

CalcuLatency: Leveraging Cross-Layer Network Latency Measurements to Detect Proxy-Enabled Abuse

Reethika Ramesh, Philipp Winter, **Sam Korman**, Roya Ensafi

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Global events affect the Internet in new ways every day. **Governments, network providers, and online threat actors** disrupt, tamper with, and monitor user traffic.

VPNs are Useful Tools

Users are turning to Virtual Private Networks (**VPNs**) as a **panacea** for security, privacy, and information restrictions.

VPNs are now a **multi-billion dollar** industry

10 / Research / VPN Demand Statistics

VPN Demand Surges Around the World

VPN searches skyrocket after Congress killed your right to internet privacy

Bloomberg

Technology

VPN Downloads Surge in Response to Hong Kong Security Law

- Privacy advocates warn of more internet controls from Beijing
- Proposed law from China would bypass Hong Kong legislature

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Net neutrality and privacy scandals are increasing VPN use

techradar pro 

A single VPN drop-out exposed breach scandal that cost Ubiquiti \$4bn

**How VPNs and Proxy Servers
Are Used For Click Fraud**

**Leave no trace: how a
teenage hacker lost
himself online**

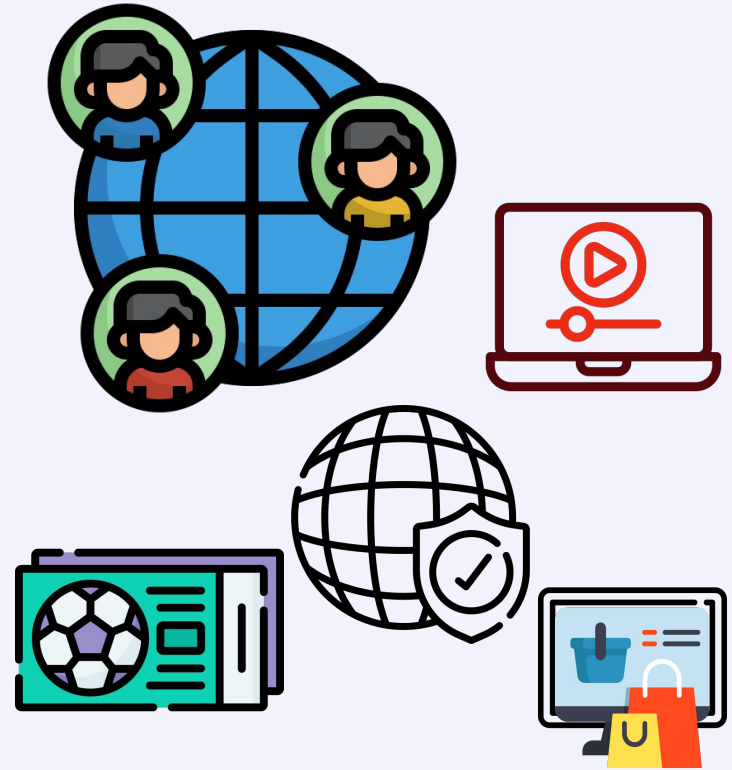
VPN Misuse is on the rise

- VPNs were intended as a privacy-enhancing tool
- Bad actors misuse VPNs and hide behind them while carrying out nefarious activities

Challenges for Server-Side Operators

Service providers impose certain restrictions on users:

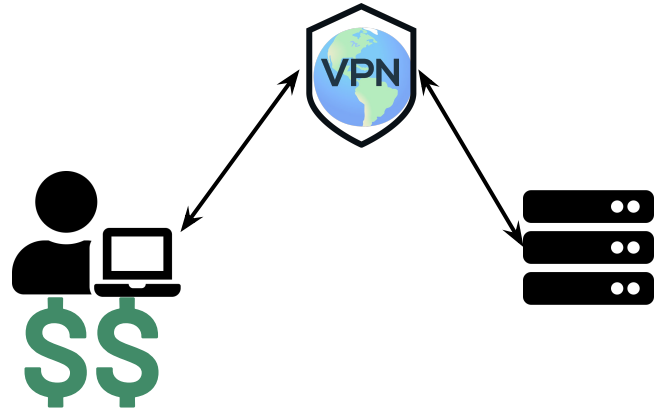
- Media licensing restrictions
- Geographic-proximity limitations
- E-commerce needs
- Security needs



