# Revisiting the Constancy of Internet Delay Properties

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## BACKGROUND & MOTIVATION

Measurements of packet delay, packet loss, and throughput are widely used for broad assessment of internet performance characteristics.
A study in 2000-01 by Zhang et al.[ZPDS01] evaluated the *constancy* of internet performance (round-trip delay, packet loss, and throughput) along three dimensions:

- **Mathematical constancy:** the measurements can be described by a time-invariant model.
- **Operational constancy:** performance characteristics are stable and conducive to good application performance.
- **Predictive constancy:** performance characteristics can be predicted with good accuracy.

Internet topology has undergone significant evolution since the ZPDS01 study:

- Logical connectivity is much less hierarchical
- Recent transport protocols are more latency-sensitive, e.g. BBR congestion control.
- The web has transitioned from largely static pages to supporting interactive applications
- Real-time applications are extremely latency-sensitive, e.g., games, videoconferencing.

In this study we seek to reproduce the original study, focusing first on round-trip delays, since latency has an especially significant impact on the performance of internet applications.

## DATA

We use anchor mesh data generated by the RIPE Atlas platform (https://atlas.ripe.net).
We initially focus on RIPE Atlas anchor data because of (likely) better measurement quality.

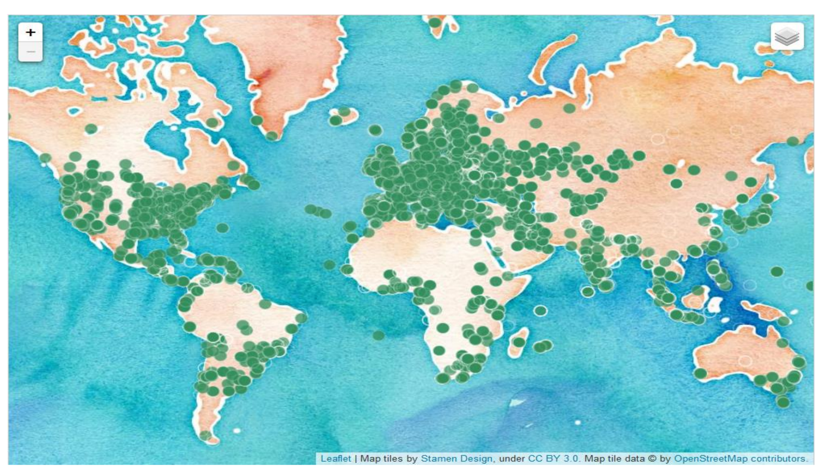

*Figure 1. Active anchors in the RIPE-Atlas network*

What we collected:

- Ping measurement round-trip times (RTTs) of probe packets sent between RIPE Atlas anchors. Probes are typically sent every 4 minutes.
- First-hop latency measurements to the first router along the path from an anchor. We analyzed these to select anchors with low-variability local networks in the same spirit as Sommers et al., 2017.

We selected one anchor from each continent. The map above shows the network of active anchors.

- Almaty, Kazakhstan (AS21299)
- Palo Alto, United States (AS1280)
- Frankfurt, Germany (AS33808)
- Belo Horizonte, Brazil (AS10417)
- Johannesburg, South Africa (AS10474)
- Melbourne, Australia (AS3879)

