Internet Measurements: IPv6 Extension Header Edition

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Active IPv6 Measurement is Difficult

- Many access networks do not support IPv6
  - e.g., mobile networks, broadband in Europe
- IPv6 server edge - hosting companies, do not always proxy IPv6 request to an IPv6 origin server
- IPv6 Top domains lists - not very diverse
- Hard to scan, but there are IPv6 hitlists
EH Measurement is *Harder*

- Some devices might not support EH to begin with
- Some hardware does not allow reading deep into a packet
  - Brokenness can be subtle, for network devices that inspect upper layer protocol information
- Network devices can be configured to filter EHs
  - e.g., at access edge or server edge
- Transit networks could be configured to filter EHs
Lots of Differing Results over the Years

- e.g., RFC 7872 [1] data showed traversal as:
  - Destination Options EH: 80-90%
  - Hop-by-Hop Options EH: 45-60%

- But, my own data [2] showed traversal as:
  - Destination Options EH: 70-75%
  - Hop-by-Hop Options EH: 15-20%

- APNIC [3] showed traversal as:
  - Destination Options EH: 30-80%
  - Hop-by-Hop Options EH: near 0%

- And then, JAMES [4] showed traversal as:
  - Destination Options EH: 94-97%
  - Hop-by-Hop Options EH: 8-9%
EH Measurements using a range of tools and vantage points

<table>
<thead>
<tr>
<th></th>
<th>Core</th>
<th>Access networks</th>
<th>Server Edge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internet Core</td>
<td>JAMES - traceroute</td>
<td>APNIC - Custom</td>
<td>UoA - Pathspider</td>
</tr>
<tr>
<td></td>
<td>N. Elkins - custom FTP measurements</td>
<td>measurements</td>
<td>RFC 7872 - traceroute</td>
</tr>
<tr>
<td>Access Networks</td>
<td>UoA @RIPE Atlas - traceroute</td>
<td>N/A</td>
<td>Jen Linkova @RIPE Atlas - traceroute</td>
</tr>
<tr>
<td>Server Edge</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Could the measurements, in fact, agree?
Examples of Different Measurement Results
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- Example 1: choice of cloud provider can influence results
- Example 2: measuring from the edge or the core does too
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- Example 2: measuring from the edge or the core does too
- Example 3: Top 1M lists need a per-AS breakdown
- Example 4: different target server types = different results
- Example 5: crowd-sourcing targets = different results
- Example 6: cloud provider targets = different results again
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- Example 4: different target server types = different results
- Example 5: crowd-sourcing targets = different results
- Example 6: cloud provider targets = different results again
- Example 7: different protocols can reveal path info
- Example 8: the same path can reveal unexpected results
Example 1: Vantage Points

<table>
<thead>
<tr>
<th>Location</th>
<th>Hop-by-Hop Options EH UDP</th>
<th>Hop-by-Hop Options EH TCP</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK (JANET)</td>
<td>11.9%</td>
<td>11.5%</td>
</tr>
<tr>
<td>Canada (OVH)</td>
<td>19%</td>
<td>19.9%</td>
</tr>
<tr>
<td>Singapore (OVH)</td>
<td>17.4%</td>
<td>25.2%</td>
</tr>
<tr>
<td>Netherlands, Belarus, US, Singapore, UK, Canada (DigitalOcean)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>US, Canada, Singapore, Japan, India (Linode)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Percentage End-to-End traversal for an 8 Byte HBH Options EH, measured in 2022

• Diverse vantage points do tell better stories!
• Digital Ocean, AWS, Linode - did not support HbH options
  • Still a valid measurement point!
• But, cannot do wide scale measurements from here
Example 2: Vantage Points

<table>
<thead>
<tr>
<th></th>
<th>Hop-by-Hop Options EH UDP</th>
<th>Destinations Options EH UDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access Networks: RIPE Atlas</td>
<td>7-16%</td>
<td>77-96%</td>
</tr>
<tr>
<td>Internet core: various cloud providers</td>
<td>11-25%</td>
<td>92-97%</td>
</tr>
</tbody>
</table>

Percentage traversal for an 8 Byte HBH Options EH, from ~1000 RIPE Atlas vantage points vs 30 cloud provider vantage points, to cloud/R&E destinations, measured in 2022

- Edge v. core networks reveal a difference:
  - Networks can also differ: e.g., mobile, satellite, ...
Example 3: Destinations

<table>
<thead>
<tr>
<th></th>
<th>Per-Host</th>
<th>Per-AS</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK (JANET)</td>
<td>71%</td>
<td>92%</td>
</tr>
<tr>
<td>UK (JANET)</td>
<td>12%</td>
<td>38%</td>
</tr>
<tr>
<td>Canada (OVH)</td>
<td>72%</td>
<td>94%</td>
</tr>
<tr>
<td>Canada (OVH)</td>
<td>19%</td>
<td>59%</td>
</tr>
</tbody>
</table>

- One third of all destinations are hosted by a small number of major hosting companies that do not support some EH types.
- Per-AS difference versus per-host difference for the same dataset.
- Top 1X lists: Looking at just hosts can make things look better or worse that they actually are!

End-to-End percentage traversal for an 8 Byte Destination Options EH, to the authoritative DNS servers for n=20082 destinations in 2867 different ASes.
### Examples 4-6: Destinations

<table>
<thead>
<tr>
<th>Dataset</th>
<th>D08</th>
<th>HBH8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web servers</td>
<td>11.88% (17.60%/20.80%)</td>
<td>40.70% (31.43%/40.00%)</td>
</tr>
<tr>
<td>Mail servers</td>
<td>17.07% (6.35%/26.98%)</td>
<td>48.86% (40.50%/65.42%)</td>
</tr>
<tr>
<td>Name servers</td>
<td>15.37% (14.29%/33.46%)</td>
<td>43.25% (42.49%/72.07%)</td>
</tr>
</tbody>
</table>

- RFC 7872: different destination infrastructure = *different results*
- Crowd sourcing destinations (APNIC): *a different story*
- FTP measurements (Nalini Elkins): *a different story*
Examples 4-6: Destinations

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Examples 4-6: Destinations

1. PDM-FTP Toronto to Warsaw - worked
2. PDM-FTP Toronto to Seattle - worked
3. PDM-FTP Toronto to Mumbai - worked
4. PDM-FTP Toronto to Melbourne - worked
5. PDM-FTP Toronto to Frankfurt - worked

• RFC 7872: different destination infrastructure = different results
• Crowd sourcing destinations (APNIC): a different story
• FTP measurements (Nalini Elkins): a different story
Example 7: Protocol Differences

EH Traversal can depend on the transport protocol carried.

- TCP/UDP difference for EH traversal in edge networks
  - Lots of edge devices mess with TCP; could there be a link between those devices and traversal?
Example 8: LB
## Recap

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| UoA @RIPE Atlas - traceroute | N/A | Jen Linkova @RIPE Atlas - traceroute |
| N/A | N/A | N/A |

- Wide-scale measurement can be difficult; our data works together!
What next?

• Traversal depends on many factors
  • How, where, to, and when you measure influences the final result
• End-to-end + path measurements + diverse targets, destinations and protocols mitigates limitations of each way to measure!

• Still several areas for exploration:
  • Example 7: Do network devices read EH?
  • Example 8: To what extent are forwarding decisions influenced by the presence of EH?
Could you provide a home for our measurement probe?
Questions?

- [3] https://blog.apnic.net/2022/10/13/ipv6-extension-headers-revisited/