Threats Due to Proxy and VPN Misuse

Attackers **fabricate their geolocation** to access geo-restricted content, or falsify activity to profit monetarily

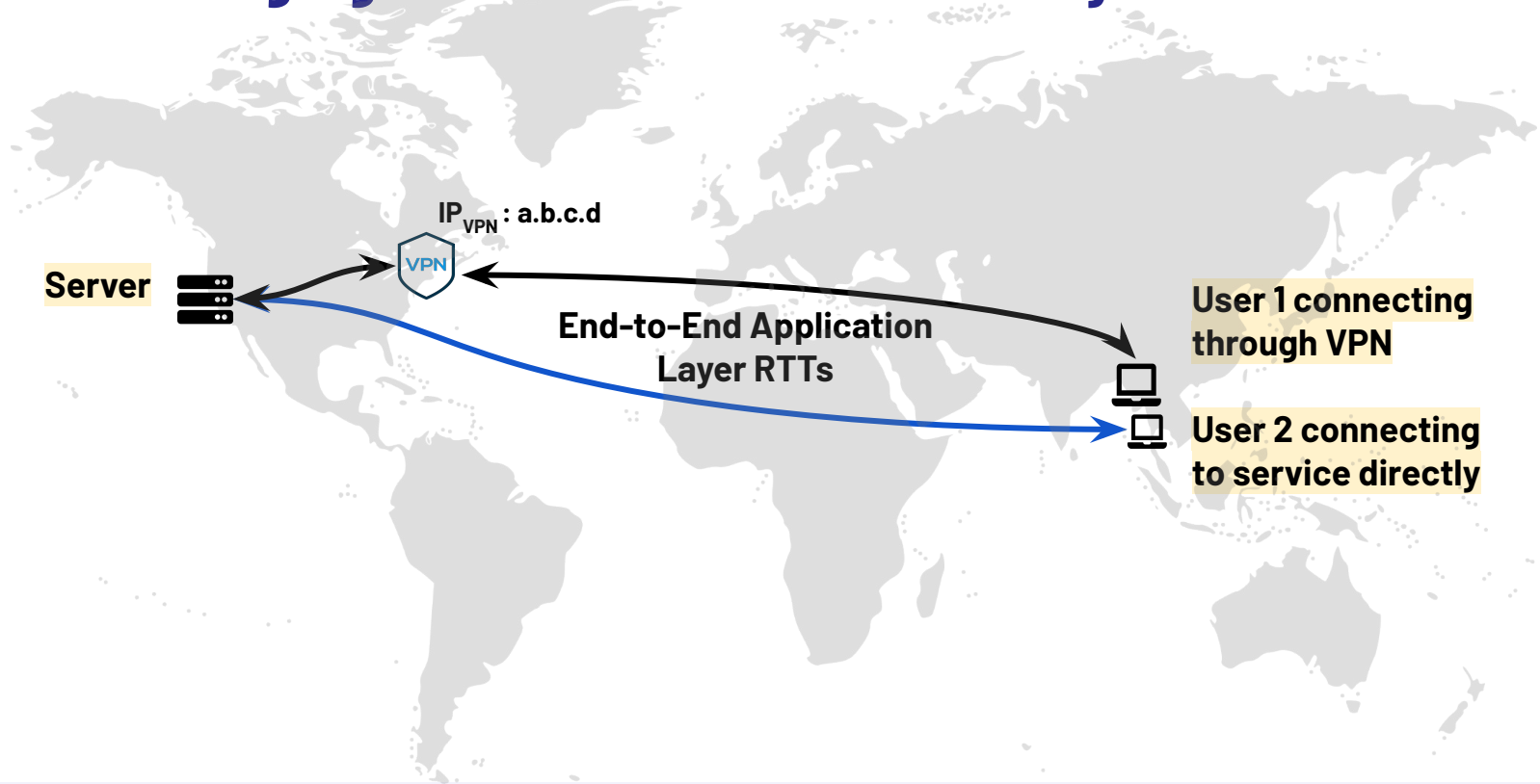
Balancing abuse-prevention techniques with a privacy-first approach is a hard challenge



