BANDWIT: Visualization Tool for Hop-by-Hop Delay and Bandwidth Analytics

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Outline

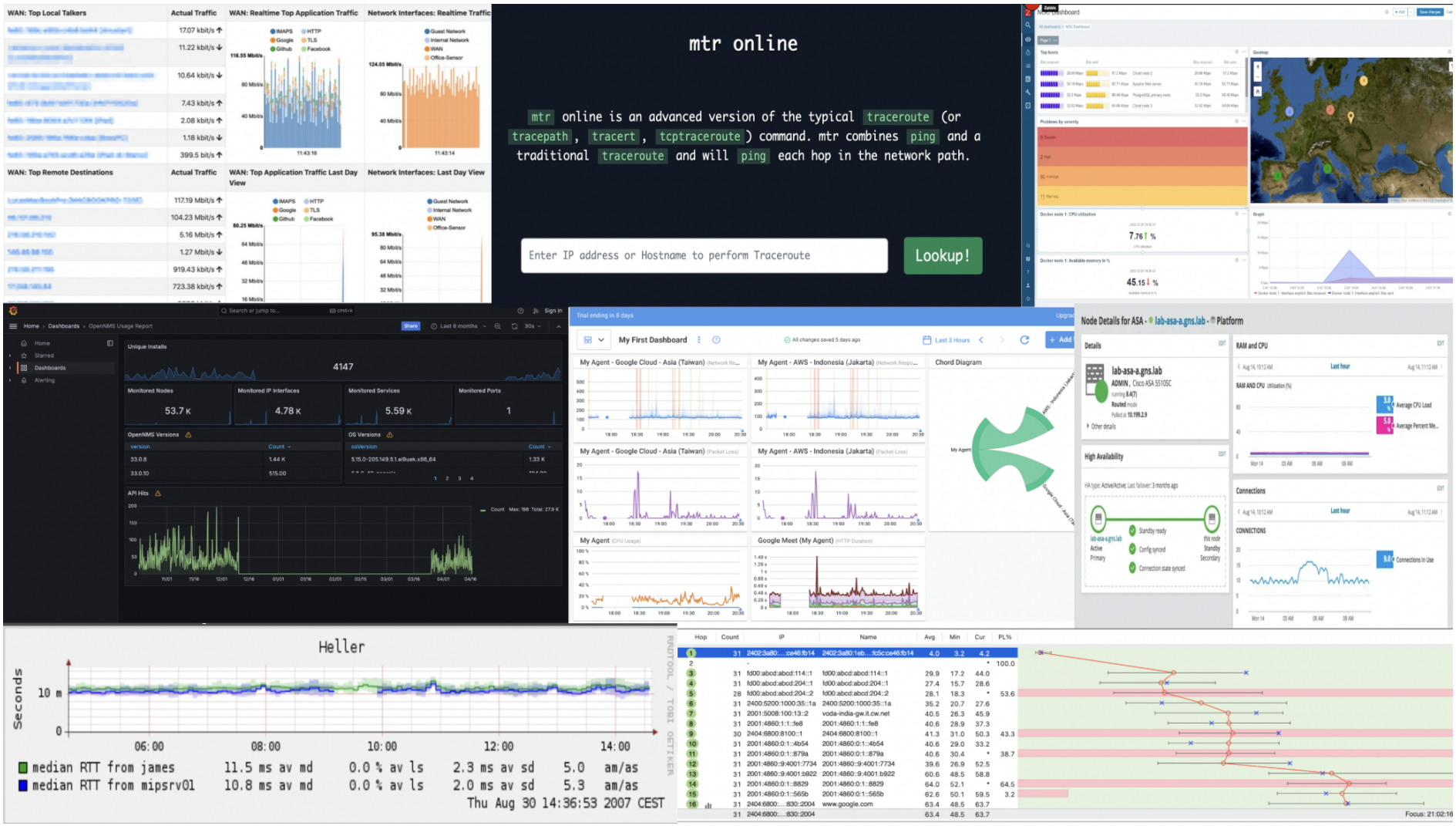
Motivation

- Traditional tools like `traceroute` provide hop-level RTT but lack bandwidth insights.
- Diagnosing network performance issues requires visibility into bandwidth bottlenecks.
- Need for an interactive, hop-aware tool that integrates delay and bandwidth estimation.
- **Aim**: Build a tool that estimates RTT, jitter, and bandwidth per hop, and helps visualize the data intuitively.

