Bypassing Tunnels: Leaking VPN Client Traffic by Abusing Routing Tables

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Contributions

We make VPN clients leak traffic

- By **manipulating the client's routing table**
- Attacks are independent of the crypto protocol

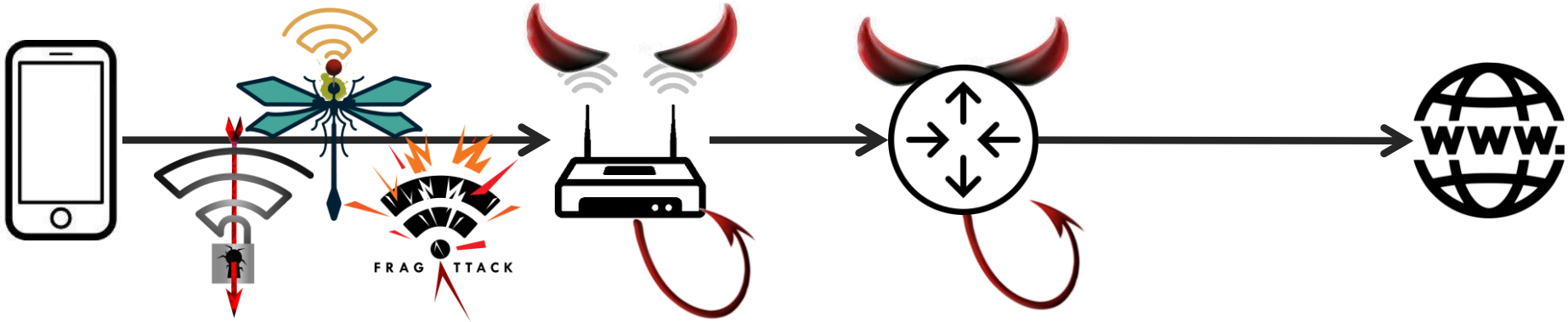
Tested 67+ VPN clients

- >248 experiments → **66% attack success**
- Every VPN is vulnerable on at least one OS

→ Widespread design issues!

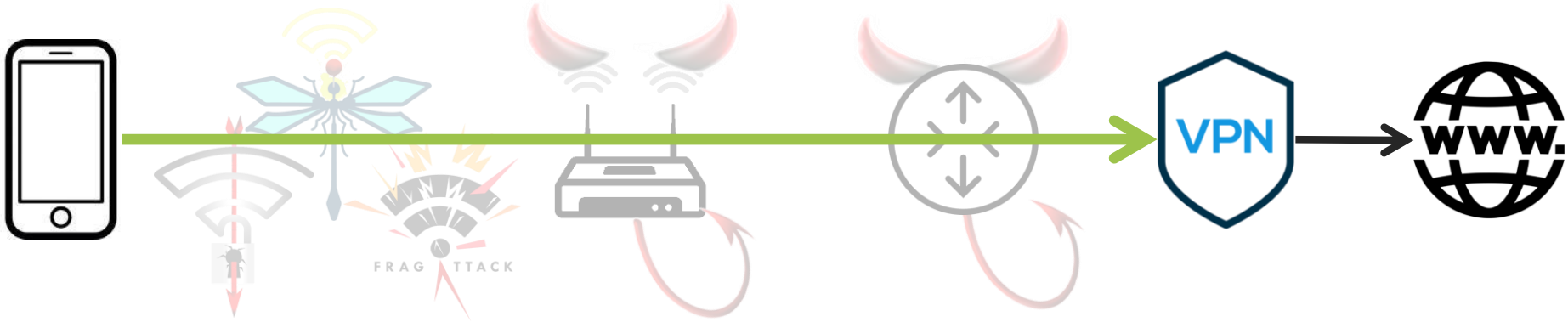
Usage of VPNs: watch videos from other country

Usage of VPNs: protect your traffic



- Identify website visits: IP address, plaintext DNS, SNI,…
- Attack TLS: no cert check, sslstrip, academic attacks,…

Usage of VPNs: protect your traffic



- Defend against untrusted Wi-Fi & compromised core routers
- Research goal: can we trick the client into leaking packets?
  - Yes, by manipulating the client's routing table → **~66% vulnerable!**
  - Attacks are independent of the crypto protocol

Background: VPN client routing table


```
$ ip route                                  # Detailed ouput
1  default via 10.0.0.1 dev tun0
2  192.168.1.0/24 dev eth0 proto kernel scope
      link src 192.168.1.2 metric 100
3  2.2.2.2 via 192.168.1.2 dev eth0
```

Background: VPN client routing table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$ ip route          # Simplified ouput
default via tun0
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2. **LocalNet exception**: local network is directly accessible

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1. By default, send packets over tun0 = over the VPN tunnel
2. **LocalNet exception**: local network is directly accessible
3. **ServerIP exception**: avoid re-encryption of VPN packets

