

Ghost Calls: Abusing Web Conferencing for Covert Command & Control

Adam Crosser

Introduction



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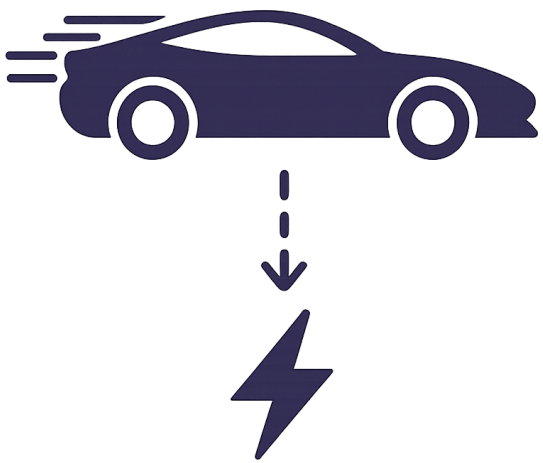
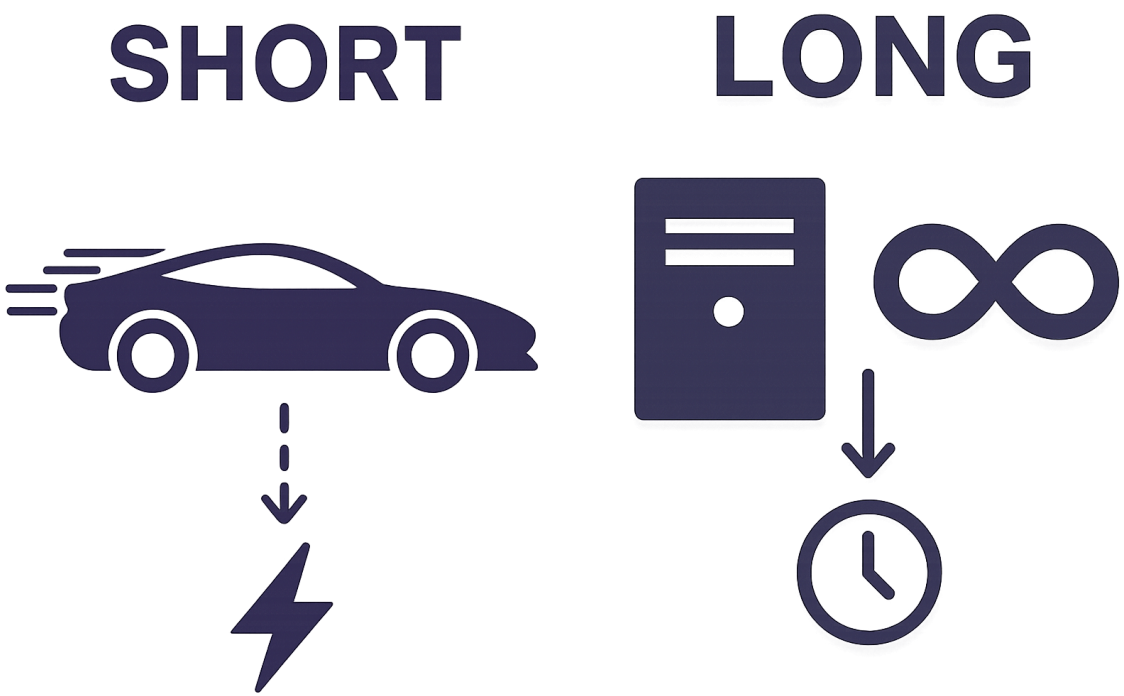
Types of Command-and-Control Channels