Key Features

- ICMP and UDP based probing using raw sockets
- Hop-by-hop RTT, bandwidth, and jitter estimation
- Bottleneck detection based on lowest per-hop bandwidth
- Interactive frontend using FastAPI and Streamlit
- Visual representation of route topology and metrics

Literature Review



Tool Architecture

- **Backend (C++):** Handles probing, RTT, jitter and bandwidth calculation
- **Intermediate Files:** Results stored in text and CSV files
- **Frontend (Python):** Parses results and builds visualizations using Pyvis. Web interface built using streamlit and backend built using fastapi

Probing Techniques: ICMP-Based

- **Packet Generation:**
  - Constructs raw ICMP echo request packets with 16 bit checksum.
  - Increasing TTL values to discover each hop.

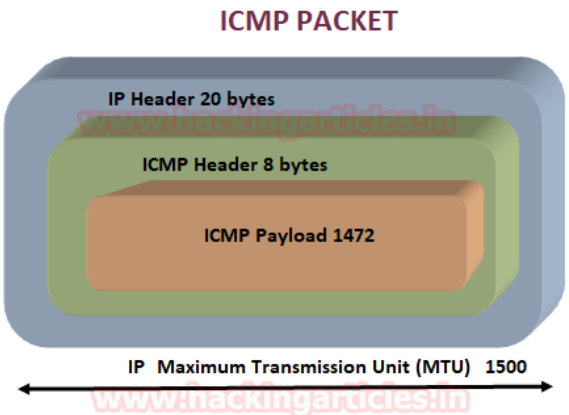


Figure: ICMP Packet

- **RTT Measurement:**
  - Calculated as the time difference between sending and receiving replies.

Probing Techniques: ICMP-Based

- **Bandwidth Estimation:**
  - Uses the packet-pair dispersion method, i.e, uses two large ICMP packets sent back-to-back and measures time gap between responses
  - Formula:

$$\text{Bandwidth (Mbps)} = \frac{\text{Packet Size (bits)}}{\text{Inter-Arrival Time}(\mu\text{s})}$$

- **Jitter Calculation:**
  - Jitter is calculated as the std. deviation in RTTs received for each estimation call.
  - Helps identify hop-level instability and delay fluctuations.
- **Output:**
  - Hop number, IP address, RTT, estimated bandwidth, jitter and successful probes
  - Saved in text file as well as csv.

Probing Techniques: UDP-Based

- **Rationale:** Overcome issues like rate limiting in ICMP.
- **UDP Probing:**
  - Sends UDP packets to an unreachable high-numbered port.
  - Receives ICMP 'Port Unreachable' and 'Time Exceeded' messages, ensuring reliable hop discovery.

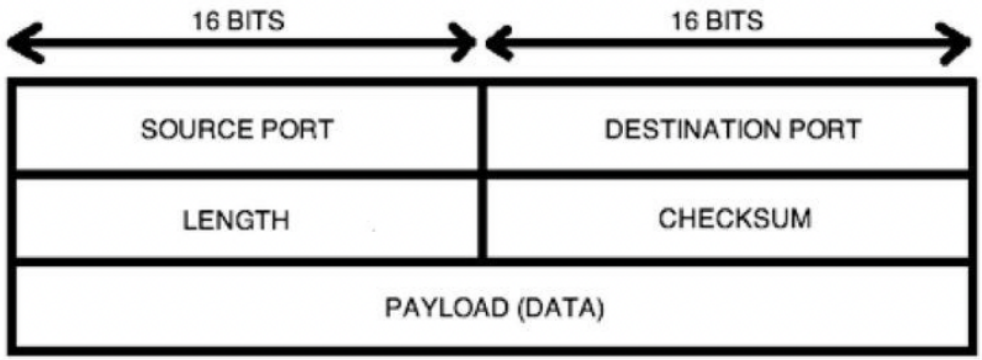


Figure: UDP Packet

Probing Techniques: UDP-Based

- **Bandwidth Estimation:**
  - Similar packet pair dispersion technique as the one in icmp.
- **Logging:**
  - Records Hop number, IP address, RTT, estimated bandwidth, jitter and successful probes to the same structured file.