We assume secure DNS behavior


```
$ cat /etc/resolv.conf
nameserver 6.6.6.6
```

Can’t trust the network’s DNS server

We assume secure DNS behavior

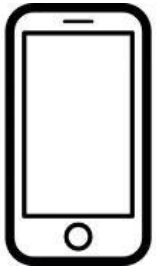

```
$ cat /etc/resolv.conf
nameserver 2.2.2.3
```

Can’t trust the network’s DNS server

1. Once connected, VPN client sets a **trusted DNS server**
2. DNS is sent **through the VPN tunnel**

   \+ we assume other routing-based attacks are prevented

LocalNet attack

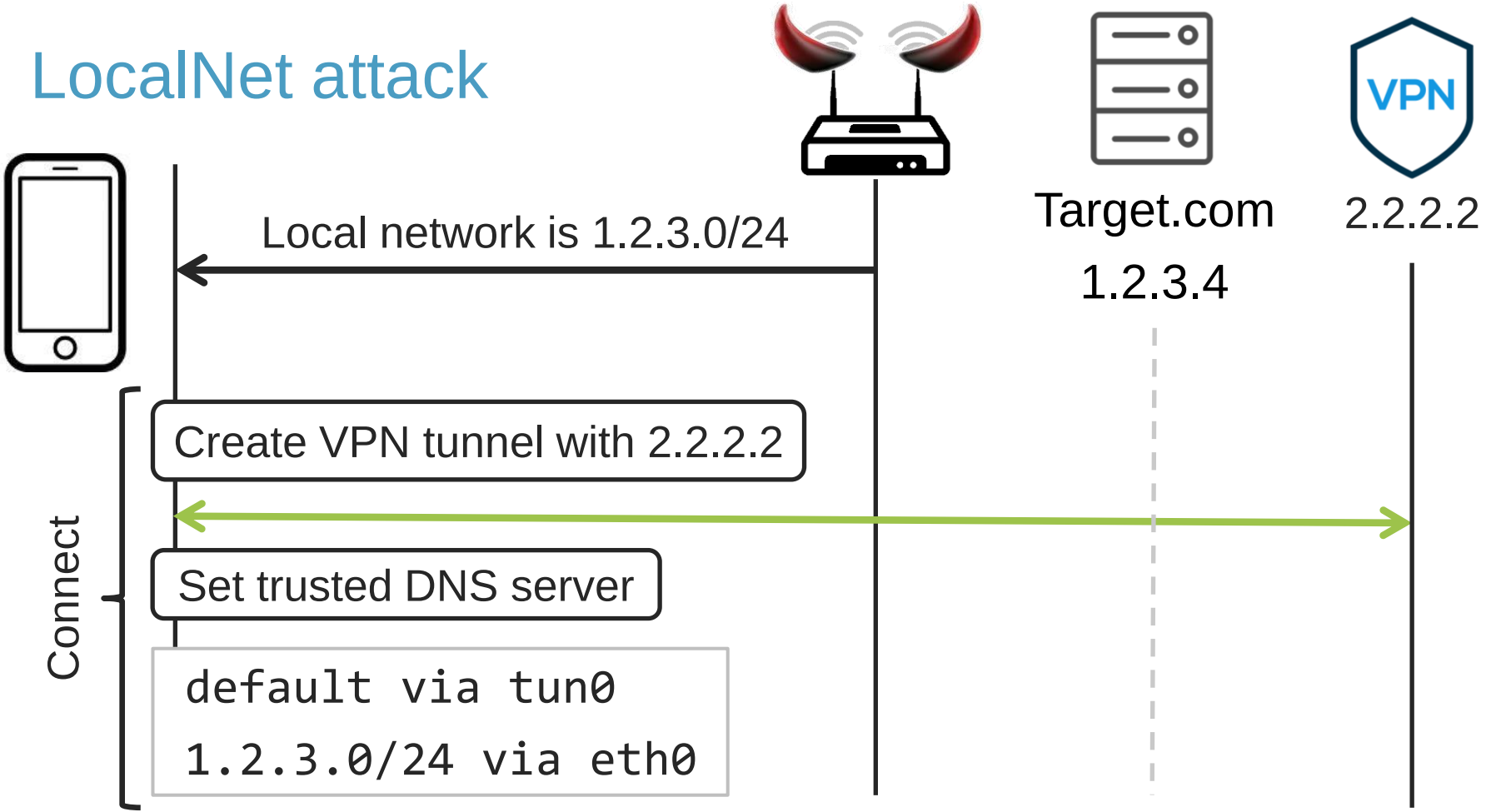


Target.com

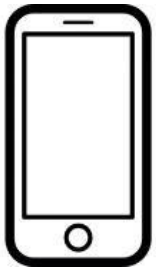
1.2.3.4

2.2.2.2

LocalNet attack



LocalNet attack



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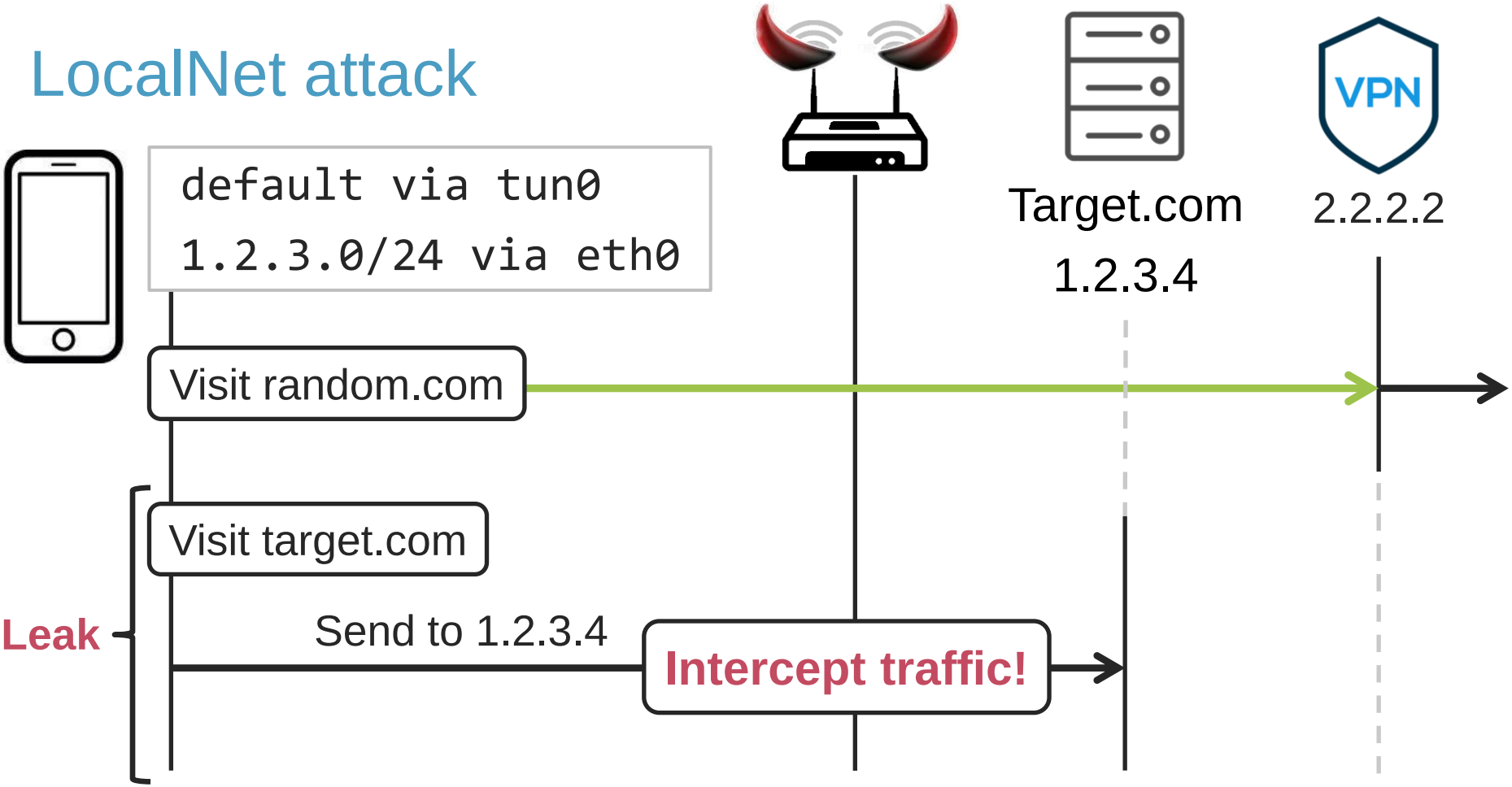
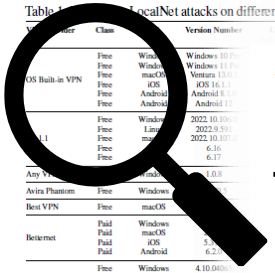
```
default via tun0
1.2.3.0/24 via eth0
```