Types of Command-and-Control Channels

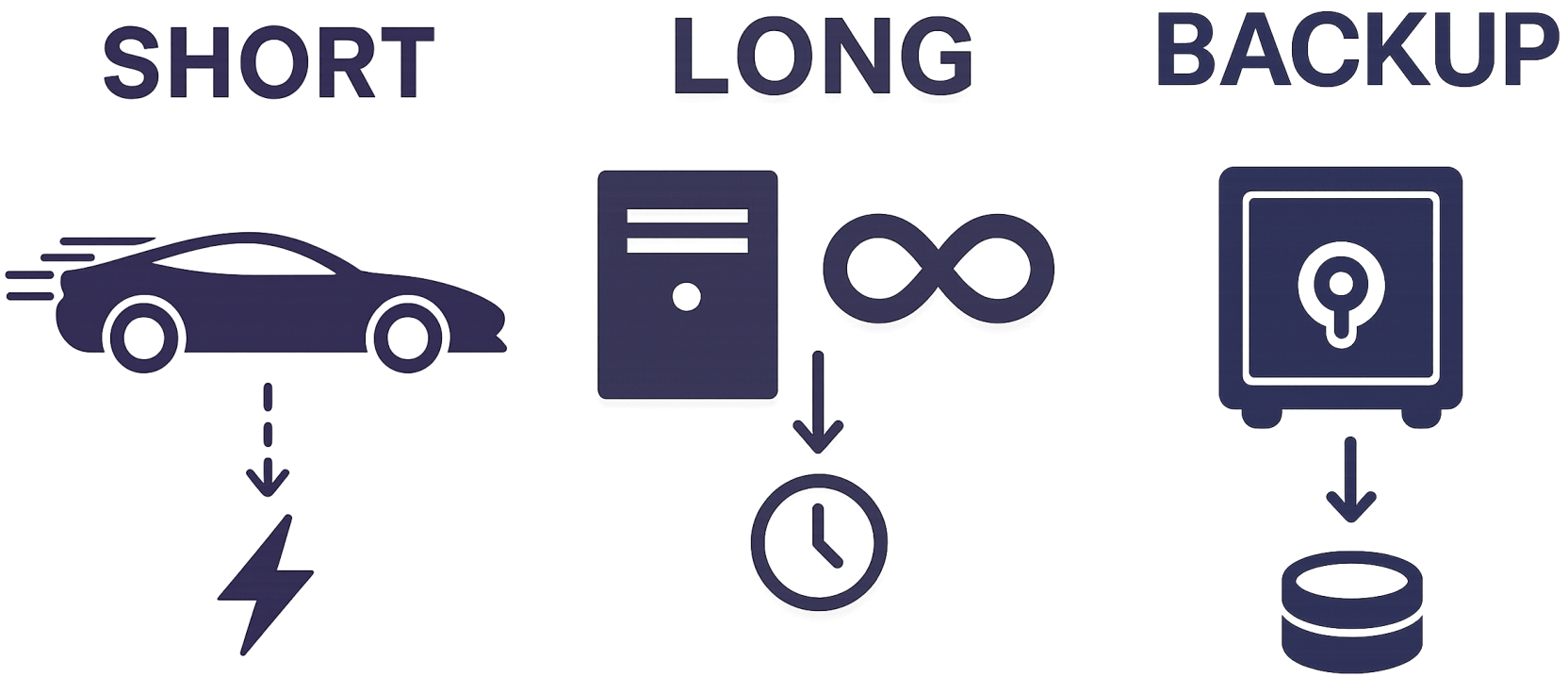
SHORT



Types of Command-and-Control Channels



Types of Command-and-Control Channels



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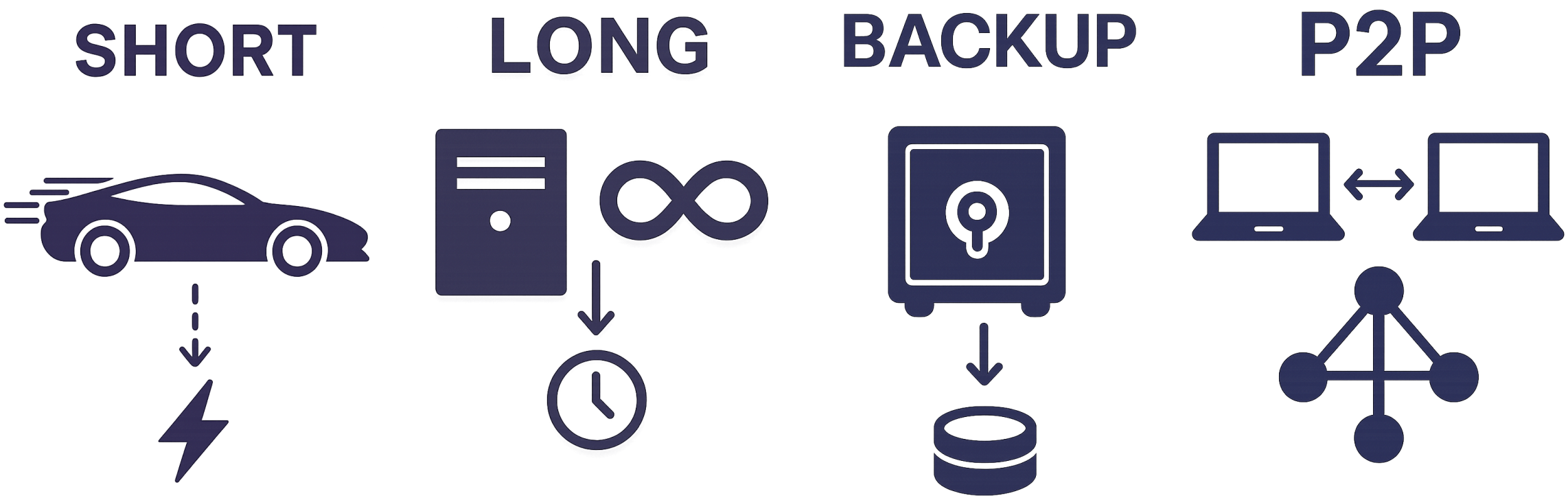