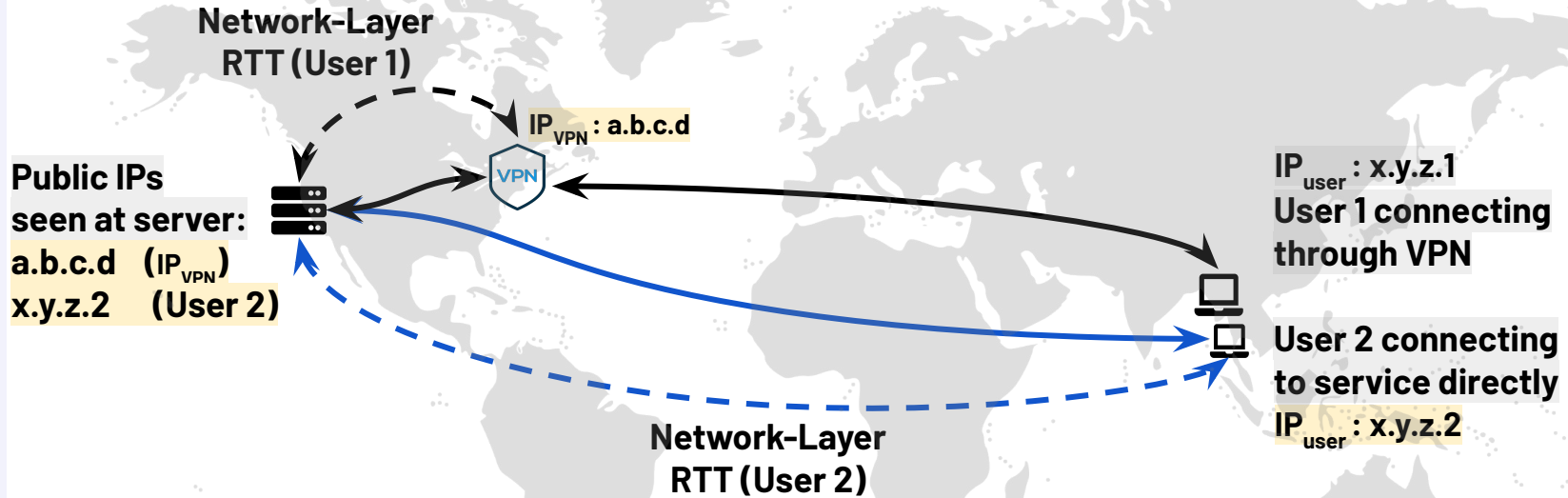
Can we use minimal connection features, such as latency, to infer proxy use, without jeopardizing user privacy?

Leveraging Different Network Latency Measurements

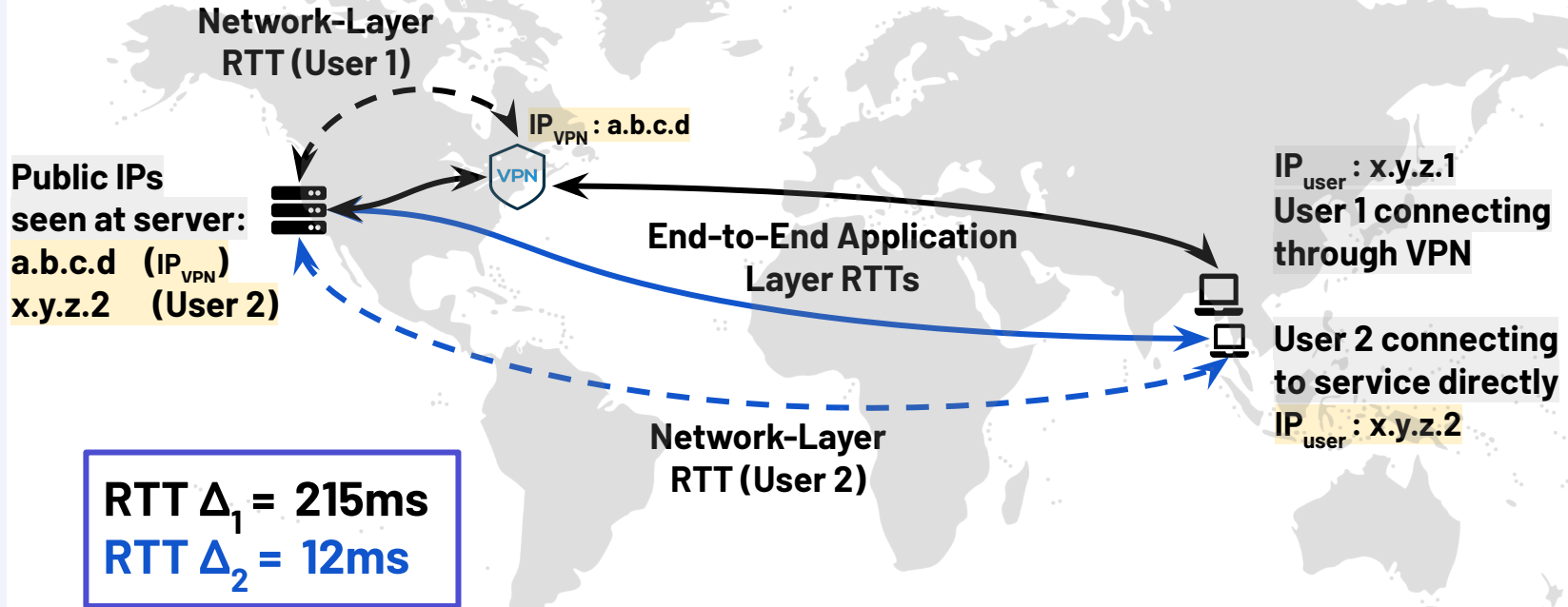
Leveraging Different Network Latency Measurements