LocalNet attack

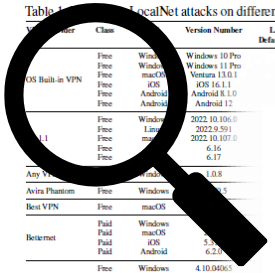


LocalNet attack: 195 experiments



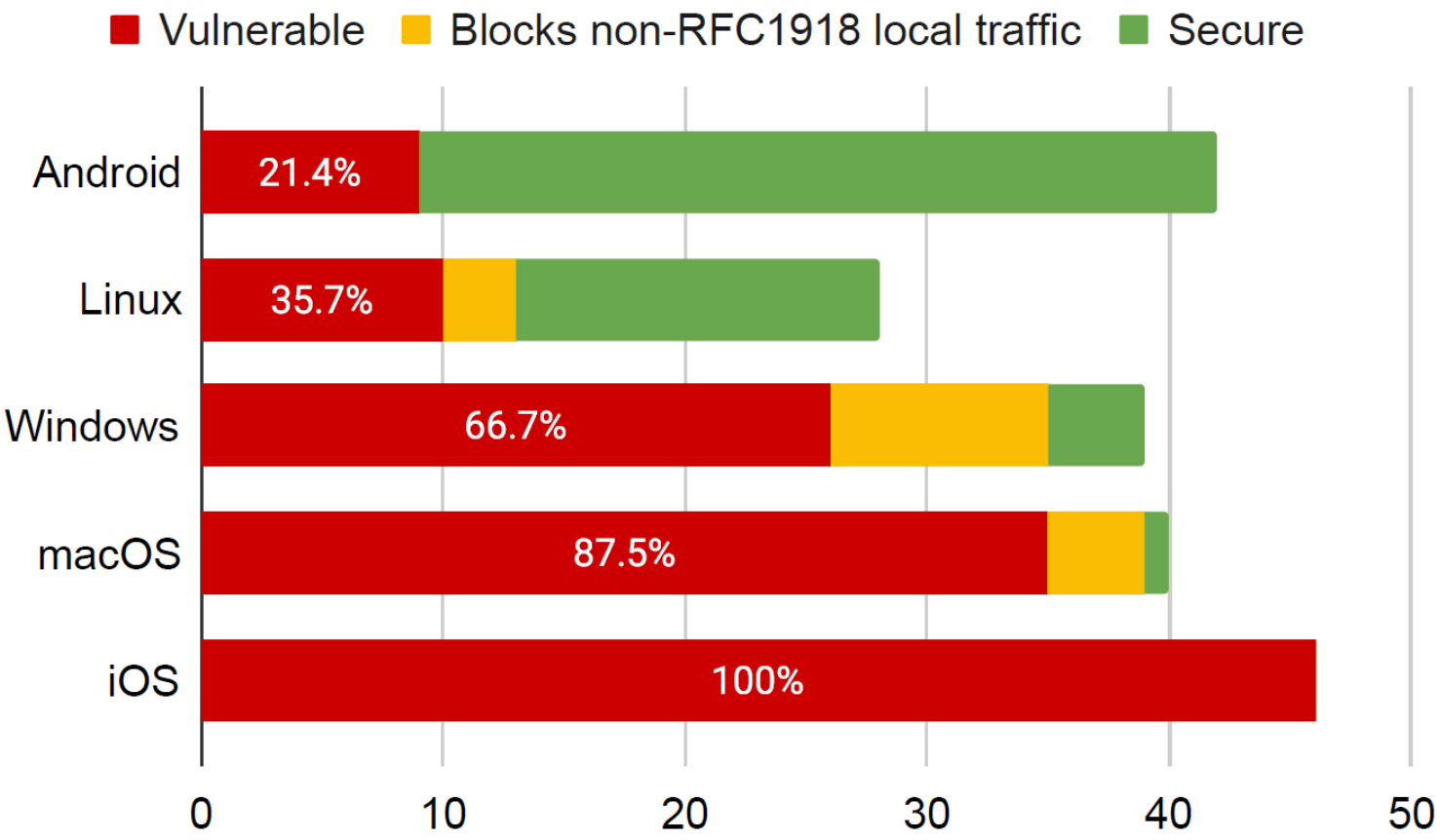
VPN Provider	Class	OS	Version Number	LAN Setting | Default LAN Access	Result
OS Built-in VPN	Free	Windows	Windows 10 Pro	No | N/A	✘
	Free	Windows	Windows 11 Pro	No | N/A	✘
	Free	macOS	Ventura 13.0.1	No | N/A	✘
	Free	iOS	iOS 16.1.1	No | N/A	✘
	Free	Android	Android 8.1.0	No | N/A	✔
	Free	Android	Android 12	No | N/A	✔
1.1.1.1	Free	Windows	2022.10.106.0	No | N/A	✔
	Free	Linux	2022.9.591	No | N/A	✔
	Free	macOS	2022.10.107.0	No | N/A	△
	Free	iOS	6.16	No | N/A	✘
	Free	Android	6.17	No | N/A	✔