BRAINSTORMING SOLUTIONS

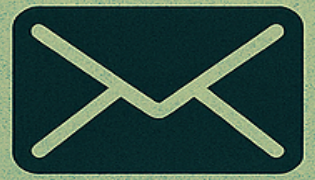
CLOUD STORAGE



DNS OVER HTTPS



EMAIL MESSAGING



B64 EMAIL

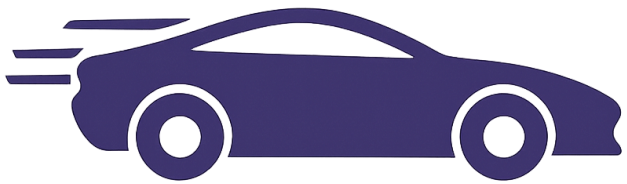




Ideal Short-Term Command and Control

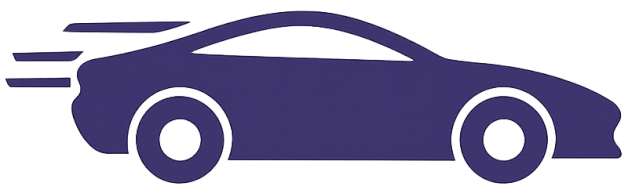
Ideal Short-Term Command and Control

LATENCY



Ideal Short-Term Command and Control

LATENCY

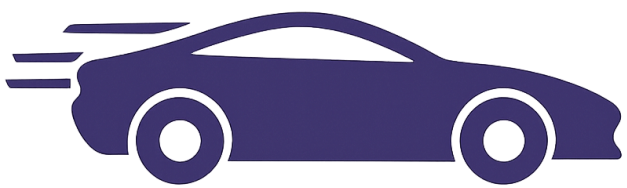


THROUGHPUT



Ideal Short-Term Command and Control

LATENCY



THROUGHPUT

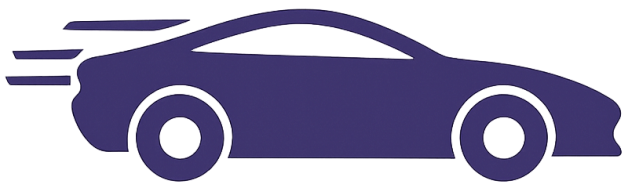


REACH



Ideal Short-Term Command and Control

LATENCY



THROUGHPUT



REACH

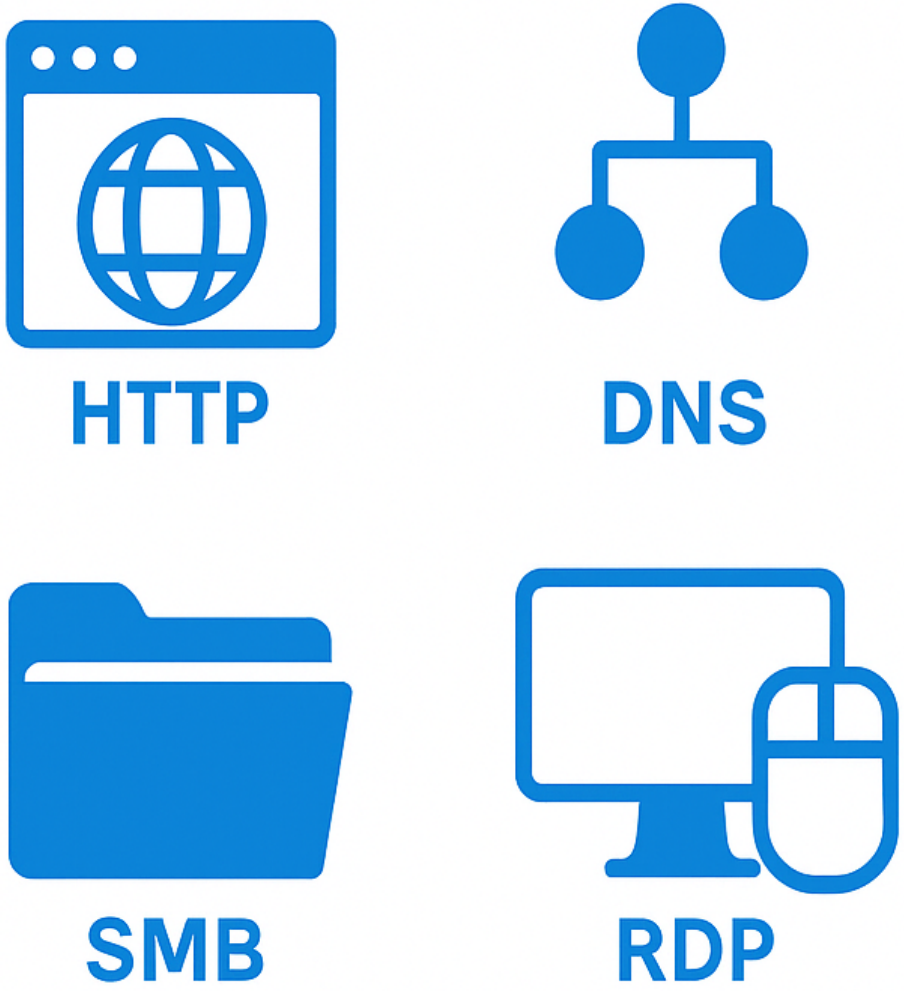


TRUST



Selection Criteria

- Focused on services egressing from user devices
- Must be broadly used across enterprise roles
- Applicable to non-technical departments (e.g., HR, sales)
- Protocols favored by technical users were excluded
- Thought through common workflows and use-cases



