"Where the !?*! are the packets going?”

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Traceroute

Traceroute is one of the most famous and long-lasting diagnostic tools in networking environment

First implementation by Van Jacobson in late 80s to answer the question:

"where the !?*! are the packets going" ?

```
Posted-Date: Tue, 20 Dec 88 05:13:28 PST
Received-Date: Tue, 20 Dec 88 05:14:46 PST
Received: from helios.ee.lbl.gov by venera.isi.edu (5.54/5.51)
        id AA25560; Tue, 20 Dec 88 05:14:46 PST
Received: by helios.ee.lbl.gov (5.59/s2.2)
        id AA03127; Tue, 20 Dec 88 05:13:30 PST
Message-Id: <8812201313.AA03127@helios.ee.lbl.gov>
To: ietf@venera.isi.edu, end2end-interest@venera.isi.edu
Subject: 4BSD routing diagnostic tool available for ftp
Date: Tue, 20 Dec 88 05:13:28 PST
From: Van Jacobson <van@helios.ee.lbl.gov>
Content-Length: 2373
X-Lines: 46
Status: RO

After a frustrating week of trying to figure out "where the !?*!
are the packets going?", I cobbled up a program to trace out
the route to a host.  It works by sending a udp packet with a
ttl of one & listening for an icmp "time exceeded" message.  If
it gets one, it prints the source address from the icmp message,
then bumps the ttl by one & etc.  (As usual, I didn't come up
with this clever idea -- I heard Steve Deering mention it at an
end-to-end task force meeting.)
```

Traceroute implementations

- Many traceroute implementations have been created on different OSes
- Over the years it became one of the most used tools in the Internet measurement and topology discovery fields (multipath, de-aliasing, NAT traversal, …)
  - Paris, Dublin, Pamplona traceroute…

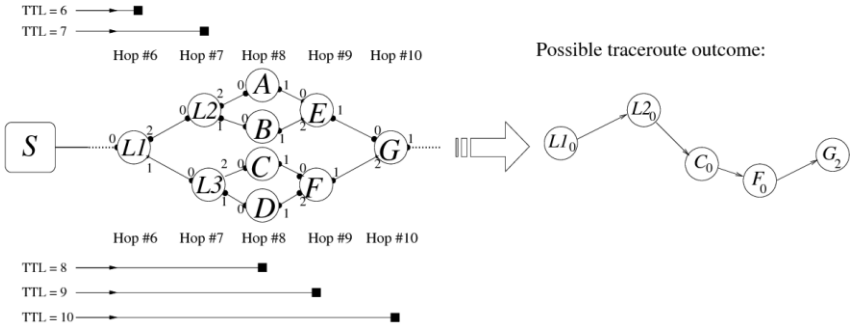


Fig. 1. Traceroute under load balancing

Augustin, Brice, Timur Friedman, and Renata Teixeira. "Multipath tracing with Paris traceroute." Workshop on End-to-End Monitoring Techniques and Services. IEEE, 2007.

Linux traceroute

- We leverage Dmitry Butskoy's "Linux traceroute"
  - Very fast
  - Open source
  - Easily extendible


Project Page Download Mail List

This is a new modern implementation of traceroute(8) utility for Linux systems.

It has replaced the old one in the majority of distributions now, including Fedora, RHEL, Debian, Mandriva, Gentoo, Ubuntu.

- During the years we enhanced this traceroute to include new monitor capabilities
- We hope these enhancements can be useful to the community

Pietrasanta Traceroute

"A noble town since 1841 and a city of art"
(and where our Italian office is located!)

