Accuracy improvement for spatial composition-based end-to-end network measurement

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Overlay network
- Application-level logical network build upon the under-layer IP network
- An overlay link corresponds to an IP route in under-layer network

Overlay network paths
- \(N \times (N-1)\) overlay links (paths) can be chosen in overlay network with \(N\) overlay nodes
  - Overhead for measuring overlay paths quickly increases as the number of overlay nodes increases
  - Multiple overlay paths share the under-layer IP routers and links
  - Measurement overhead on routers/links increases
  - Accuracy of measurements degrades due to measurement overlaps

Application traffic control on overlay network
- Application-layer traffic routing on the overlay network
  - No need to change IP routing configurations
  - Measuring network performance between overlay nodes is important to provide a good route to upper-layer applications

Measuring overlay network paths
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Spatial composition of measurement results
- When overlay path \(AC\) includes overlay node \(B\), we avoid measuring performance of path \(AC\) and estimate it from measurement results of shorter paths \(AB\) and \(AC\) constructing path \(AC\)
  - Delay: \(D_{AC} = D_{AB} + D_{BC}\)
  - Bandwidth: \(B_{AC} = \min(b_{AB}, b_{BC})\)
  - Packet loss ratio: \(P_{AC} = 1 - (1 - p_{AB})(1 - p_{BC})\)

Effect on reducing measurement overhead
- \(1/40\) measurements with spatial composition
- Full mesh measurement

Estimation accuracy of spatial composition

- The accuracy of spatial composition depends on measurement accuracy of shorter paths composing a longer path.
- When we predict that the estimation accuracy is bad, we need to directly measure the longer path.
- We should utilize accurate measurement results of shorter paths for maintaining overall measurement accuracy.

\[
\text{Packet Loss Ratio} = P_{AC} = (1 - (1 - p_{AB})(1 - p_{BC}))
\]

Objectives of this research

- Propose statistical methods to improve the accuracy of spatial composition.
- Based on temporal changes in measurement results.
- Two methods:
  - Remove outliers from measurement results by Smirnov-Grubbs’ test.
  - Discard whole measurement results based on statistical metrics.
- We only focus on packet loss ratio measurements.

Assumptions and motivations

- Packet loss ratios are measured periodically.
- \( X = \{X_1, X_2, X_3, \ldots, X_K\} \): measurement results of packet loss ratio of a path.
- Packet loss ratio of a path: \( P = (X_1 + X_2 + X_3 + \ldots + X_K)/K \)

Statistical metrics for assessing reliability of measurement results

- \( I_1 = \frac{\text{stddev}(X)}{\text{avg}(X)} \)
- \( I_2 = \frac{\max(X) - \min(X)}{\text{avg}(X)} \)
- \( I_3 = \frac{\max(X)}{\text{avg}(X)} \)
- \( \text{avg}(X), \max(X), \min(X), \text{stddev}(X) \): average, maximum, minimum, and standard deviation of \( \{X_1, X_2, X_3, \ldots, X_K\} \).
- Large values of these metrics for a path mean that the whole measurement results of the path are less reliable.
- Not used for spatial composition.
- Discard all measurement results for the path and conduct new measurement.

Performance evaluation settings

- Measurement results on PlanetLab (1,109 servers).
- 3,348 datasets for overlay node combination (A, B, C).
- 2,500 UDP packets used for measuring \( X_1, X_2, X_3, \ldots, X_{20} \) (K=20).
- 50,000 packets in total.
- Evaluation metric: Estimation error \( E = |\log_{10}P_{AC} - \log_{10}P'_{AC}| \)
  - \( P_{AC} \): actual measurement value.
  - \( P'_{AC} \): estimated value.

http://www.planet-lab.org/
Evaluation results (1): Smirnov-Grubbs’ test

- 90% value without test
- 90% value with test
- 36% reduction
- Mean value without test
- Mean value with test
- 26% reduction

Estimation error

Significance level

Evaluation results (2): Discarding measurement results based on statistical metrics

\[ I = \frac{\text{stddev}(X)}{\text{avg}(X)} \]

- Number of paths whose measurement results are discarded

1. Without Smirnov-Grubbs test
2. With Smirnov-Grubbs test

- Without both methods
- By discarding measurement results of 500 paths, 23%/45% of estimation error are reduced without/with Smirnov-Grubbs test

Conclusion

- Improving estimation accuracy of packet loss measurement on overlay networks with spatial composition
  - Remove outliers from measurement results by Smirnov-Grubbs’ test
  - Discard whole measurement results based on statistical metrics
- Up to 45% reduction in estimation error by combining two methods
- Future work
  - Evaluations with other measurement datasets
  - Application to other path performance metrics
    - Delay, bandwidth, TCP throughput, …