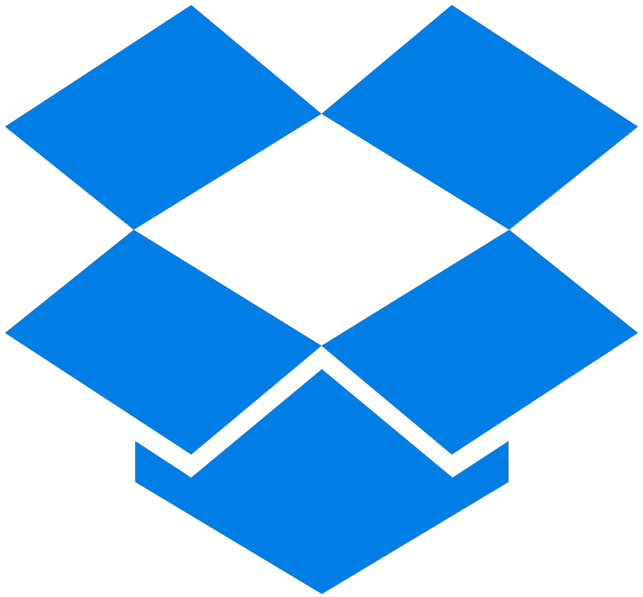
DNS over HTTP (DoH)



DNS over HTTPS

- ✓ LATENCY
- ✗ THROUGHPUT
- ● REACH
- ✓ TRUST

Cloud File Storage







- ✗ LATENCY
- ✓ THROUGHPUT
- ✓ REACH
- ● TRUST

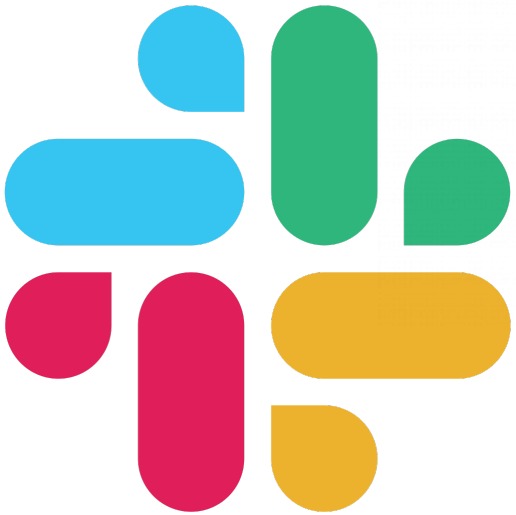
Attacker Virtual Machine with Classified Domain



- ✓ LATENCY
- ✓ THROUGHPUT
- ✗ REACH
- ✗ TRUST

Email and Messaging Applications







- LATENCY
- ✗ THROUGHPUT
- ✓ REACH
- ✓ TRUST

Web Conferencing



- ✓ LATENCY
- ✓ THROUGHPUT
- ✓ REACH
- ✓ TRUST

Microsoft Teams Split Tunneling Guidelines

Configure split-tunnel VPN	We recommend that you provide an alternate path for Teams traffic that bypasses the virtual private network (VPN), commonly known as split-tunnel VPN. Split tunneling means that traffic for Microsoft 365 or Office 365 doesn't go through the VPN but instead goes directly to Microsoft 365 or Office 365. Bypassing your VPN has a positive impact on Teams quality, and it reduces load from the VPN devices and the organization's network. To implement a split-tunnel VPN, work with your VPN vendor. Other reasons why we recommend bypassing the VPN: • VPNs are typically not designed or configured to support real-time media. • Some VPNs might also not support UDP (which is required for Teams). • VPNs also introduce an extra layer of encryption on top of media traffic that's already encrypted. • Connectivity to Teams might not be efficient due to hair-pinning traffic through a VPN device. • Traffic might be routed to a service front door location that is further away from the end user, introducing extra latency and jitter.

https://learn.microsoft.com/en-us/microsoftteams/prepare-network

Microsoft Teams TLS Inspection

Not using a proxy server is recommended

Many organizations utilize proxy servers today within their network. As Microsoft Teams and Skype for Business traffic is already encrypted, passing this traffic through a proxy server doesn't make the traffic any more secure.

Proxies can cause issues too. Performance-related problems can be introduced to the environment through latency and packet loss by attempting to route Teams traffic through a proxy server. This can be caused by the proxy being unable to handle the amount of traffic passing through it, or by incorrectly routing the traffic to a Microsoft network service front door location that is further away from the end user.

Issues such as these will result in a negative experience within Teams and Skype for Business.

We recommend that Teams traffic bypasses proxy server infrastructure, including SSL inspection. You may wish to achieve this by putting Teams Phones and Meeting Room devices on their own VLAN and providing them with Internet access.

https://learn.microsoft.com/en-us/microsoftteams/proxy-servers-for-skype-for-business-online

Zoom Split Tunneling Recommendations

VPN Split Tunneling Recommendations

English (Original) 2025-03-06 16:55:57 Copy Permalink

Virtual Private Network (VPN) services are crucial to securing data accessed by users working from remote locations.

One of the biggest challenges Zoom customers experience is related to not allowing our real-time media services over UDP 8801-8810 to split tunnel. Not allowing split tunneling for UDP 8801-8810 and TCP 443 to Zoom resources, does cause customers to experience significant additional load on their corporate internet connections due to the Zoom traffic having to enter the corporate network, only to exit again to the Zoom cloud for real-time meeting termination. This also places a significant amount of burden on VPN concentrators and in many cases can cause overloading and congestion of this infrastructure.

https://support.zoom.com/hc/en/article?id=zm_kb&sysparm_article=KB0065998

Zoom TLS Inspection Recommendations

Proxy server

We support HTTPS/SSL proxy servers via port 443 for Zoom traffic.