LocalNet attack: 195 experiments

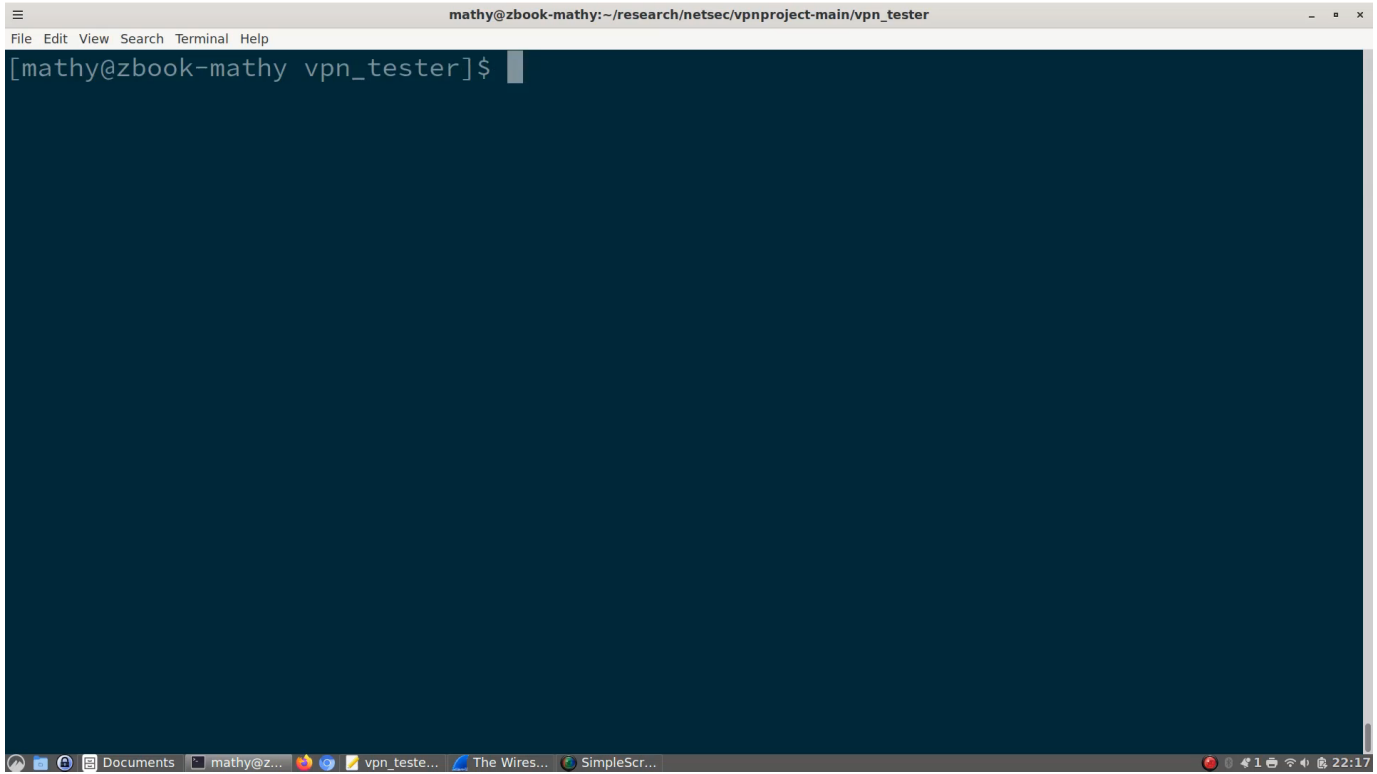


ExpressVPN	Paid	Windows	12.37.0	Yes | Yes	△
	Paid	Linux	3.36	No | N/A	△
	Paid	macOS	11.12.0	Yes | Yes	△
	Paid	iOS	11.70.0	Yes | Yes	✗
	Paid	Android	10.63.2	Yes | Yes	✔
VPN Proxy Master for iPhone	Free	iOS	2.1.5	No | N/A	✝

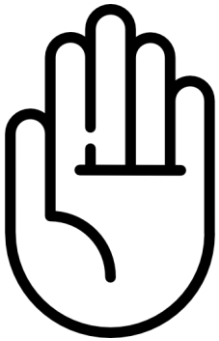
LocalNet attack: summary



DEMO


mathy@zbook-mathy:~/research/netsec/vpnproject-main/vpn_tester
File Edit View Search Terminal Help
[mathy@zbook-mathy vpn_tester]$
Documents
mathy@z...
vpn_teste...
The Wires...
SimpleScr...
22:17

Selected special cases



Some clients block traffic to local network

- Problem when local network uses public IPs
- Traffic to these public IPs gets blocked!

