Measuring and Understanding Internet Performance: A Personal View

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10 July 2012
Measuring end-to-end performance

Source: Akamai’s network performance comparison
Why measuring network path?

Performance metrics
- Latency
- Delay variation (jitter)
- Connectivity
- Packet loss/reordering
- Link/path capacity
- Available Bandwidth
- TCP throughput
- Router hop (count)
- Packet duplication

Applications
- Traffic engineering
  - Network tomography
  - Path fingerprinting
  - Routing optimization
  - QoS routing, admission control, channel assignment in WLAN
- User profiling
  - Network resource planning
  - SLA verification
- Application performance tuning
  - Rate adaption for VoIP/video streaming apps
  - Distance/location prediction for overlay networks, P2Ps, CDNs
An unfinished business

- Much had been done in late 1990 and early 2000.
- Very few measurement tools have made their way into wide deployment.
- The Internet is no longer friendly to measurement probes.
  - Many unfriendly and intelligent middleboxes
  - Measurement Lab from Google, PlanetLab, …
- Measurement results may not reflect the experience of data packets.
- Continuous monitoring for inter-domain paths is hard without receiving complaints.
Challenges to active measurement

- Measurement scalability
  - Measure many network paths
- Measurement reliability
  - Measurement will not be interfered or interrupted
- Measurement representativeness
  - Measurement traffic representing the traffic of interest
- Measurement accuracy
  - Measurement results are accurately statistically.
- Bi-directional measurement
  - Measure both directions
- Measuring multiple metrics
Challenges to active measurement

- Measurement scalability
  - Cooperative measurement paradigm (e.g., OWAMP) not scalable
- Measurement reliability
  - Interference from various middleboxes and firewalls
- Measurement representativeness
  - Using control channel to measure data channel
- Measurement accuracy
  - Sampling rate and patterns
- Bi-directional measurement
  - Measure from both directions
- Measuring multiple metrics
  - Need multiple tools
A sampling of measurement tools

<table>
<thead>
<tr>
<th>Tools</th>
<th>Mode</th>
<th>Direction</th>
<th>Probing method</th>
<th>Probing packets</th>
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<td>Sting [21]</td>
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<td>F, B</td>
<td>Induce different TCP ACKs</td>
<td>TCP data segments in a single connection</td>
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<td>BADABING [22]</td>
<td>Coop.</td>
<td>F</td>
<td>Improved probing algorithm</td>
<td>Packet trains</td>
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<td>Dual connection test [2]</td>
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<td>F, B, D</td>
<td>Induce different ACK pairs with IPIDs</td>
<td>Two TCP data segments in two connections</td>
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<td>F, B, D</td>
<td>Induce different TCP data and ACKs</td>
<td>Two TCP data/ACKs in a single connection</td>
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<td>Reordering, loss and queueing delay:</td>
<td>Uncoop.</td>
<td>F, B, D</td>
<td>Induce ICMP replies with IPIDs</td>
<td>Two/three ICMP timestamp requests</td>
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Our approach to active measurement

- Measurement scalability
  - Non-cooperative measurement paradigm
- Measurement reliability
  - Use standard protocol and legitimate application data
- Measurement representativeness
  - Using data channel to measure data channel
- Measurement accuracy
  - Supporting different sampling rate and patterns
- Bi-directional measurement
  - Measure from only one direction
- Measuring multiple metrics
  - Obtain multiple metrics from one side
HTTP/OneProbe

- Use normal **TCP** data packet to measure data-path quality.
- Use normal and basic **TCP** data transmission mechanisms specified in **RFC 793**.
- Integrated into normal **HTTP** application sessions.
What does HTTP/OneProbe offer?