Note: This does not apply to the Zoom Phone service.

Zoom automatically detects your proxy settings. In some instances, you may be prompted to enter the proxy username/password.

Note: We recommend allowing **zoom.us** and ***.zoom.us** from proxy or SSL inspection.

https://support.zoom.com/hc/en/article?id=zm_kb&sysparm_article=KB0060548

Quick Disclaimer

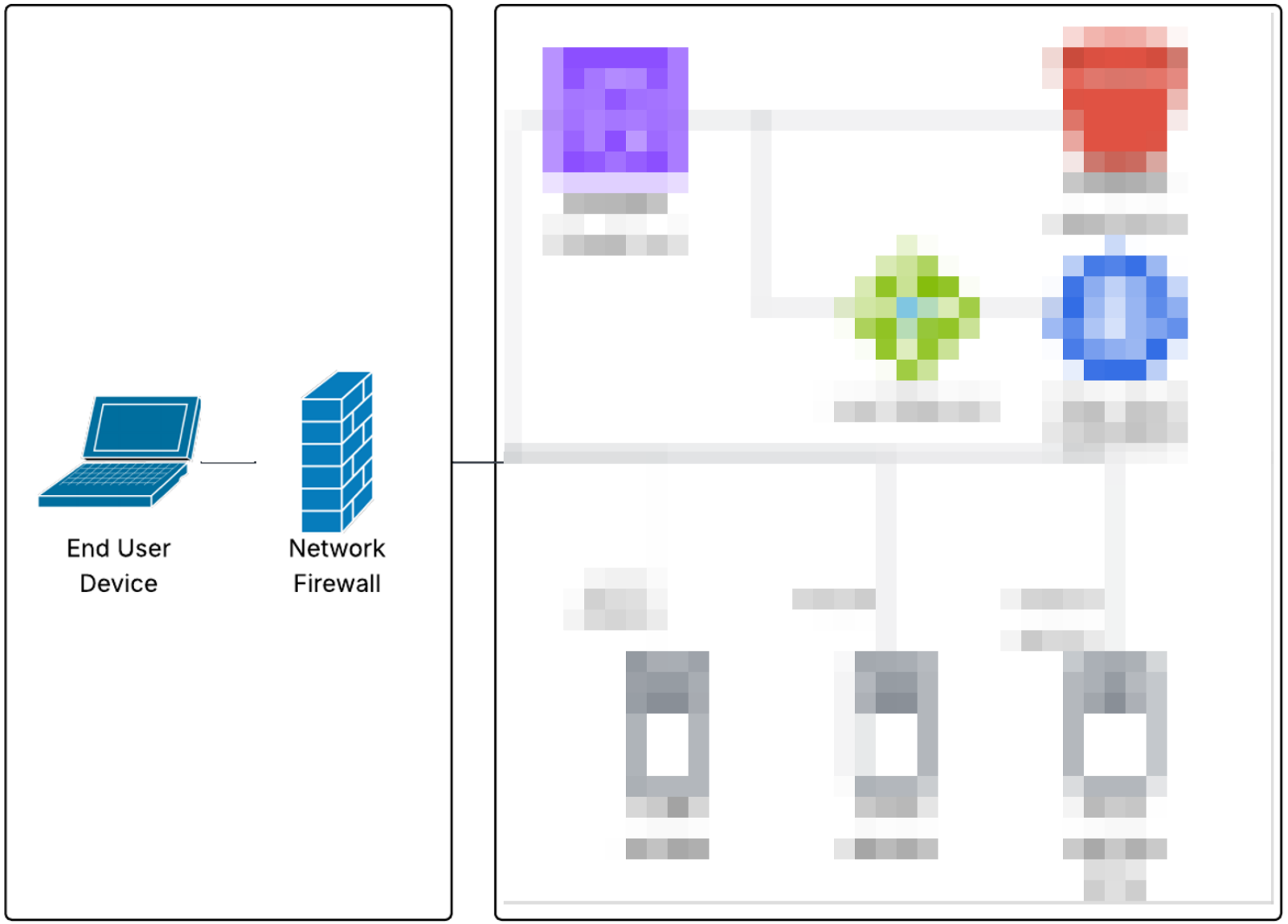
- Providers aren’t being malicious
- Performance is the main design driver
- Latency must be minimized for app reliability
- These configs are often intentional not careless
- Inspection or routing can overwhelm systems