Leveraging Different Network Latency Measurements



Leveraging Different Network Latency Measurements



System Assumptions

- ↪ **Require an application-layer connection** between the client and the server—e.g. HTTP(S), WebSocket
- ↪ We detect **long-distance, remote proxy** use, i.e. the proxy is geographically far from the user
- ↪ **Clients do not control the network behavior** of the proxy and therefore cannot selectively delay packets

Measurement Methods on Different Layers

Application Layer Latency

- WebSocket
- WebRTC
- HTTP page load times

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- HTTP page load times

Network Layer Latency

- TCP Handshake RTT
- ICMP Ping
- **Modified Traceroute**

Modified **Traceroute**—Otrace

Traceroute: Send packets with incrementing TTL to determine **the path** and **the time taken** for a packet to reach a destination

Challenge: Get remote IP address' network stack to respond to unsolicited IP packets reliably

Modified Traceroute—Otrace

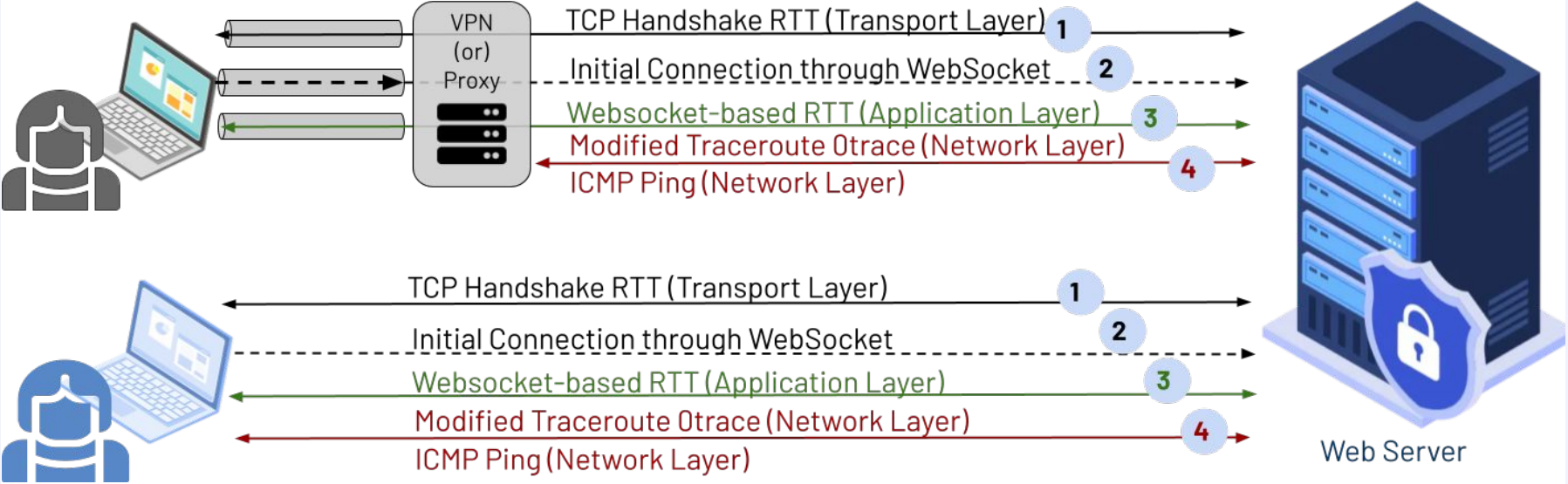
Traceroute: Send packets with incrementing TTL to determine **the path** and **the time taken** for a packet to reach a destination