Data Parsing and Visualization Pipeline

- **Data Parsing:**
  - A Python parser reads `traceroute_output.txt`.
  - Extracts hop details (hop number, IP address, RTT, bandwidth, jitter and successful probes) using regular expressions.
- **Visualization:**
  - Geo-IP map showing router locations (via ipinfo API)
  - Employs `Pyvis` to generate interactive, browser-based graphs.
- **Visualization Features:**
  - Blue nodes for source and destination
  - Green nodes for high bandwidth
  - Orange nodes for medium bandwidth
  - Red nodes for low bandwidth
  - Gray nodes for unexpected hops
  - White coloured node represents bottleneck link.
  - Tooltips show detailed hop statistics.
- Shows historical performance which can be filtered based on the time of the day and the destination.

Experimental Setup

- Conducted on a Linux machine with root privileges.
- Parameters:
  - Maximum hops: 30.
  - Probes per hop for traceroute: 3
  - Probes per traceroute-probe for statistics: 10
  - Packet sizes for ICMP based traceroute: 56 bytes + 20 bytes (IP header) + 8 bytes (ICMP header)
  - Packet sizes for UDP based traceroute: 5 bytes (payload) + 20 bytes (IP header) + 8 bytes (UDP header)
  - Timeout: 3 seconds.
- Test destination: Public endpoints (e.g., DNS server 8.8.8.8).

Demonstration

BANDWIT DEMONSTRATION!

Results: ICMP vs. UDP Probing

- Destination: ims.iitgn.ac.in

```
Traceroute to ims.iitgn.ac.in (10.0.137.79), 30 hops max
----------------------------------------------------------------------
Hop 1:
  Probe 1: 172.17.144.1 | RTT: 0.739 ms | BW: 3733.333333 Mbps | Successful probes
  Probe 2: 172.17.144.1 | RTT: 0.467 ms | BW: 3266.666667 Mbps | Successful probes
  Probe 3: 172.17.144.1 | RTT: 0.418 ms | BW: 3266.666667 Mbps | Successful probes
  [Stats] Avg RTT: 0.541333 ms | Jitter: 0.141196 ms | Avg BW: 3422.222222 Mbps
----------------------------------------------------------------------
Hop 2:
  Probe 1: 10.7.0.5 | RTT: 2.182 ms | BW: 42.828823 Mbps | Successful probes(/10):
  Probe 2: 10.7.0.5 | RTT: 2.158 ms | BW: 1140.973783 Mbps | Successful probes(/10
  Probe 3: 10.7.0.5 | RTT: 2.075 ms | BW: 38.219848 Mbps | Successful probes(/10):
  [Stats] Avg RTT: 2.13833 ms | Jitter: 0.0458427 ms | Avg BW: 407.340818 Mbps
----------------------------------------------------------------------
Hop 3:
  Probe 1: 10.0.137.79 | RTT: 1.914 ms | BW: N/A | Successful probes(/10):0
  [Stats] Avg RTT: 1.914 ms |No unexpected hops detected.
Results saved to traceroute_output.txt, traceroute_icmp.csv, and stats.txt
nation reached at hop 3.
No unexpected hops detected.
```

Figure: ICMP Trace

```
Hop 1:
  Probe 1: 172.17.144.1 | RTT: 0.802 ms | BW: 3733.333333 Mbps | Successful probes
  Probe 2: 172.17.144.1 | RTT: 0.687 ms | BW: 2800.000000 Mbps | Successful probes
  Probe 3: 172.17.144.1 | RTT: 0.719 ms | BW: 3733.333333 Mbps | Successful probes
  [Stats] Avg RTT: 0.736 ms | Jitter: 0.048463 ms | Avg BW: 3422.222222 Mbps
----------------------------------------------------------------------
Hop 2:
  Probe 1: 10.7.0.5 | RTT: 2.454 ms | BW: 2240.000000 Mbps | Successful probes(/10
  Probe 2: 10.7.0.5 | RTT: 2.566 ms | BW: 2520.000000 Mbps | Successful probes(/10
  Probe 3: 10.7.0.5 | RTT: 2.14 ms | BW: 13.256294 Mbps | Successful probes(/10):1
  [Stats] Avg RTT: 2.38667 ms | Jitter: 0.180313 ms | Avg BW: 1591.085431 Mbps
----------------------------------------------------------------------
Hop 3:
  Probe 1: 10.0.137.79 | RTT: 1.788 ms | BW: 2240.000000 Mbps | Successful probes(
  [Stats] Avg RTT: 1.788 ms | Jitter: 0 ms | Avg BW: 2240.000000 Mbps
----------------------------------------------------------------------
Destination reached at No unexpected hops detected.
Results saved to traceroute_output.txt, traceroute_udp.csv, and stats.txt
```