VPN Proxy Master for iPhone (and others)

- DNS server returns private-use IP addresses
- VPN server forwards traffic to real IP address

The iOS case

Prevent attacks by setting `includeAllNetworks=True`

- And `excludeLocalNetworks=False` on iOS ≥ 14.2
- Causes reliability issues, vendors hesitant to enable this

Result is that **iOS remains less secure**

- Context: VPNs on iOS were already known to leak traffic in certain scenarios.
- E.g., OS traffic may leak, leaks when switching networks,…

We were warned in the past…

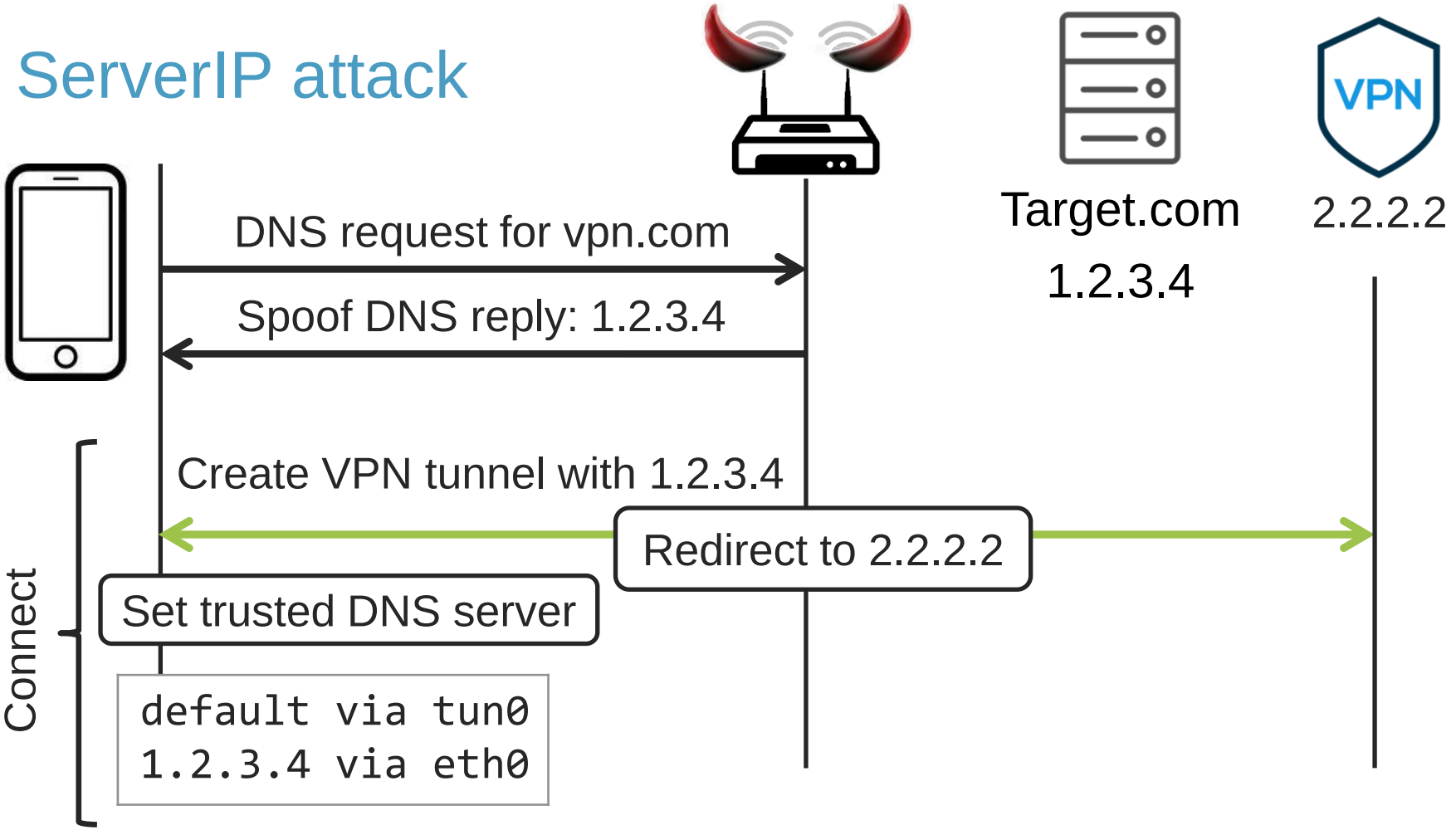
Andrew Ayer: Hardening OpenVPN for DEF CON (2015)

- Guide for OpenVPN on Linux
- Essentially suggested the risk of LocalNet attacks!