Challenge: Get remote IP address' network stack to respond to unsolicited IP packets reliably

Otrace leverages existing TCP connections initiated by a client:

- Sends trace packets that **match the five-tuple** of an already established connection
- Can pass **stateful firewalls** and **traverse NATs**

CalcuLatency



Evaluation and Results

Two Sets of Evaluations

Building Block

Reliability of:

- WebSocket Pings
- TCP Handshake RTT
- Otrace Pings: Variance of Latency Across the Internet

CalcuLatency System

Evaluating the system in practice:

- Control Testbed Evaluation
- Real-world Crowdsourced Evaluation

Controlled Testbed

- Automated testing with Selenium from devices in 12 networks
- Tested on four popular browsers
- Four countries and geo-distributed servers from ten VPN providers

891 experiments: 337 VPN IPs in 82 ASes, 17 direct connections from 12 ASes in 4 countries

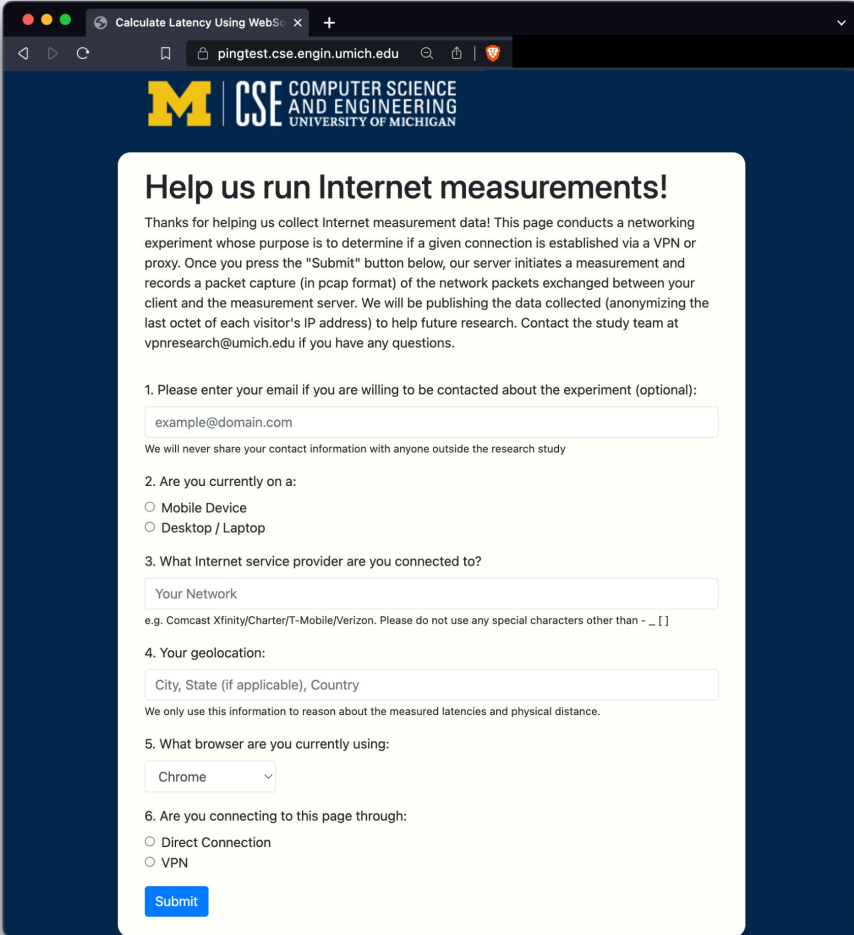
User Testing Locations:
USA, Canada, India, UAE