- Continuous path monitoring in an HTTP session (stateful measurement)
- All in one:
  - Round-trip time
  - Loss rate (uni-directional)
  - Reordering rate (uni-directional)
  - Capacity (uni-directional)
  - Loss-pair analysis
  - …

The probe design

- Send two back-to-back probe data packets.
  - Capacity measurement based on packet-pair dispersion
  - At least two packets for packet reordering
  - Determine which packet is lost.
The probe design (cont’d)

- Similarly for the response packets

- Each probe packet elicits a response packet.
  - Adv. Window = 2 and acknowledge only 1 packet.
Bootstrapping and continuous monitoring
Loss and reordering measurement via response diversity

(a) FR×R0

(b) F1×R0

(c) F2×R0

(d) F3
18 possible path events

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Based on their response packets

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<td>3'</td>
<td>S3</td>
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<tr>
<td>5. F0 × R3</td>
<td>S3</td>
<td>4'</td>
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<td>6. FR × R0</td>
<td>S3</td>
<td>2'</td>
<td>S4</td>
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<td>7. FR × RR</td>
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<td>8. FR × R1</td>
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<td>11. F1 × R0</td>
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<td>15. F1 × R3</td>
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<td>16. F2 × R0</td>
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<td>17. F2 × R1</td>
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<td>18. F3</td>
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Path event distinguishability

- All 18 cases can be distinguished except for
  - A1. $F_1 \times R_2$ and $F_1 \times R_3$
  - A2. $F_1 \times RR$ and $F_1 \times R_1$
  - A3. $F_0 \times R_3$ and $FR \times R_3$

- Resolving the ambiguities
  - A1 and A2: use RTT.
  - A3: use TCP timestamping.
Our measurement methods

- Round-trip delay, asymmetric packet loss and packet reordering measurement

- Capacity measurement

- Loss-pair measurement

- Available bandwidth measurement
The capacity measurement and loss-pair measurement

Design and analyze three packet-pair methods for sound network measurements

- MDDIF [CoNEXT 09], TRIO [CoNEXT 11], Loss pair [IMC 10]
- Fundamentals: decompose + recompose + recycle

Incorporate all the methods into a non-cooperative measurement tool – HTTP/OneProbe [USENIX 08]
Network capacity

One-way (Forward path) capacity

A router hop

Sub-path

Forward path

Reverse path

Source

Destination

Source

Destination

Network capacity

One-way (Forward path) capacity

A router hop

Sub-path

Forward path

Reverse path

Source

Destination

Network capacity

One-way (Forward path) capacity

A router hop

Sub-path

Forward path

Reverse path

Source

Destination

Network capacity

One-way (Forward path) capacity

A router hop

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Destination

Network capacity

One-way (Forward path) capacity

A router hop

Sub-path

Forward path

Reverse path

Source

Destination
Cross-traffic impact on packet pairs

- **Existing techniques**: Identify the unaffected packet pair/train

 Graduate Forum, Sun Yat-sen University July 2012
Delay difference = PPD

- The MPPDF = p6’s delay - p5’s delay between first and second packets’ minimum delays (minDelays)
TRIO: measuring asymmetric capacity with three minRTTs

- Exploit 1-RTP and (1,1)-TWP with $S_f = S_r = S$

- $d_{j-1}^T - d_{j-1}^R = S/C_f$.
- $d_j^T - d_{j-1}^T = S/C_r$.
- Reuse $d_{j-1}^T$.
- Avoid probe interference!

For self-diagnosis

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Taxonomy of capacity measurement techniques

Capacity metrics
- Per-hop link capacity
- Sub-path capacity
- Congested-link capacity
- One-way/round-trip/asymmetric capacity

Measurement traffic
- Hop-limited probe
- Tailgating probe
- Packet pair/Packet train

Measurement data
- Packet delay
- Delay variation/Packet dispersion
- Minimum delay
- Mode
- Heuristics

Filtering methods

Available tools:
- AsymProbe
- CapProbe
- PingPair
- Nettimer (tailgating)
- Packet quartet
- BBScope
- Envelope
- MultiQ
- Bprobe
- Pathrate
- Paśtor’s method
- PBM
- DSLprobe
- SProbe
Loss-pair measurement

- Packet pair with exactly **one** lost packet (defined by Liu & Crovella [liu01imw])

  - Path queueing delay $\Theta$
    - $\text{LP}_{01}: \Theta_{j-1} = d_{j-1} - \text{minRTT}$.
    - $\text{LP}_{10}: \Theta_j = d_j - \text{minRTT}$.
  