Pietrasanta Traceroute

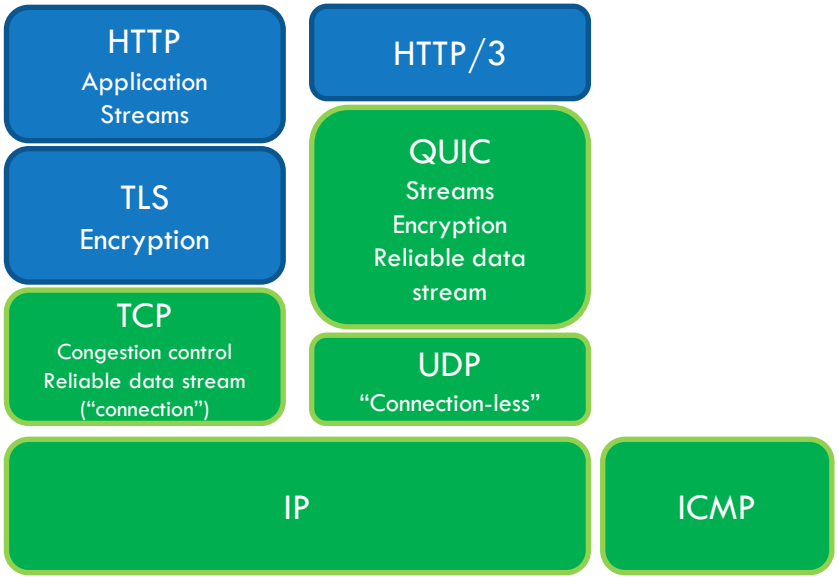
- QUIC traceroute
- TCP InSession
- Work in Azure environment
- ECN-awareness (IP and transport level)
- Path MTU performance improvements
- Report ToS/DSCP hop by hop
- Report MSS when running in TCP mode
- Handle print in a separate thread (speed up)
- Overall timeout
- Avoid UDP standard filtering

https://github.com/catchpoint/Pietrasanta-traceroute

QUIC traceroute

QUIC

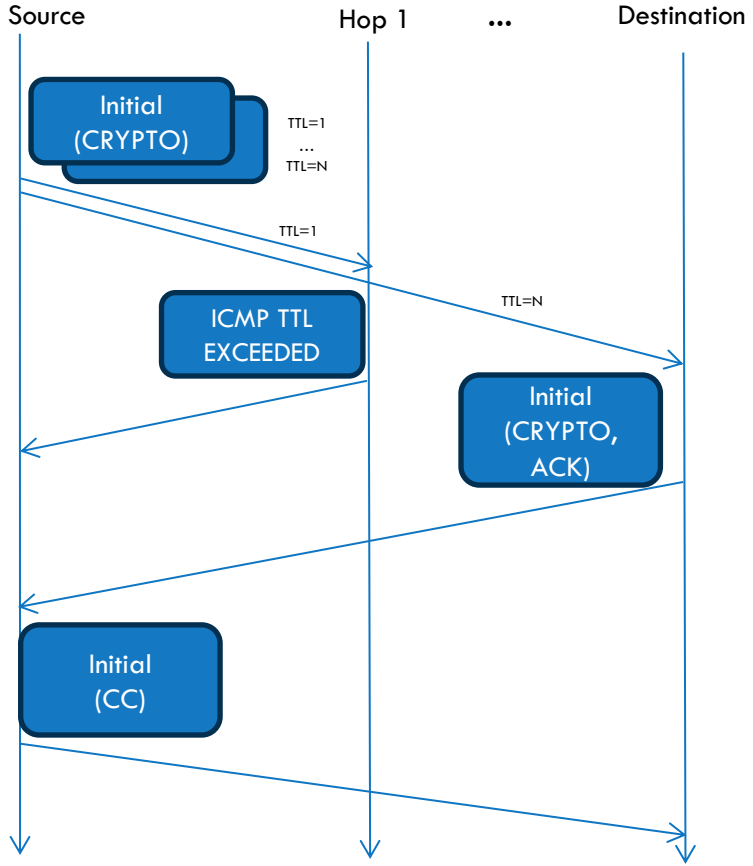
- QUIC is considered a transport layer protocol
  - More than just “UDP”
  - e.g., it is the transport layer of HTTP/3



QUIC assumes responsibility for the confidentiality and integrity protection of packets. For this it uses keys derived from a TLS handshake, but instead of carrying TLS records over QUIC (as with TCP), TLS handshake and alert messages are carried directly over the QUIC transport, which takes over the responsibilities of the TLS record layer.