10 different **VPN Providers** offering WireGuard, OpenVPN, proprietary protocols, and own SOCKS5 implementation

Public Crowdsourced

- Deployed CalcuLatency system, hosted on a university subdomain
- Recruited users on Twitter and collected data for 15 days
- 37 countries from all (six) continents

283 experiments: 122 VPN IPs in 51 ASes, 161 direct connections from 93 ASes in 37 countries



Calculate Latency Using WebS: x +

pingtest.cse.engin.umich.edu

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Help us run Internet measurements!

Thanks for helping us collect Internet measurement data! This page conducts a networking experiment whose purpose is to determine if a given connection is established via a VPN or proxy. Once you press the "Submit" button below, our server initiates a measurement and records a packet capture (in pcap format) of the network packets exchanged between your client and the measurement server. We will be publishing the data collected (anonymizing the last octet of each visitor's IP address) to help future research. Contact the study team at vpnresearch@umich.edu if you have any questions.

1. Please enter your email if you are willing to be contacted about the experiment (optional):

We will never share your contact information with anyone outside the research study
2. Are you currently on a:
 Mobile Device
 Desktop / Laptop
3. What Internet service provider are you connected to?

e.g. Comcast Xfinity/Charter/T-Mobile/Verizon. Please do not use any special characters other than - _ []
4. Your geolocation:

We only use this information to reason about the measured latencies and physical distance.
5. What browser are you currently using:
6. Are you connecting to this page through:
 Direct Connection
 VPN

Empirically viable RTT
difference threshold is
50 milliseconds

Evaluation Results

98% direct measurements:

$\Delta\text{RTT} < 50\text{ms}$

89.1% and **63.9%** VPN measurements:

$\Delta\text{RTT} > 50\text{ms}$

50ms covers almost all cases of direct
measurements, i.e. low false positive rate

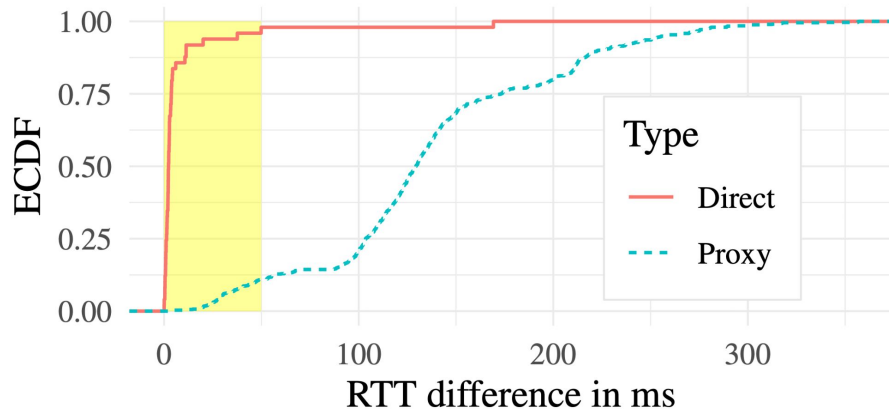
Controlled Testbed Evaluation

98% of direct measurements:

$\Delta \text{RTT} < 50 \text{ ms}$

89.1% of VPN measurements:

$\Delta \text{RTT} \gg 50 \text{ ms}$

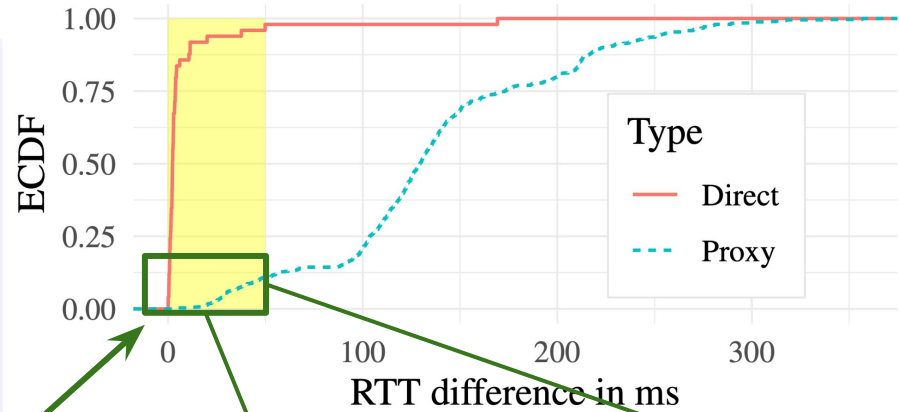


891 experiments: 337 VPN IPs in
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Controlled Testbed Evaluation