  - Buffer size of congested hop $h'$ [liu01imw]:
    \[ B = \Theta_j \times C^{(h')} . \]

Three questions:

1. $\Theta_{j-1} = \Theta_j$?
2. Is $B$ accurate?
3. Any additional info from $\Theta_{j-1}$ and $\Theta_j$?
Loss pairs

Forward Path

Reverse Path
Collaborative path-quality measurement
HARNET measurement (since 1 Jan 2009)
Running OneProbe at the 8 Us

- 24x365 probing of the paths to 40+ websites
40+ web servers selected by the JUCC

Measurement side:
- OneProbe@HKU
- OneProbe@CUHK
- OneProbe@PolyU
- OneProbe@CityU
- OneProbe@BU
- OneProbe@HKUST
- OneProbe@LU
- OneProbe@HKIED

User side:
- HKU
- CUHK
- PolyU
- CityU
- BU
- HKUST
- LU
- HKIED

Planetopus, database, etc
### Home > Round Trip Time

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<th>URL</th>
<th>U B</th>
<th>U F</th>
<th>U C</th>
<th>U A</th>
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<td>245.1</td>
<td>225.0</td>
<td>249.1</td>
<td>229.1</td>
<td>243.0</td>
<td>221.2</td>
</tr>
</tbody>
</table>
Application: Impact analysis of submarine cable faults
Eyjafjallajökull volcano eruption
Path-quality degradation for NOK (Finland) and ENG (in UK)

(a) The ENG path’s RIT.

(b) The NOK path’s RIT.

(c) The ENG path’s forward-path loss.

(d) The NOK path’s forward-path loss.

(e) The ENG path’s reverse-path loss.

(f) The NOK path’s reverse-path loss.
(a) UB→NOK’s RTT and loss rates.

(b) UB→BBC’s RTT and loss rates.
Network congestion caused by the volcano ashes?

- The surges on packet loss and RTT occurred on 14 April 2009.
- But
  - The onsets of the path congestion and air traffic disruption do not entirely match.
  - Some of the peak loss rate and RTT occurred on weekends.
  - Path congestion can still be observed at the end of the measurement period.
A SEA-ME-WE 4 cable fault

- The SEA-ME-WE 4 cable encountered a shunt fault on the segment between Alexandria and Marseille on 14 April 2010.
- The repair was started on 25 April 2010, and it took four days to complete.
- During the repair, the service for the westbound traffic to Europe was not available.
The SEA-ME-WE 4 cable
A plausible explanation for the network congestion

- The congestion in the FLAG network was caused by taking on rerouted traffic from the faulty SEA-ME-WE 4 cable.
- FLAG does not use the SEA-ME-WE 4 cable for Hong Kong → NOKIA, ENG3, and BBC.
- FLAG uses FEA for Hong Kong → NOKIA, ENG3, and BBC
- TATA uses different cables between Mumbai and London.
The current phase

- Server-side measurement methods
  - Induce data from clients for measurement.
  - Quality measurement without user intervention
- NetMagic implementation of measurement boxes
  - Supporting client-side and server-side measurement
  - [http://www.netmagic.org/](http://www.netmagic.org/)
- CERNET-2 measurement platform
  - Deploy a measurement platform on CERNET-2
  - IPv6 measurement
- Residential broadband measurement platform
  - SLA measurement
  - Facilitate a social network for network diagnosis and monitoring
More projects

- Network performance data analytics
  - What and when to induce for measurement?
  - What can we say from the measurement data with high confidence?
- Automating diagnosis and patch-up of network performance problems
  - By a group of individual home users?
  - Network tomography
- Creative performance data visualization
  - Spatial and temporal data visualization
  - Visualization for naked-eye diagnosis
Conclusions

- Develop a suite of atomic path-quality measurement methods.
  - Atomic => application specific, e.g., video, cloud services
  - Path quality => QoE
  - Client side => server side

- Network data research
  - Mining network data
  - Designing measurement “experiments” to facilitate network data mining
  - Towards a science of network research

- Operational experience informs research; research underpins network operations
  - Unearthing important problems and questions from operations
  - Putting research output into practice.
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