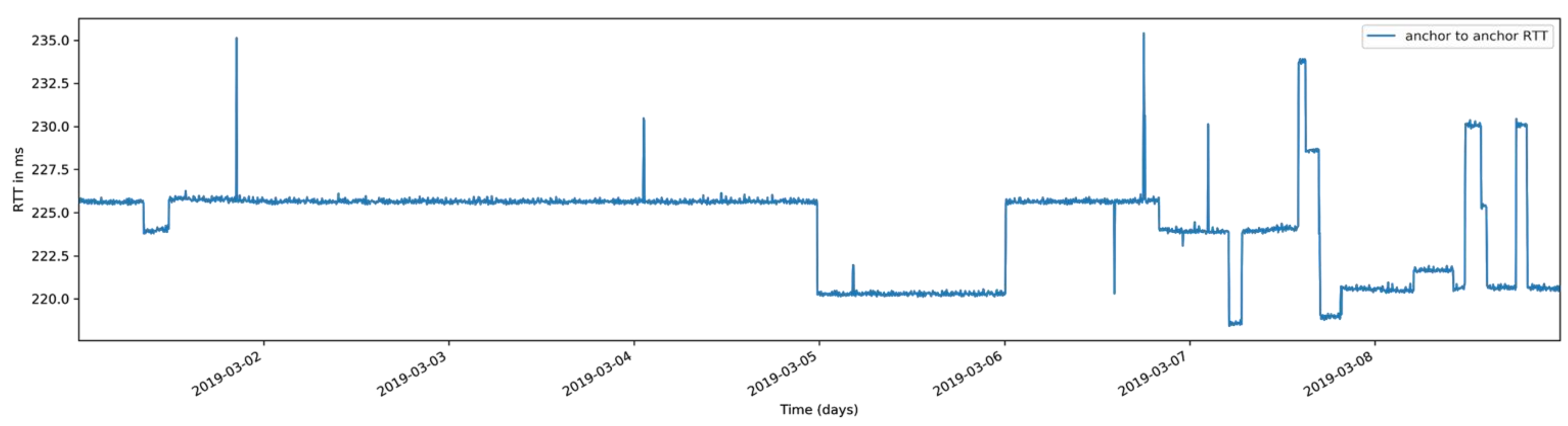


*Figure 2. Ping measurement results between anchors in Belo Horizonte and Frankfurt collected between 2019/03/01 and 2019/03/09*

## MATHEMATICAL CONSTANCY ANALYSIS

- We developed implementations (in Python) of the two changepoint detection algorithms (CP_bootstrap and CP_rank). We also used the changepoint package in R as a point of comparison (cp.var with PELT in particular).
- Using the changepoints identified, we determine periods of mathematical constancy in the data collected.

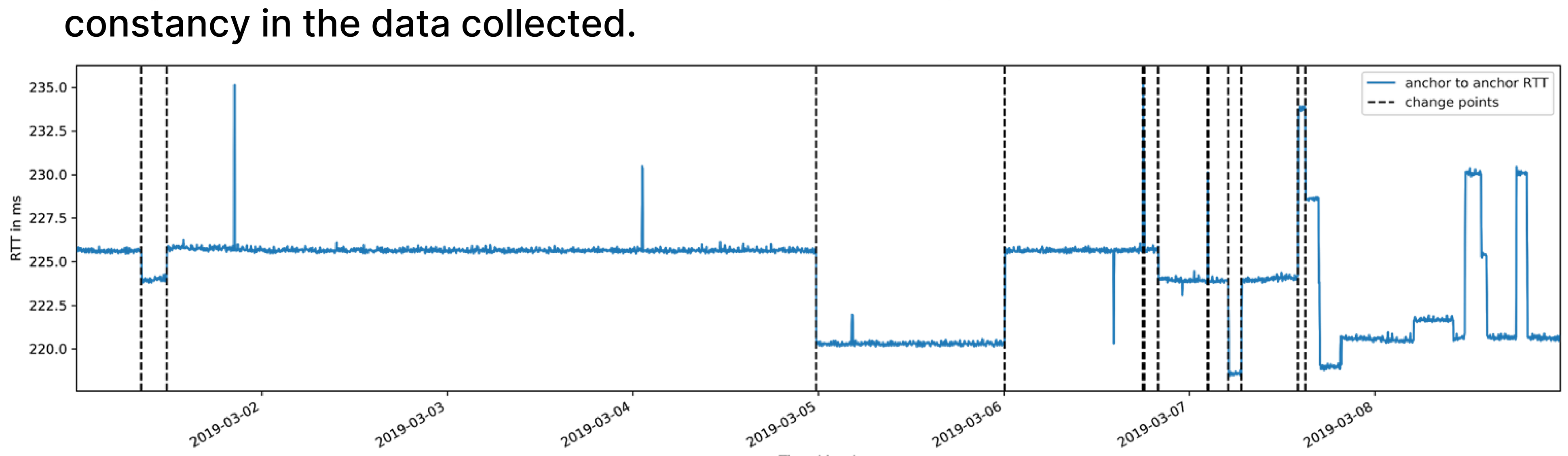


*Figure 3. The vertical lines are detected changepoints. Each period between the changepoints can be described with a time-invariant model - they're mathematically "constant"*

The cumulative distribution function (CDF) plots below visualize the cumulative likelihood of occurrence for periods of constancy in the connection between any pairs of anchors.