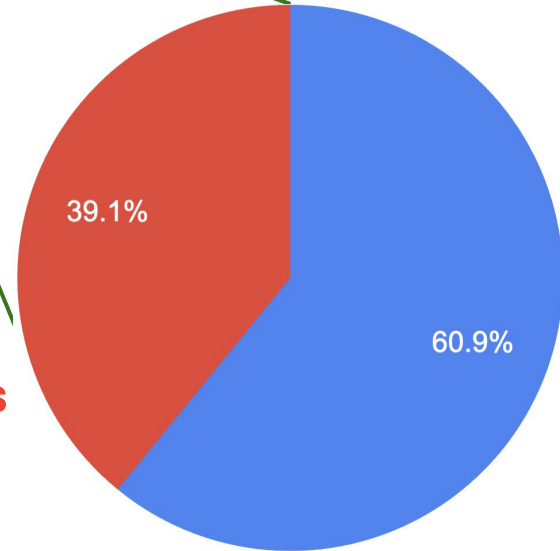
Of the remaining 10.9%,
60.9% of the time, the VPN
was located very close to user

And 39.1% mapped to 14
unique VPN IPs



**60.9%: VPN
close to user**

**39.1%: 14
unique VPN IPs**



Controlled Testbed Evaluation

Investigating the **network layer RTTs** for these IPs: 6 of their **advertised VPN locations are an impossibility** based on speed of Internet approximations $4 \cdot c$ [28]



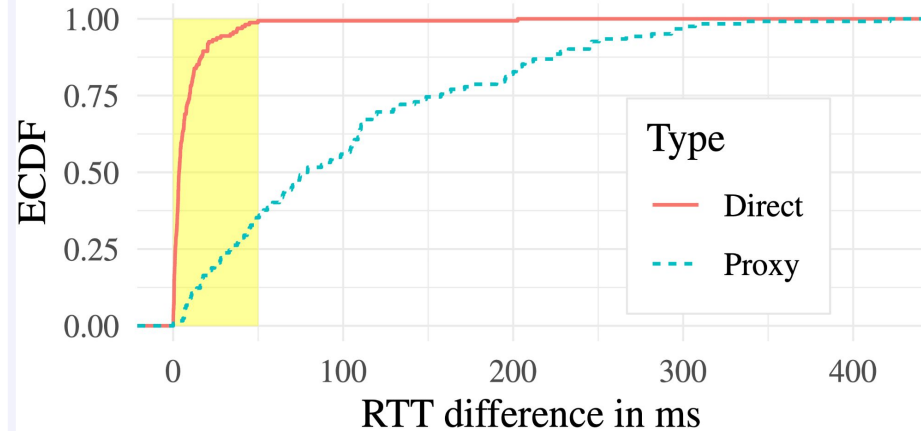
Public Crowdsourced Evaluation

98.8% of direct measurements:

$\Delta \text{RTT} < 50 \text{ ms}$

63.9% of VPN measurements:

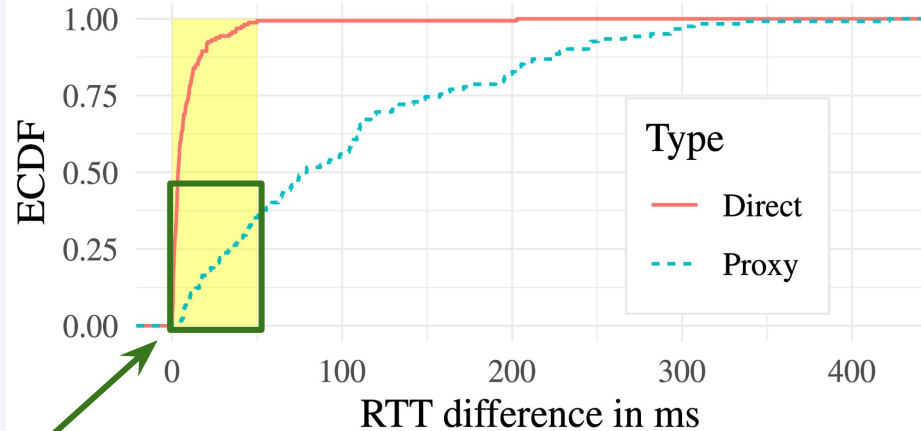
$\Delta \text{RTT} \gg 50 \text{ ms}$



283 experiments: 122 VPN IPs in
51 ASes, 161 direct connections
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Public Crowdsourced Evaluation

Of the remaining 44 experiments, in **34 of them, the VPN was located close to user** (outside our scope) and another 1 was actually a direct connection, and the remaining 9 are false-negatives



Network latency differences can be leveraged **as a first-step to identify clients connecting through remote, long-distance proxies**

Not all VPN traffic is abusive

- Not all VPN users are attackers—CalcuLatency is a labelling technique and is **not a catch-all solution**
- Users can evade detection by using VPNs close to their location which provides better performance and the requisite privacy and security features of a VPN

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Evaluating Reliability of Each Measurement

WebSocket
RTT

TCP Handshake
RTT

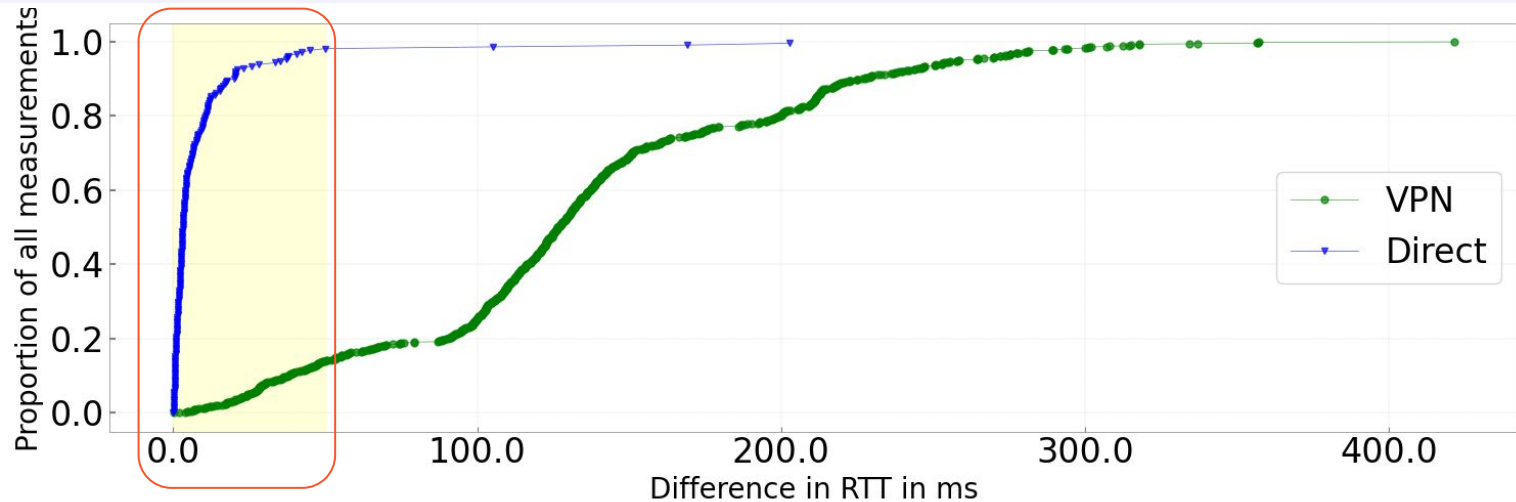
Otrace Ping
RTT

Results

Of 210 direct measurements, **only 3** had a RTT difference above 50ms

86% VPN measurements had an RTT difference above 50ms

Other 14%, majority were VPN server located close to the user (**not remote proxy**)



Building Block Evaluations

WebSocket Pings

We tested 10,000 sequential WebSocket echo requests to the client

TCP Handshake

Otrace Pings