Figure: UDP Trace

Results: ICMP vs. UDP Probing

- Destination: aws.amazon.in

```
lavanya04@LavanyaPC:/mnt/c/users/lavanya/documents/github/network-analyser$ sudo ./traceroute aws.amazon.com
Traceroute to aws.amazon.com (108.158.232.78), 30 hops max
----------------------------------------------------------------------
Hop 1:
  Probe 1: 172.17.144.1 | RTT: 1.219 ms | BW: 2240.000000 Mbps | Successful probes(/10):10
  Probe 2: 172.17.144.1 | RTT: 0.947 ms | BW: 2800.000000 Mbps | Successful probes(/10):10
  Probe 3: 172.17.144.1 | RTT: 0.376 ms | BW: 3266.666667 Mbps | Successful probes(/10):10
  [Stats] Avg RTT: 0.847333 ms | Jitter: 0.351295 ms | Avg BW: 2768.888889 Mbps
----------------------------------------------------------------------
Hop 2:
  Probe 1: 10.7.0.5 | RTT: 5.401 ms | BW: 17.015495 Mbps | Successful probes(/10):10
  Probe 2: 10.7.0.5 | RTT: 3.858 ms | BW: 15.811277 Mbps | Successful probes(/10):10
  Probe 3: 10.7.0.5 | RTT: 4.66 ms | BW: 18.947137 Mbps | Successful probes(/10):10
  [Stats] Avg RTT: 4.63967 ms | Jitter: 0.630091 ms | Avg BW: 17.257970 Mbps
----------------------------------------------------------------------
Hop 3:
  Probe 1: 172.16.4.4 | RTT: 3.217 ms | BW: 17.127535 Mbps | Successful probes(/10):2
  Probe 2: 172.16.4.4 | RTT: 4.401 ms | BW: N/A | Successful probes(/10):0
  Probe 3: 172.16.4.4 | RTT: 17.763 ms | BW: 2240.000000 Mbps | Successful probes(/10):1
  [Stats] Avg RTT: 8.46033 ms | Jitter: 6.59571 ms | Avg BW: 1128.563767 Mbps
----------------------------------------------------------------------
Hop 4:
  Probe 1: 14.139.98.1 | RTT: 18.152 ms | BW: 2.446799 Mbps | Successful probes(/10):10  [!] Bottleneck
  Probe 2: 14.139.98.1 | RTT: 21.362 ms | BW: 1600.000000 Mbps | Successful probes(/10):10
  Probe 3: 14.139.98.1 | RTT: 8.755 ms | BW: 12.778099 Mbps | Successful probes(/10):10
  [Stats] Avg RTT: 16.0897 ms | Jitter: 5.34939 ms | Avg BW: 538.408299 Mbps
----------------------------------------------------------------------
Hop 5:
  Probe 1: 10.117.81.253 | RTT: 6.202 ms | BW: 9.613612 Mbps | Successful probes(/10):10  [!] Bottleneck
  Probe 2: 10.117.81.253 | RTT: 2.032 ms | BW: 19.785136 Mbps | Successful probes(/10):10
  Probe 3: 10.117.81.253 | RTT: 5.13 ms | BW: 12.773234 Mbps | Successful probes(/10):10
  [Stats] Avg RTT: 4.45467 ms | Jitter: 1.7681 ms | Avg BW: 14.057327 Mbps
----------------------------------------------------------------------
Hop 6:
  Probe 1: * Request timed out
  Probe 2: * Request timed out
  Probe 3: * Request timed out
----------------------------------------------------------------------
Hop 7:
  Probe 1: * Request timed out
  Probe 2: * Request timed out
  Probe 3: * Request timed out
----------------------------------------------------------------------
Hop 8:
  Probe 1: * Request timed out
  Probe 2: * Request timed out
  Probe 3: * Request timed out
----------------------------------------------------------------------
```