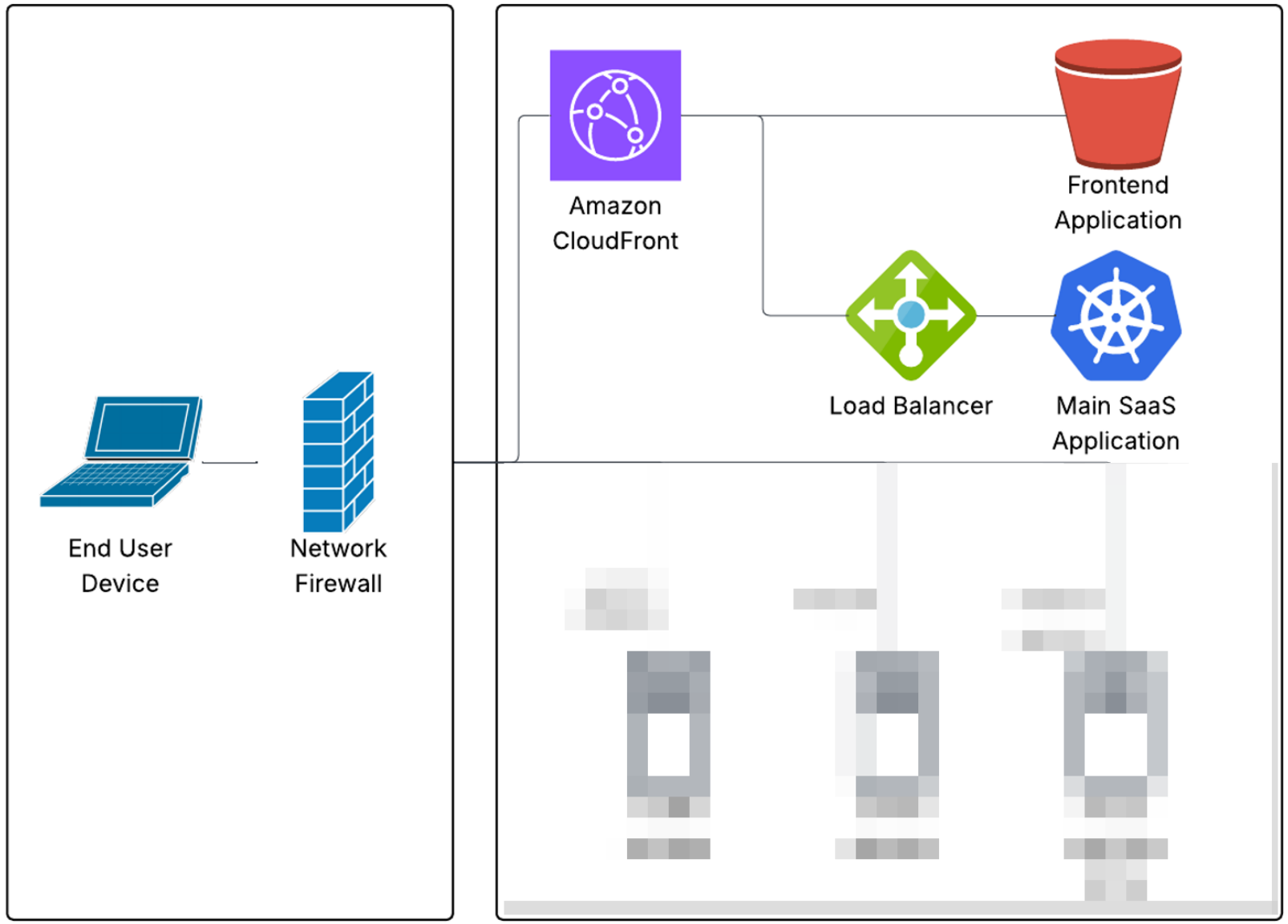
HOW IT WORKS



General Web Conferencing Architecture



General Web Conferencing Architecture