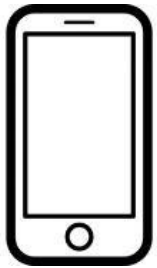
Unclear how widespread this issue (already) was at the time

- VPN clients were not systematically tested → vendors were not warned, so clients never were not audited either
- Using domain names would still enable ServerIP attacks…

ServerIP attack



ServerIP attack



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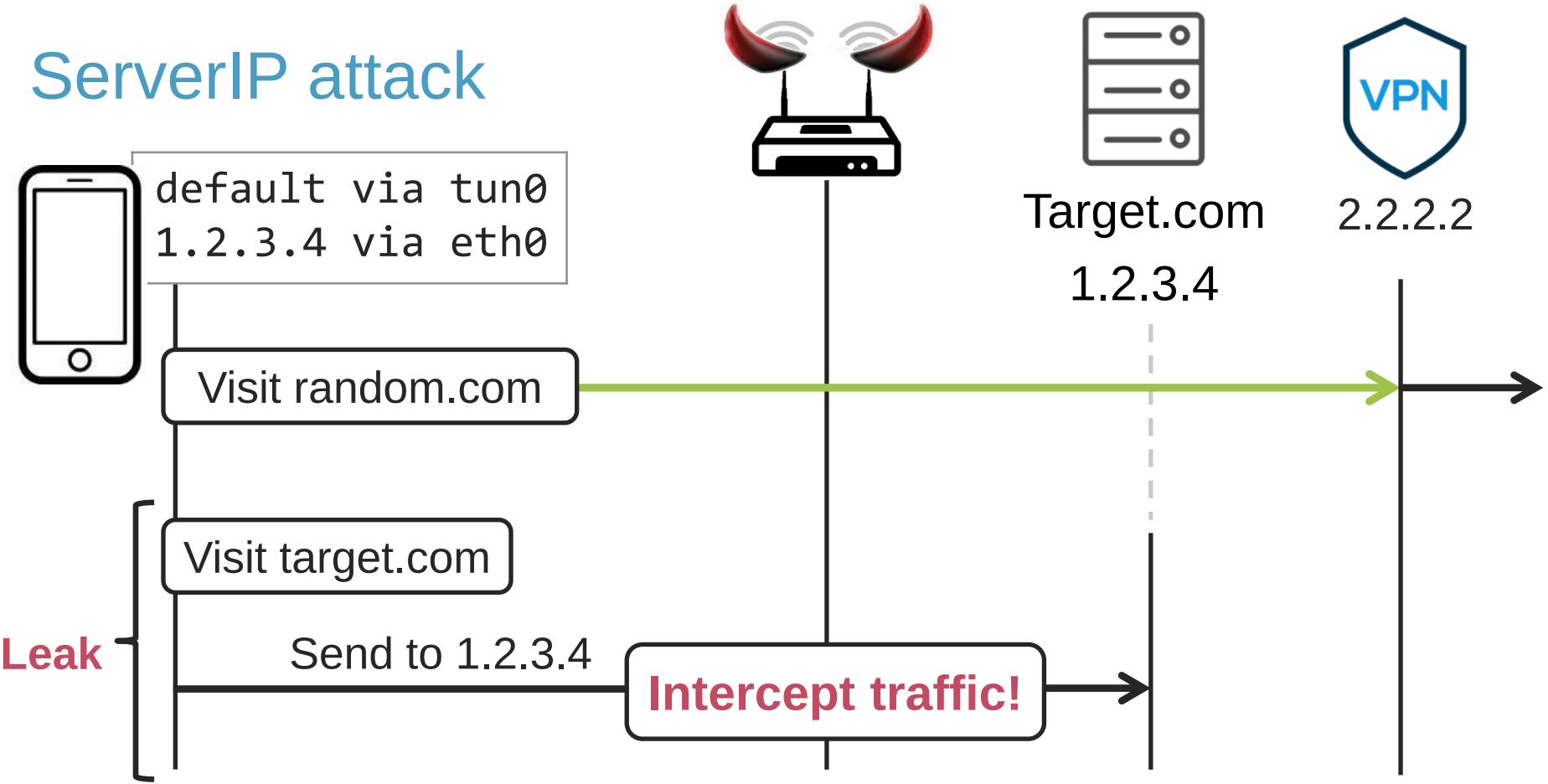
ServerIP attack