RFC9001 - Using TLS to Secure QUIC

QUIC traceroute



- Packets sent are QUIC compliant, so the header is protected and the payload (frames) are encrypted
  - We leverage openssl3
- Nice “side effects”
  - Check whether the path filters QUIC
  - Determine if the destination supports QUIC
  - Check whether ECN is supported
    - Set IP-ECN in probes

QUIC traceroute

- Like "TCP half open"
- Do a QUIC handshake then closes the session (if opened)
  - Send QUIC "Initial" packet
    - Include a CRYPTO frame with TLS "Server Hello"
  - Intermediate hops will return ICMP TTL Exceeded
  - Destination may return
    - QUIC packet
    - ICMP port unreachable (still good, dest reached)
    - Nothing (timedout)
  - Close the session if it is the case
    - Send QUIC Initial packet including a CONNECTION_CLOSE frame

TCP InSession

TCP InSession

- Classic TCP traceroute sends a different SYN for each hop
  - Different SYNs can take different paths
    - No consistency within a single traceroute
  - Many SYNs are sent per traceroute
    - Trigger firewall rules (SYN flood?)

- TCP InSession firstly opens a TCP session with the destination
- Then tracerouting is performed by sending 1-byte data packets within the session (with incremental TTL)
  - Inspired by TCP Sidecar

TCP InSession

- CONS
  - Requires SACK mechanism
  - Works only if the endpoint is listening in TCP on the target port
  - Opens a TCP session with the target host
- PROS
  - Sends 1 SYN per traceroute
    - Avoid to cause SYN flood
  - Traceroute probes are seen as part of a data flow
    - Bypass firewalls
    - Data packets are "more likely" to follow the same path

Check out our blog:
https://www.catchpoint.com/blog/traceroute-insession-catchpoints-effort-towards-a-more-reliable-network-diagnostic-tool

TCP InSession

```
[redacted] sudo ./traceroute/traceroute -n -T www.bing.com
traceroute to www.bing.com(204.79.197.200), 30 hops max, 60 byte packetsoverall timeout not set
   1  192.168.0.1  0.669 ms  0.621 ms  0.604 ms
   2  192.168.1.1  0.827 ms  0.571 ms  0.527 ms
   3  * * *
   4  172.18.33.212  5.071 ms  5.548 ms 172.18.33.196  5.530 ms
   5  172.18.33.226  6.503 ms  6.080 ms 172.18.33.228  6.060 ms
   6  172.19.184.88  12.701 ms 172.19.184.92  10.165 ms 172.19.184.90  10.119 ms
   7  172.19.177.66  10.087 ms 172.19.177.24  10.058 ms 172.19.177.20  12.082 ms
   8  195.22.192.144  12.046 ms 195.22.205.98  10.502 ms  10.047 ms
   9  195.22.208.79  10.003 ms 195.22.196.69  12.290 ms 195.22.208.79  12.248 ms
  10  195.22.196.129  22.943 ms 195.22.196.81  13.345 ms 195.22.196.129  11.678 ms
  11  13.104.182.192  11.451 ms 13.104.182.193  11.406 ms *
  12  * * *
  13  204.79.197.200 <MSS:1440>  13.649 ms * *
   Timedout: false
   Duration: 163.111 ms
   DestinationReached: true
```