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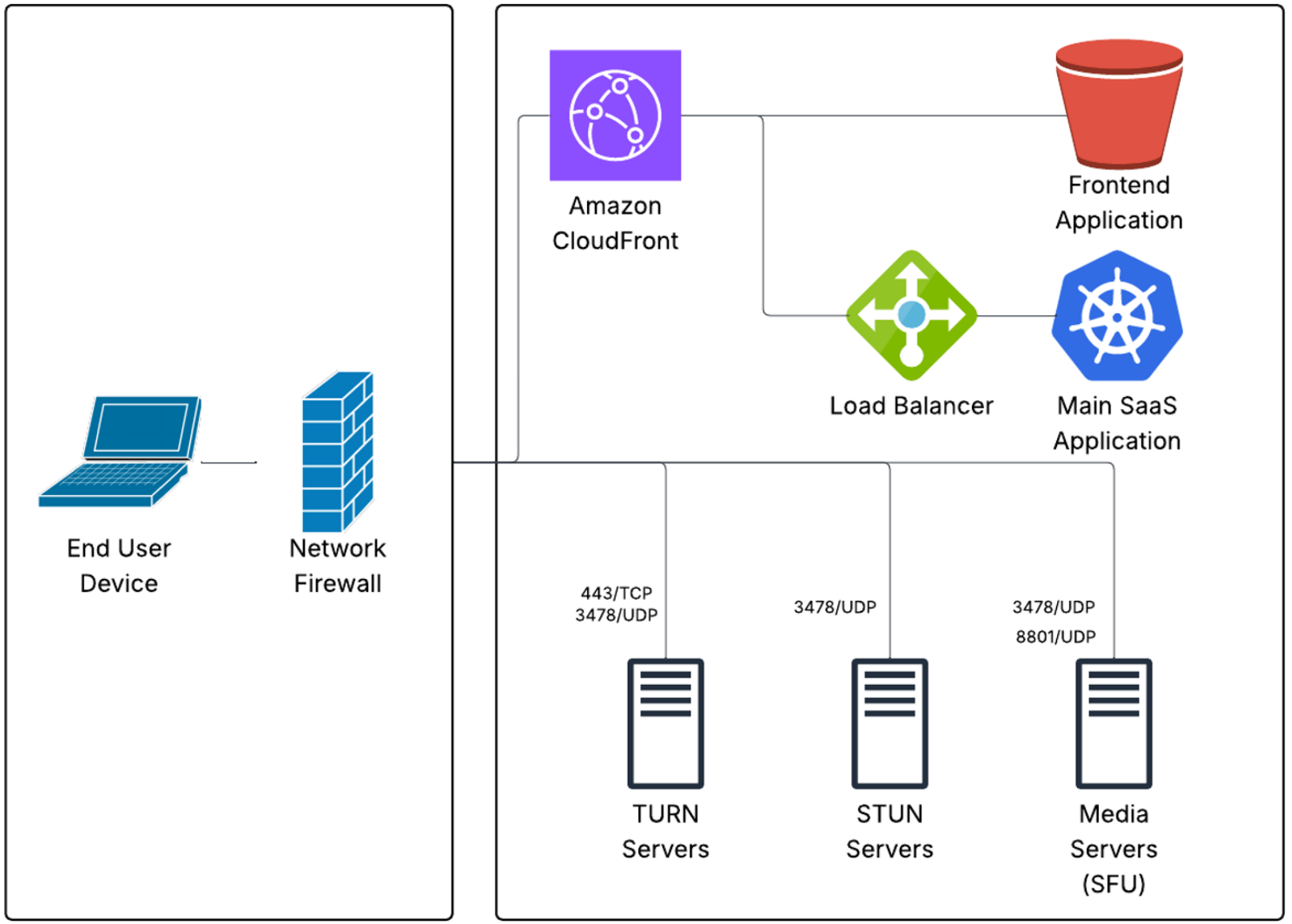
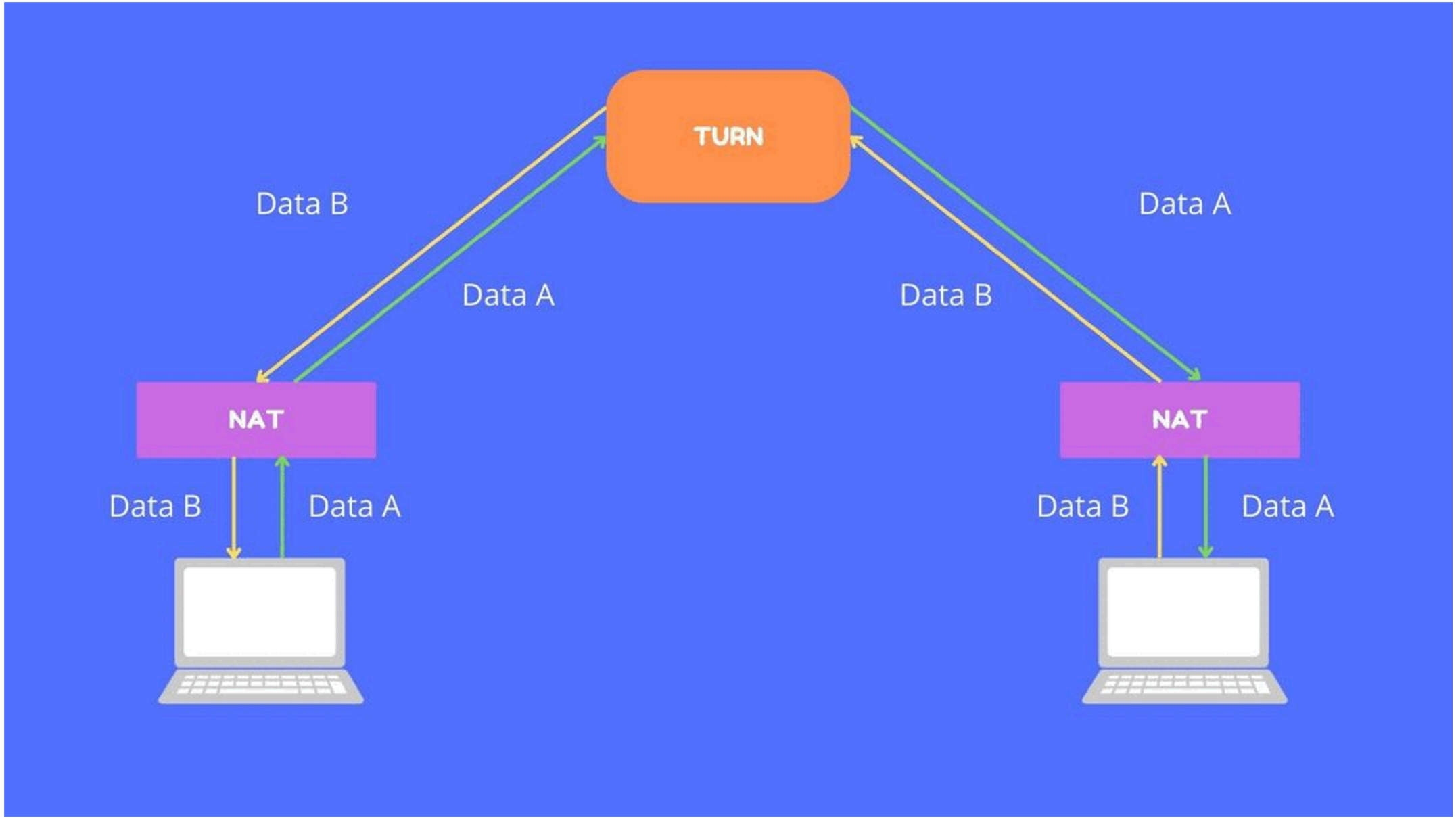


What is TURN?

