0 & \text{if } |X| < T 
\end{cases}
\]

\[
x(t) = \sum_{i=-\infty}^{\infty} \sum_{j=-\infty}^{\infty} X_j^i \psi_{i,j}(t) \quad \rightarrow \quad \sum_{i=-\infty}^{\infty} \sum_{j=-\infty}^{\infty} d_T(X_j^i) \psi_{i,j}(t)
\]
Minimizing Sync Offset Effects

- Error introduced by sync offset
  - $f(t)$: original data
  - $f(t-\Delta)$: shifted data due to sync offset
  - $f(t)-f(t-\Delta)$: error

- To minimize effects of sync offset:
  - $f(t)$ and $\psi$ should match closely
  - $f(t)-f(t-\Delta)$ and $\psi$ should not
Match Between Data Signal and Wavelet Basis

- Elliptic curve representation on time-frequency plane
  - $C, D_1$: Data Signal
  - $C, D_2$: Wavelet basis

- ISNR: similarity of elliptic curves

\[
\text{ISNR} = \frac{1}{T} \log_{10} \frac{C}{D_1 + D_2}
\]
Wavelet Basis Selection

- Differential ISNR
  - (ISNR between $f(t)$ and $\psi$) −
    (ISNR between $f(t)-f(t-\Delta)$ and $\psi$)

- Daubechies wavelets
  - Simple
  - Easy to implement
Evaluation

- Comparison with
  - MP: delay-based [Rubenstein, et al]
  - BP: loss-based [Harfoush, et al]

- Positive Ratio
  
  \[
  \frac{\text{# of answers indicating shared congestion}}{\text{# of experiments}}
  \]

  - 1: shared congestion
  - 0: no shared congestion
Common Source Topology

- $X_{src}$ and $Y_{src}$ are synchronized
- No synchronization offset
Common Source / Drop-Tail / Long-Lived TCP Traffic

- Shared: DCW > MP > BP
- Independent: MP > DCW ≈ BP
Common Source / Drop-Tail / On-Off CBR Traffic

- Slower convergence due to:
  - Delay on non-congested links → DCW, MP
  - Shorter loss runs → BP

- cf. Long-lived TCP

Diagram showing positive ratio over time for DCW shared, MP shared, BP shared, DCW independent, MP independent, BP independent.
Common Source / Drop-Tail / Short-Lived TCP Traffic

Even shorter loss runs $\rightarrow$ BP fails.
Common Source / RED

☐ DCW and MP: similar as with drop-tail

☐ BP fails
Topology without Sync Point

☐ Synchronization offset > 0
Sync Offset Tolerance

- **Long-lived TCP**
  - DCW: 1–2 sec, MP: 30–70ms, BP: < 10ms

- **On-Off CBR**

- **Short-lived TCP**

- **DCW**: 1–2 sec, **MP**: 30–70ms, **BP**: < 10ms
Internet Experiment

- Topology

- 10 seconds to converge

Graph:

- Node K
- Node T
- Node H
- Node A1
- Node A2
- Node A3

Graph with timelines for Positive Ratio:

- Shared line
- Non-shared line

Timeline:

- X-axis: Time (sec) from 0.1 to 10
- Y-axis: Positive Ratio from 0 to 1

Graph indicates that it takes 10 seconds for the system to converge.
Summary

- Proposed technique: DCW
  - Delay Correlation with Wavelet denoising
- As fast and accurate as previous techniques (with a common endpoint)
- Applicable to *any 2 Internet paths*
- Basic primitive for overlay topology improvement