- About 10% of anchor-to-anchor pairs exhibit constancy on timescales of 24 hours or longer
- Roughly 50% of constancy periods last around 2-3 hours
- On closer look, the duration of constancy at several timestamps is highly variable among anchor-to-anchor measurements

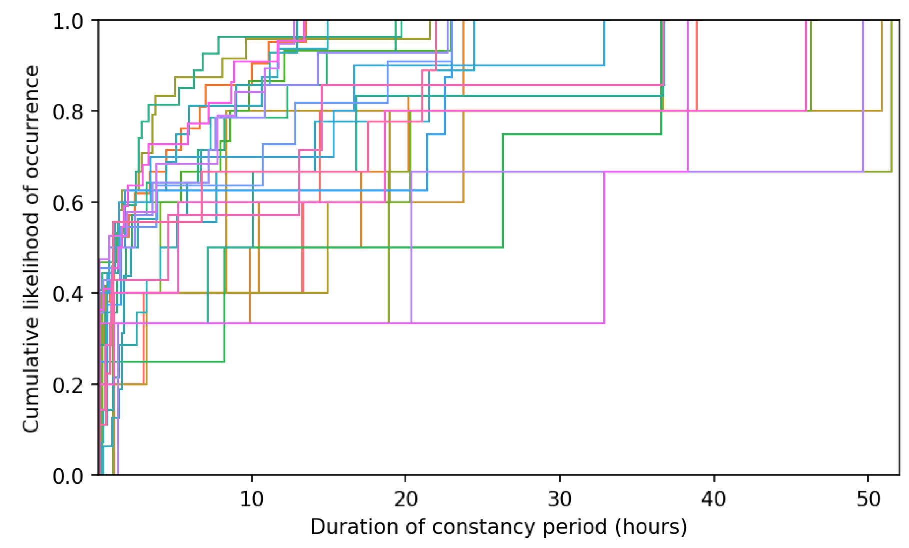


*Figure 4. CDF plot of the constancy durations of each anchor-to-anchor measurement*

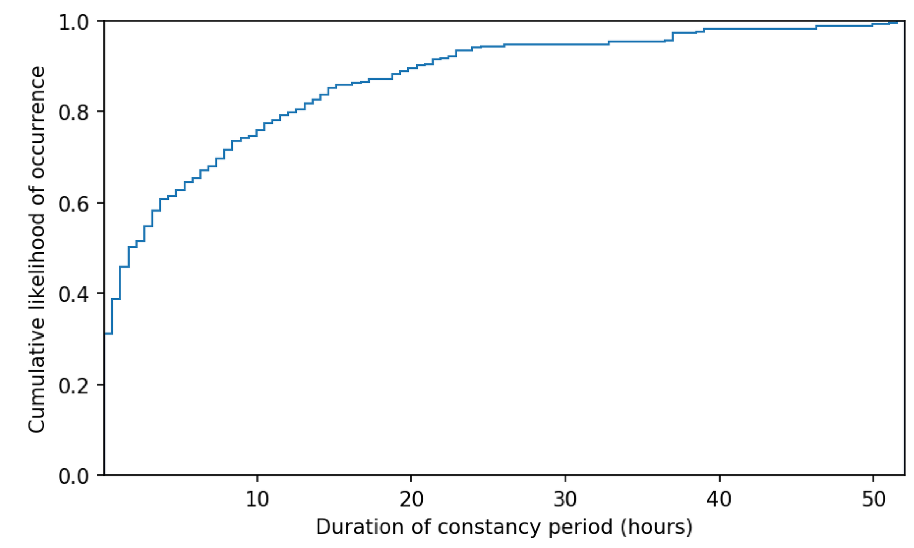


*Figure 5. Aggregated CDF plot for all anchors*

## OPERATIONAL CONSTANCY ANALYSIS

We perform a longitudinal analysis, selecting a period of two weeks every four months in the data.
For the BH-Frankfurt anchor pair, the plot on the right indicates that RTTs between these two anchors generally remain within 200 - 300ms, suggesting that there is not a notable change in performance on this network.
Therefore, this path is quite operationally constant.