Classic TCP traceroute

- Almost each hop has multiple IP addresses
- The destination replied only once

TCP InSession

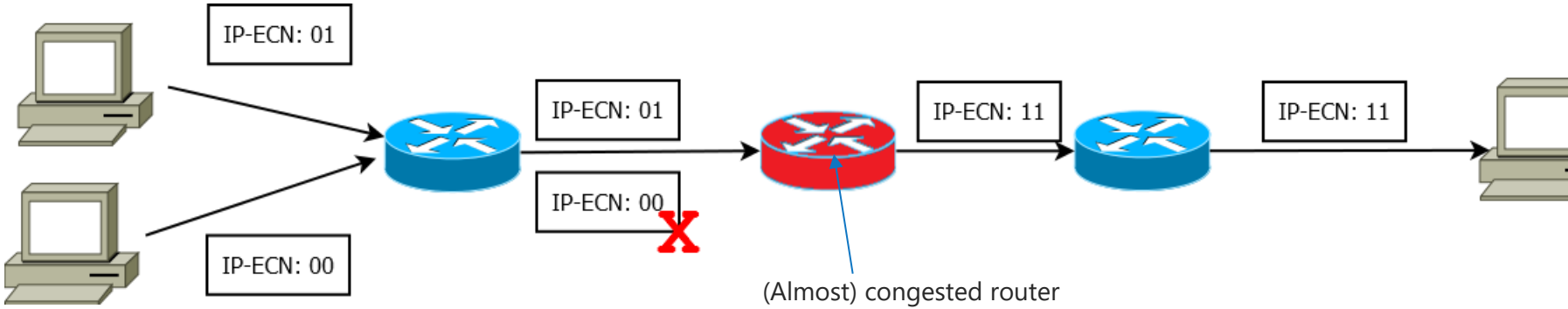
- Each hop has one IP address
- The destination replied to all probes

```
[redacted] sudo ./traceroute/traceroute -n --tcpinsession www.bing.com
traceroute to www.bing.com(95.101.20.193), 30 hops max, 53 byte packetsoverall timeout not set
   1  192.168.0.1  0.490 ms  0.452 ms  0.440 ms
   2  192.168.100.1  5.520 ms  5.511 ms  5.672 ms
   3  * * *
   4  172.18.33.212  5.640 ms  5.632 ms  6.129 ms
   5  172.18.33.230  6.124 ms  6.776 ms  6.774 ms
   6  172.19.184.92  10.463 ms  10.996 ms  10.975 ms
   7  172.19.177.60  10.612 ms  9.895 ms  9.872 ms
   8  151.99.72.197  26.336 ms  26.313 ms  26.302 ms
   9  23.210.57.131  10.219 ms  10.192 ms  10.887 ms
  10  95.101.20.193  9.663 ms  12.033 ms  9.457 ms
   Timedout: false
   Duration: 71.904 ms
   DestinationReached: true
   MSS: 1452
```

ECN bleaching detection

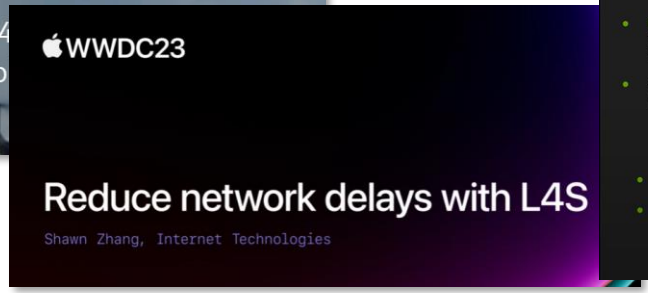
ECN mechanism

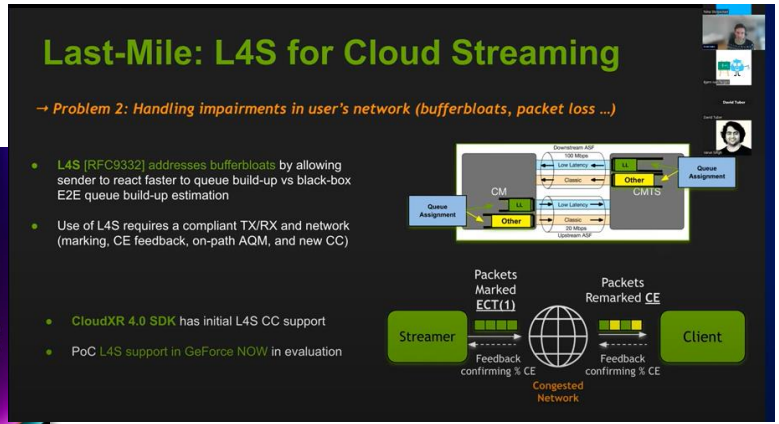
- *The Addition of Explicit Congestion Notification to IP*, rfc3168, 2001
  - Two bits in the IP header (in TOS/Traffic Class)
- The source declares that a packet should be treated with ECN
  - Set IP-ECN fields either to 01 or 10
- When congestion is (almost) happening, instead of dropping the packet the router sets the IP-ECN fields to 11 (Congestion Experienced)
- The destination reports this event to the source (typically at transport level)



ECN and L4S

- Recently, ECN mechanism got renewed attention due to L4S (Low Latency, Low Loss, and Scalable Throughput – rfc9330, rfc9331, rfc9332 - 2023)
- L4S requires an ECN feedback *more accurate* wrt the "classic" 2001 version
  - "More accurate" = Feedback contains exact counters of IP-ECN values received