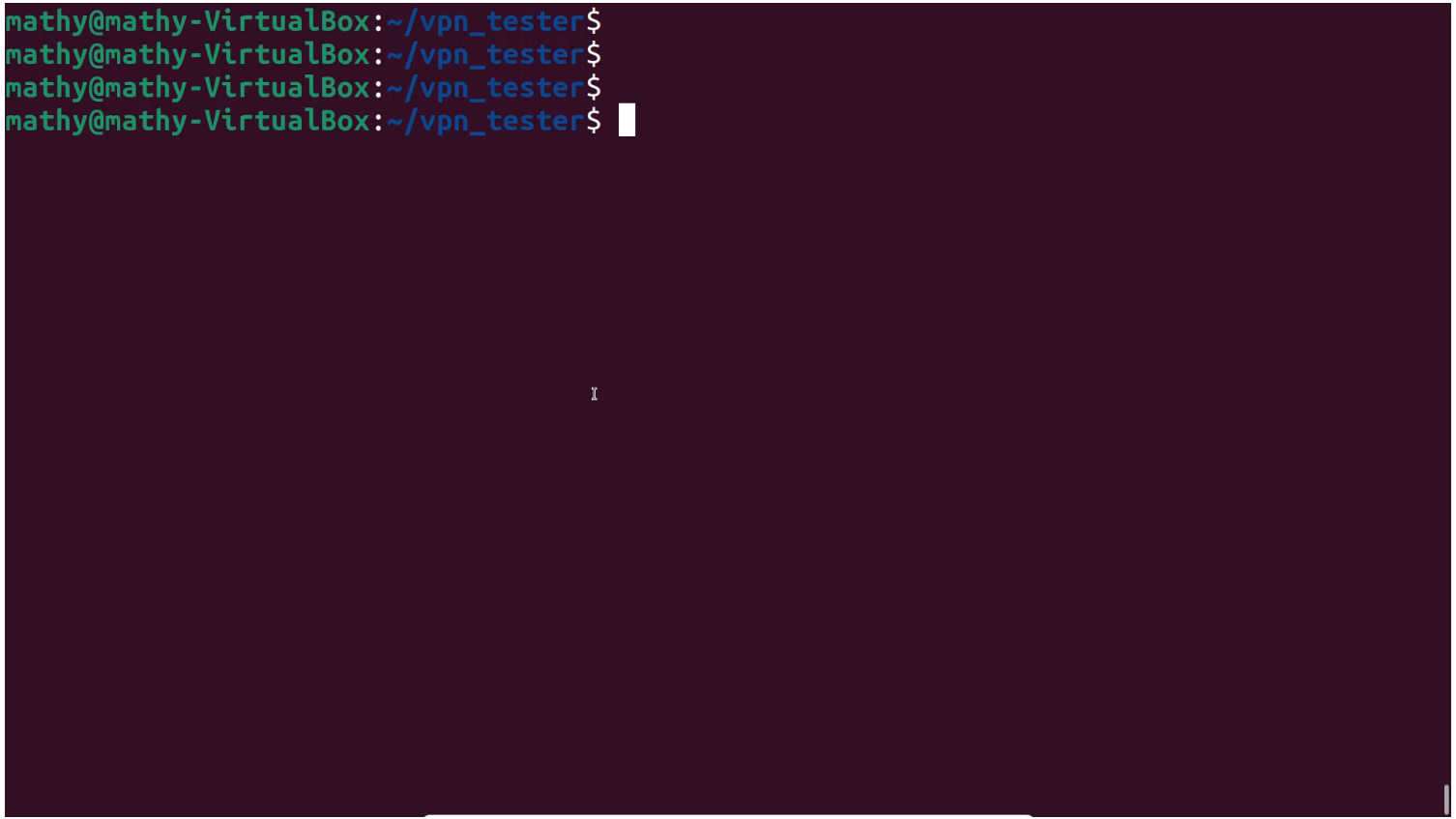
ServerIP attack: 53 experiments

- Many **built-in clients** are affected (Windows, macOS, Linux)
- Legacy built-in VPN on **Android 11 and below** was affected
- Most iOS/Android apps not vulnerable

Impact: can leak traffic to single IP address

- Can target the DNS server set by the VPN client ☺
- Or repeat the attack for different IPs…

DEMO


mathy@mathy-VirtualBox:~/vpn_tester$
mathy@mathy-VirtualBox:~/vpn_tester$
mathy@mathy-VirtualBox:~/vpn_tester$
mathy@mathy-VirtualBox:~/vpn_tester$

Defenses

LocalNet attack: disable local network access when it's using public IP addresses.

- Or allow local network access when using 192.168.* or alike

ServerIP Attack: send all traffic over VPN, except packets generated by VPN process

- On Linux, you can use fwmark (policy-based routing)
- Or quick fix: use secure DNS to get VPN server's IP address

Disclosure

- Reported to CERT/CC on May 10, 2023
- Reported to selected vendors that had a security contact:
  - Some had no e-mail contact, only a bug bounty program
  - In report say we **deviate from T&Cs** and reserve **right to disclose**

Disclosure: special cases

Dubai-based ClarioVPN

- Initially: *“MitM attacks are out of scope”*
- Later: *“Clario isn’t interested in participating in this multi-party disclosure on VPN security”*

Ivanti Pulse Secure

- Provided a test server! But at first didn’t work
- Kept asking for time-consuming recordings
- Seems like they didn’t try our PoC script…

Conclusion

- Two wide-spread flaws in VPN clients
- In hindsight easy attack, but **~66% vulnerable**
- Bad integration of protocols into real systems

- Defense: more carefully configure routing tables
- OS should have API to create VPN tunnels

Questions?

- Two wide-spread flaws in VPN clients
- In hindsight easy attack, but **~66% vulnerable**
- Bad integration of protocols into real systems

- Defense: more carefully configure routing tables
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