Figure: ICMP Trace

```
lavanya04@LavanyaPC:/mnt/c/users/lavanya/documents/github/network-analyser$ sudo ./traceroute_udp aws.amazon.com
Traceroute to aws.amazon.com (54.192.18.9), 30 hops max
----------------------------------------------------------------------
Hop 1:
  Probe 1: 172.17.144.1 | RTT: 2.971 ms | BW: 2800.000000 Mbps | Successful probes(/10): 10
  Probe 2: 172.17.144.1 | RTT: 0.669 ms | BW: 5600.000000 Mbps | Successful probes(/10): 10
  Probe 3: 172.17.144.1 | RTT: 0.671 ms | BW: 3733.333333 Mbps | Successful probes(/10): 10
  [Stats] Avg RTT: 1.437 ms | Jitter: 1.0847 ms | Avg BW: 4044.444444 Mbps
----------------------------------------------------------------------
Hop 2:
  Probe 1: 10.7.0.5 | RTT: 3.89 ms | BW: 39.997640 Mbps | Successful probes(/10): 10
  Probe 2: 10.7.0.5 | RTT: 4.761 ms | BW: 11.149621 Mbps | Successful probes(/10): 10
  Probe 3: 10.7.0.5 | RTT: 6.08 ms | BW: 14.928957 Mbps | Successful probes(/10): 10
  [Stats] Avg RTT: 4.91033 ms | Jitter: 0.900278 ms | Avg BW: 22.025406 Mbps
----------------------------------------------------------------------
Hop 3:
  Probe 1: 172.16.4.4 | RTT: 6.955 ms | BW: 707.320261 Mbps | Successful probes(/10): 2
  Probe 2: 172.16.4.4 | RTT: 26.542 ms | BW: N/A | Successful probes(/10): 0
  Probe 3: 172.16.4.4 | RTT: 35.539 ms | BW: 2.352447 Mbps | Successful probes(/10): 1  [!] Bottleneck
  [Stats] Avg RTT: 23.012 ms | Jitter: 11.9333 ms | Avg BW: 354.836354 Mbps
----------------------------------------------------------------------
Hop 4:
  Probe 1: 14.139.98.1 | RTT: 6.837 ms | BW: 636.544473 Mbps | Successful probes(/10): 10
  Probe 2: 14.139.98.1 | RTT: 6.195 ms | BW: 22.654511 Mbps | Successful probes(/10): 10
  Probe 3: 14.139.98.1 | RTT: 6.411 ms | BW: 21.364350 Mbps | Successful probes(/10): 10
  [Stats] Avg RTT: 6.481 ms | Jitter: 0.266728 ms | Avg BW: 226.854445 Mbps
----------------------------------------------------------------------
Hop 5:
  Probe 1: 10.117.81.253 | RTT: 4.264 ms | BW: 16.745210 Mbps | Successful probes(/10): 10
  Probe 2: 10.117.81.253 | RTT: 3.56 ms | BW: 21.284552 Mbps | Successful probes(/10): 10
  Probe 3: 10.117.81.253 | RTT: 5.741 ms | BW: 21.745997 Mbps | Successful probes(/10): 10
  [Stats] Avg RTT: 4.52167 ms | Jitter: 0.90884 ms | Avg BW: 19.925253 Mbps
----------------------------------------------------------------------
Hop 6:
  Probe 1: 10.154.8.137 | RTT: 72.404 ms | BW: 1422.222222 Mbps | Successful probes(/10): 10
  Probe 2: 10.154.8.137 | RTT: 16.662 ms | BW: 717.891374 Mbps | Successful probes(/10): 10
  Probe 3: 10.154.8.137 | RTT: 28.457 ms | BW: 13.403065 Mbps | Successful probes(/10): 10
  [Stats] Avg RTT: 39.1743 ms | Jitter: 23.9853 ms | Avg BW: 717.838887 Mbps
----------------------------------------------------------------------
Hop 7:
  Probe 1: 10.255.239.170 | RTT: 17.392 ms | BW: 16.364545 Mbps | Successful probes(/10): 10
  Probe 2: 10.255.239.170 | RTT: 13.563 ms | BW: 18.947232 Mbps | Successful probes(/10): 10
  Probe 3: 10.255.239.170 | RTT: 17.681 ms | BW: 47.538873 Mbps | Successful probes(/10): 10
  [Stats] Avg RTT: 16.212 ms | Jitter: 1.87684 ms | Avg BW: 27.616883 Mbps
----------------------------------------------------------------------
Hop 8:
  Probe 1: 10.152.7.38 | RTT: 15.272 ms | BW: 634.476052 Mbps | Successful probes(/10): 10
  Probe 2: 10.152.7.38 | RTT: 14.501 ms | BW: 1400.000000 Mbps | Successful probes(/10): 9
  Probe 3: 10.152.7.38 | RTT: 14.738 ms | BW: 1500.000000 Mbps | Successful probes(/10): 10
```