ECN bleaching detection

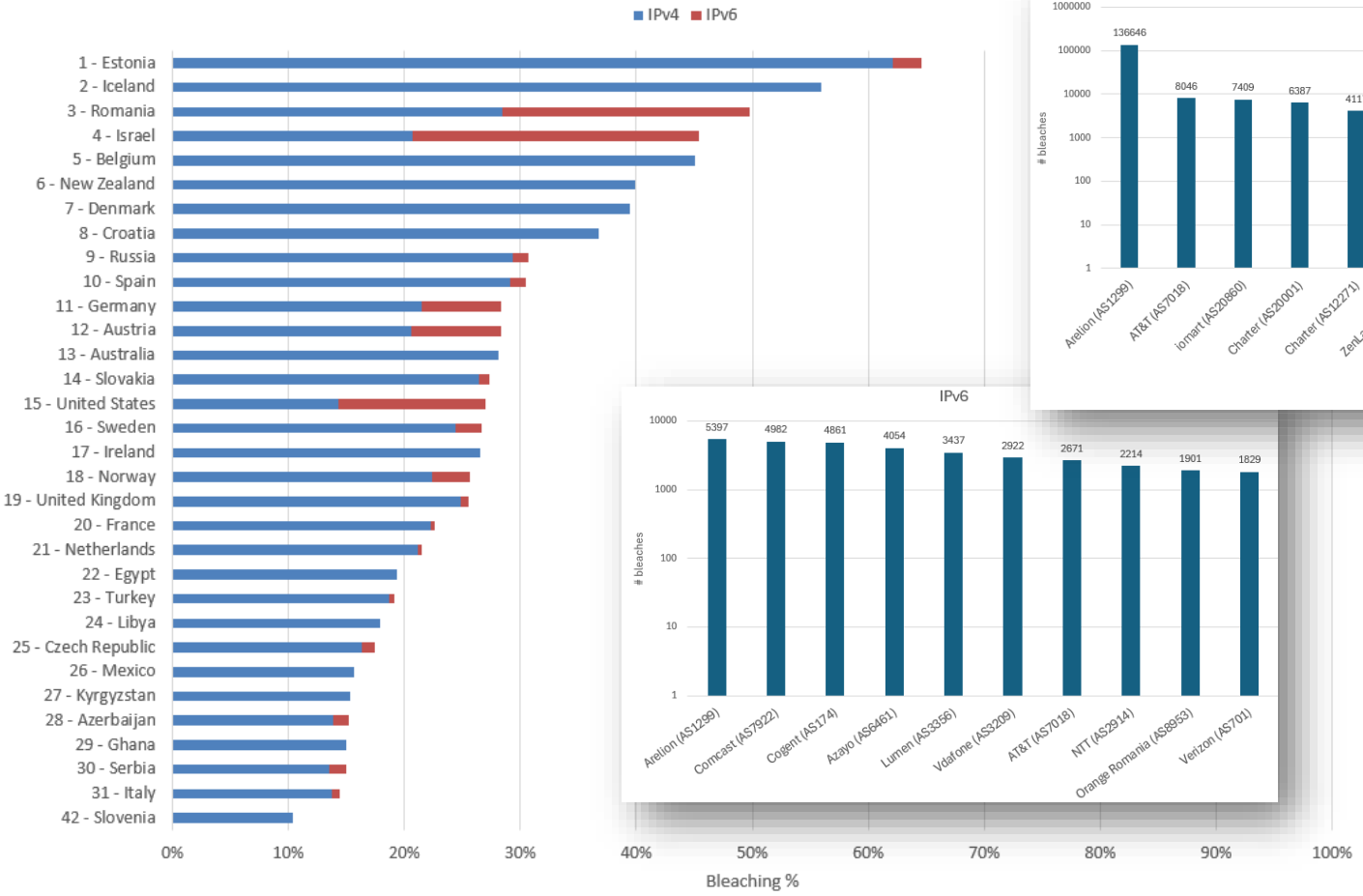
- Intermediate hops can bleach/alter the value of ECN into the IP header
- See for example: *The Benefits of Using Explicit Congestion Notification (ECN)* – rfc8087, 2017:

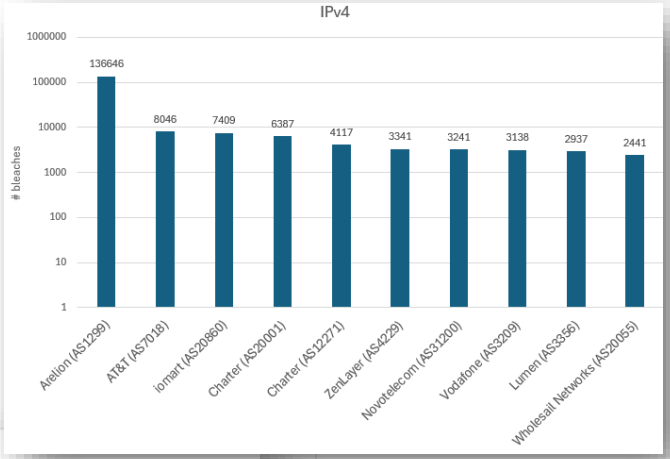
> Cases have been noted where an endpoint sends a packet with a non-zero ECN mark, but the packet is received by the remote endpoint with a zero ECN codepoint [TR15]. This could be a result of a policy that erases or "bleaches" the ECN codepoint values at a network edge (resetting the codepoint to zero). Bleaching may occur for various reasons (including normalizing packets to hide which equipment supports ECN). This policy prevents use of ECN by applications.

IP-ECN bleaching in the wild

- We run Pietrasanta traceroute from Catchpoint nodes deployed around the world to understand how many traceroutes show the effects of ECN bleaching
- Period of reference: August 2024
- Besides research curiosity, this can be useful to understand how much the network is prepared to accommodate L4S
- This is not intended to be a rigorous research work
  - The results presented are obviously biased by the node selection
  - We tried to be as fair and distributed as possible in selecting sources and destinations

Results


IPv4
IPv6
1 - Estonia
2 - Iceland
3 - Romania
4 - Israel
5 - Belgium
6 - New Zealand
7 - Denmark
8 - Croatia
9 - Russia
10 - Spain
11 - Germany
12 - Austria
13 - Australia
14 - Slovakia
15 - United States
16 - Sweden
17 - Ireland
18 - Norway
19 - United Kingdom
20 - France
21 - Netherlands
22 - Egypt
23 - Turkey
24 - Libya
25 - Czech Republic
26 - Mexico
27 - Kyrgyzstan
28 - Azerbaijan
29 - Ghana
30 - Serbia
31 - Italy
42 - Slovenia
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Bleaching %


IPv4
bleaches
1000000
100000
10000
1000
100
10
1
136646
8046
7409
6387
4117
3341
3241
3138
2937
2441
Arelion (AS1299)
AT&T (AS7018)
iomart (AS20860)
Charter (AS20001)
Charter (AS12271)
ZenLayer (AS4229)
Novotelecom (AS31200)
Vodafone (AS3209)
Lumen (AS3356)
Wholesail Networks (AS20065)

IPv6
bleaches
10000
1000
100
10
1
5397
4982
4861
4054
3437
2922
2671
2214
1901
1829
Arelion (AS1299)
Comcast (AS7922)
Cogent (AS174)
Azayo (AS6461)
Lumen (AS3356)
Vodafone (AS3209)
AT&T (AS7018)
NTT (AS2914)
Orange Romania (AS8953)
Verizon (AS701)

Analyses and campaigns

Not only traceroute…

- DNS performance: Recently we run a DNS measurement campaign in collaboration with IBM to measure the performance of the global DNS infrastructure
  - https://www.catchpoint.com/asset/the-need-for-speed

- BGP analyses
  - BGP outage analyses
  - We are working on a way to report several kinds of BGP routing anomalies (hijacks and leaks, stay tuned!)

- And many more! (feel free to checkout our blog!)
  - https://www.catchpoint.com/blog

How to contribute

- Join and participate in expanding our global observability network. Two different ways:

- Active measurements
  - Host a Catchpoint synthetic node to run active measurements if you can provide a VPS connected to the Internet
- Passive measurements
  - Share a BGP feed with us simply by setting up a multihop session against one of our collectors, more on https://www.catchpoint.com/bgp/partner

Thank you!

https://github.com/catchpoint/Pietrasanta-traceroute