User-level Internet Path Diagnosis

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Where does the problem begin?

- Ideal trace-based solution
- Packet-based solution
  1. Complete embedding
  2. Reduced embedding
  3. Constant space embedding
  4. Real clocks
Where does the problem begin?

- Ideal trace-based solution
- Packet-based solution
  1. Complete embedding
  2. Reduced embedding (IP identifier, TTL…)
  3. Constant space embedding (SampleTTL…)
  4. Real clocks (unsynchronized clock)
Our diagnosis architecture is ...

<table>
<thead>
<tr>
<th>Field</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Path signature</td>
<td>Records path information</td>
</tr>
<tr>
<td>Sample TTL</td>
<td>Selects the sampling router</td>
</tr>
<tr>
<td>Timestamp</td>
<td>Time at the sampling router</td>
</tr>
<tr>
<td>Counter</td>
<td>Flow counter from the sampling router</td>
</tr>
<tr>
<td>Interface Id</td>
<td>Interface address of the sampling router</td>
</tr>
</tbody>
</table>
Before practical diagnosis tools …
Internet approximation of primitives

- In-band sampling -> Out-of-band measurement probes
- Router timestamps -> ICMP timestamp requests
- Per-flow counters -> IP identifiers
Before practical diagnosis tools …

Properties influence the performance

1. Packet reordering
Before practical diagnosis tools ...

Properties influence the performance

2. Packet loss
Before practical diagnosis tools …

Properties influence the performance

3. Packet queuing
Our diagnosis tool is ... Tulip

- Traceroute -> path to the destination & measurable routers
- User option -> parallel search
- User option -> binary search
- Network load
- Diagnosis time
Evaluation on Tulip…

Diagnosis Granularity

Diagnosis granularity for loss and queuing
Evaluation on Tulip...

Accuracy in measuring

1. Reordering
   - End-to-end correctness
   - Internal consistency

![Graphs showing reordering rate delta for forward path and round trip]
2. Loss

- End-to-end correctness
- Internal consistency
Evaluation on Tulip...

Accuracy in measuring

3. Queuing delay
   - End-to-end correctness
   - Internal consistency

![Graph showing queuing delay](image)
Evaluation on Tulip...

Accuracy in measuring

Internal consistency

![Graph showing median queuing delay vs hops from source.](image)
Evaluation on Tulip...

Locate loss and delay

(a) loss

(b) queuing
Evaluation on Tulip...

Persistence of faults

(a) loss

(b) queuing
Limitations of Tulip...

- In-band sampling -> Out-of-band measurement probes
- Router timestamps -> ICMP timestamp requests
- Per-flow counters -> IP identifiers

Differences between them are likely to grow as the complexity of the network increases.

The router selects which counter to use for the response IP-ID by hashing the source address in the probe. In the absence of collisions, this is like a per-flow counter for the probing host. But since source addresses are hashed, any collision would be deterministic.

The path to the router may not be a prefix of the path to the destination.
Summary

- Address the problem of letting unprivileged users diagnose communication path problems in a large, heterogeneous, distributed system such as the Internet.

- Build tulip, a practical tool to diagnose reordering, loss, and significant queuing delay – three properties that impact application performance.

- Tulip leverages ICMP timestamps and IP identifiers to diagnose paths from the source to arbitrary destinations.
Thanks for listening.