Figure: UDP Trace

Comparison with existing tools

```
anura2004@Anura:/mnt/c/Users/anura/Network-Analyser$ python3 verify.py 8.8.8.8

Traceroute Results
------------------------------------------------------------------------
Hop   IP Address          RTT (ms)
------------------------------------------------------------------------
1     172.26.192.1        0.700
2     10.7.0.5            2.300
3     172.16.4.4          2.200
4     14.139.98.1         3.700
5     10.117.81.253       2.800
6     10.154.8.137        12.100
7     10.255.239.170      12.300
8     10.152.7.214        15.300
9     72.14.204.62        11.900
10    142.251.76.27       14.200
11    142.250.238.203     14.000
12    8.8.8.8             12.100

Destination reached in 12 hops!
```

Figure: MyTraceroute

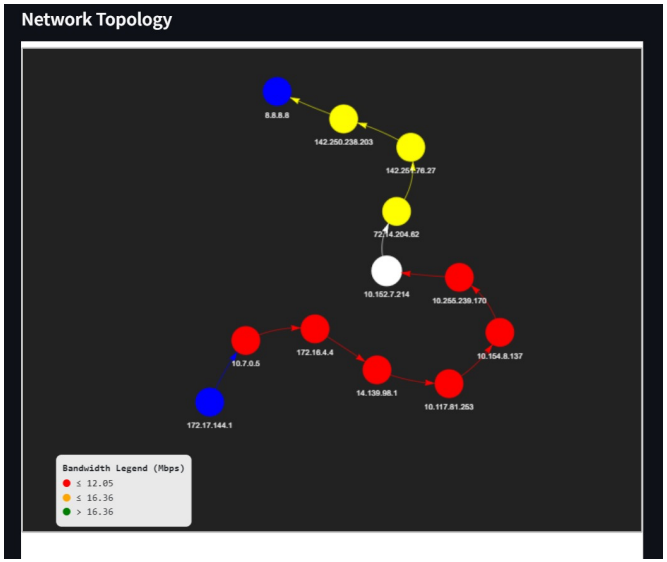


Figure: BANDWIT

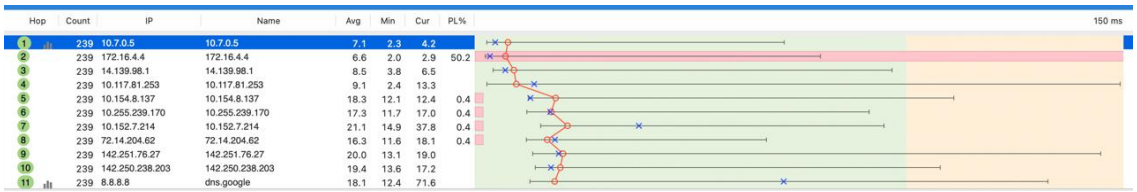


Figure: PingPlotter

- Same hops observed for destination ip = 8.8.8.8.
- Our tool provides additional bandwidth insights and interactive

Challenges and Limitations

- ICMP and UDP packets are rate-limited or dropped by some routers
- Dynamic probing tool couldn't be easily hosted on platforms
- Multiple paths made identifying the main route non-trivial
- No open geo-IP database; had to rely on APIs like ipinfo
- Most state-of-the-art tools were proprietary or difficult to install.
- Currently the tool works only in Linux environments.

Future Work

- **TCP Probing:** Extend support to TCP packets for firewall-friendly operation.
- **Real-Time Monitoring:** Enable automated continuous, live updates of network graphs.
- **Cross-Platform Support:** Improve functionality on Windows and macOS.
- **Multi-path:** Enhanced route selection algorithms under multipath routing.
- **IPv6 support:** Adding support for tracing IPv6 addresses
- **Deployment:** Deploy as a containerized microservice for easier hosting

Conclusion

- Integrates dual probing techniques (ICMP and UDP) for comprehensive network analysis.
- Fills a critical gap in hop-aware bandwidth and delay monitoring
- Combines raw probing, bandwidth estimation, per-hop RTT and jitter measurement.
- Generates interactive, detailed visualizations that highlight bottleneck and performance over time.
- Results consistent with industry-standard tools like MTR and pingplotter
- Provides a foundation for extensible and user-friendly network analytics

Questions?