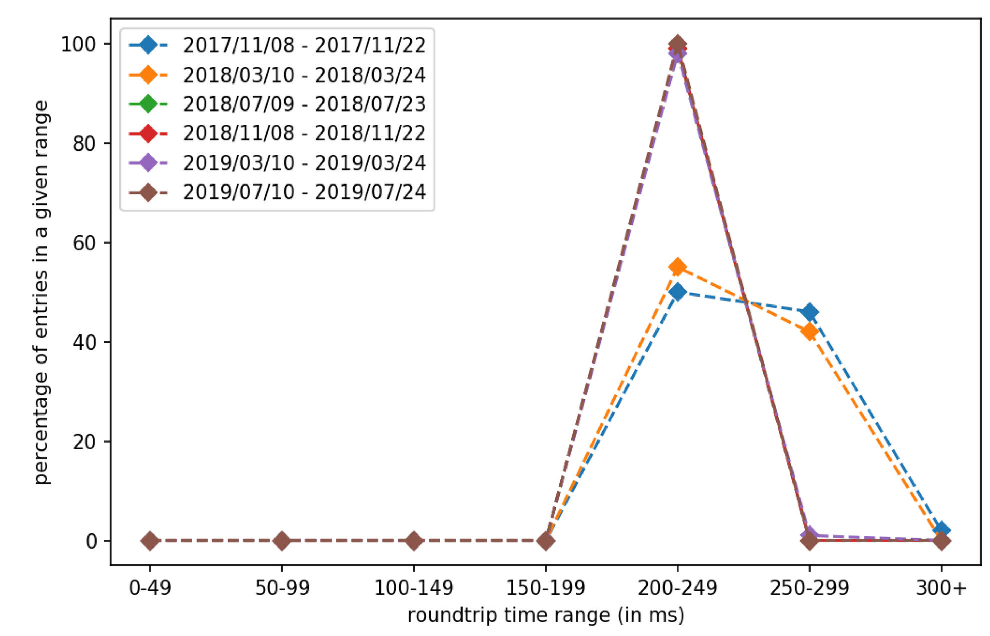


*Figure 6. Longitudinal analysis of operational constancy for Belo Horizonte-Frankfurt*

## RESULTS

Overall we observe:

- A wide range of CFR durations across different paths
- Unlike ZPDS01, delays along many paths may be considered operationally constant.
- No clear difference between IPv4 and IPv6 (weak evidence for longer CFRs on IPv6).
- CP_bootstrap method is suggestive of longer CFRs, cp.var suggestive of shorter CFRs.
- Changepoint detection method matters (a lot)!

## NEXT STEPS

- Investigation of better changepoint detection algorithm(s).
- Expanding scope of data analysis.
- Additional analyses within categories of anchors, e.g., within the same continent, within tier-1 providers.
- Consideration of longer time duration.
- Longitudinal analysis of constancy (to the extent possible with available data).
- Expand analyses to consider Atlas probes (v3 and v4) more broadly.
- Analysis of "lossy" vs. "non-lossy" paths as with ZPDS01.
- Examination of constancy of packet loss and throughput.

## REFERENCES

- Zhang Y., Duffield N., Paxson V., and Shenker S. On the constancy of Internet Path Properties. Proceedings of IMW, 2001.
- Sommers J., Durairajan R., and Barford P. Automatic metadata generation for active measurement. Proceedings of IMC, 2017.
- Thanks to the RIPE Atlas team for making measurement data available to the research community.