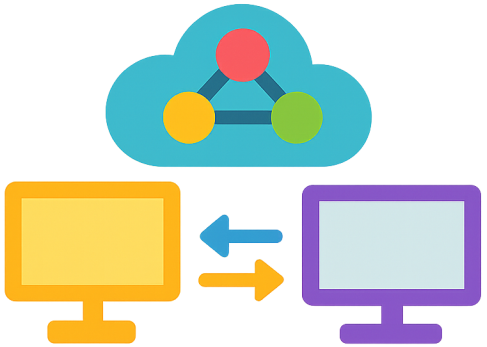


source

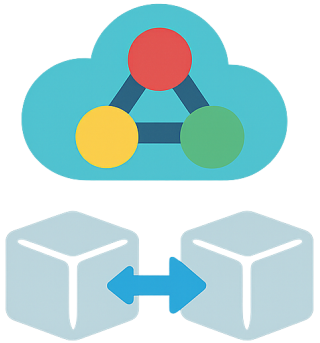
WebRTC Core Protocols



DTLS



SCTP

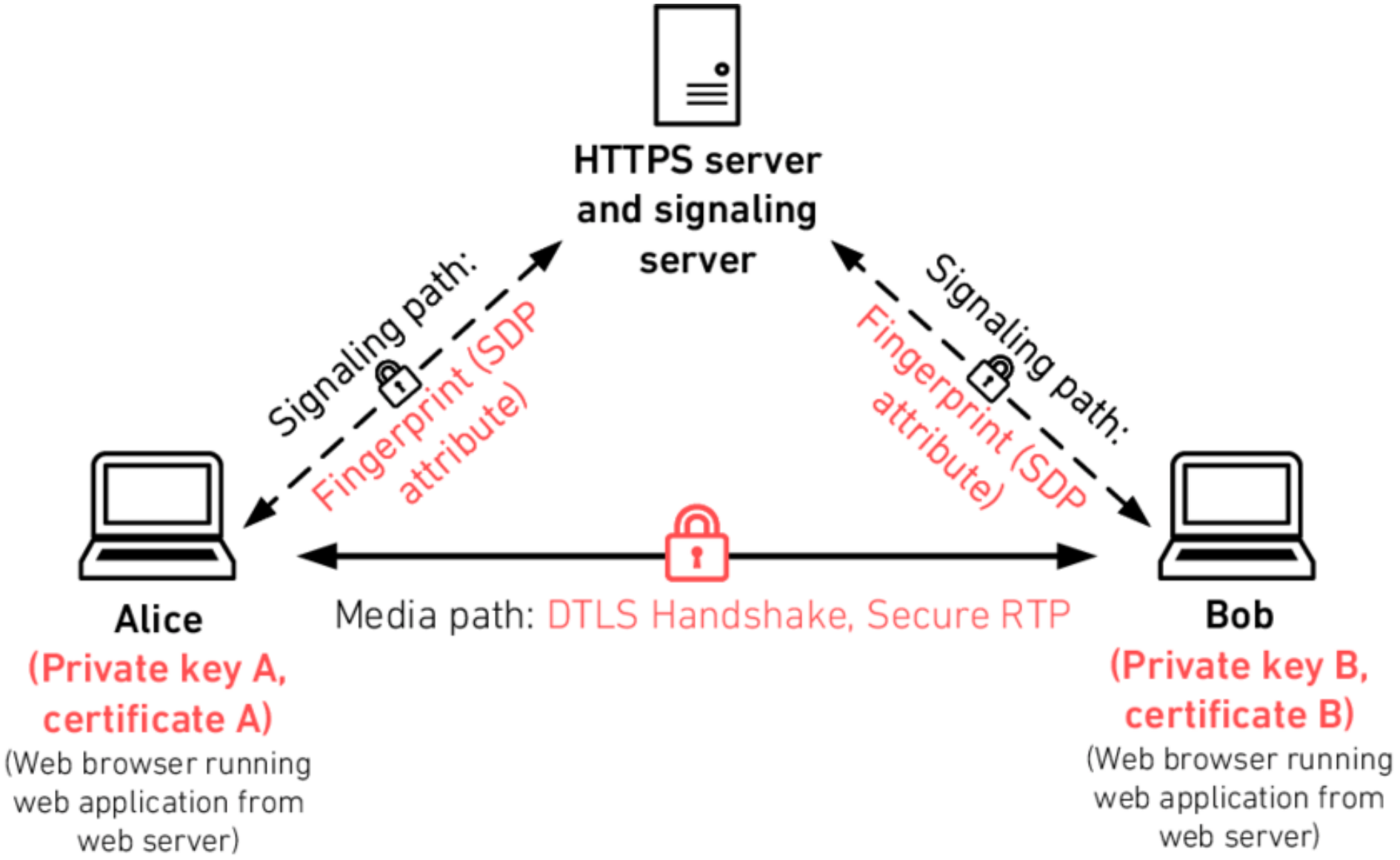


ICE



SRTP

WebRTC Handshake Process

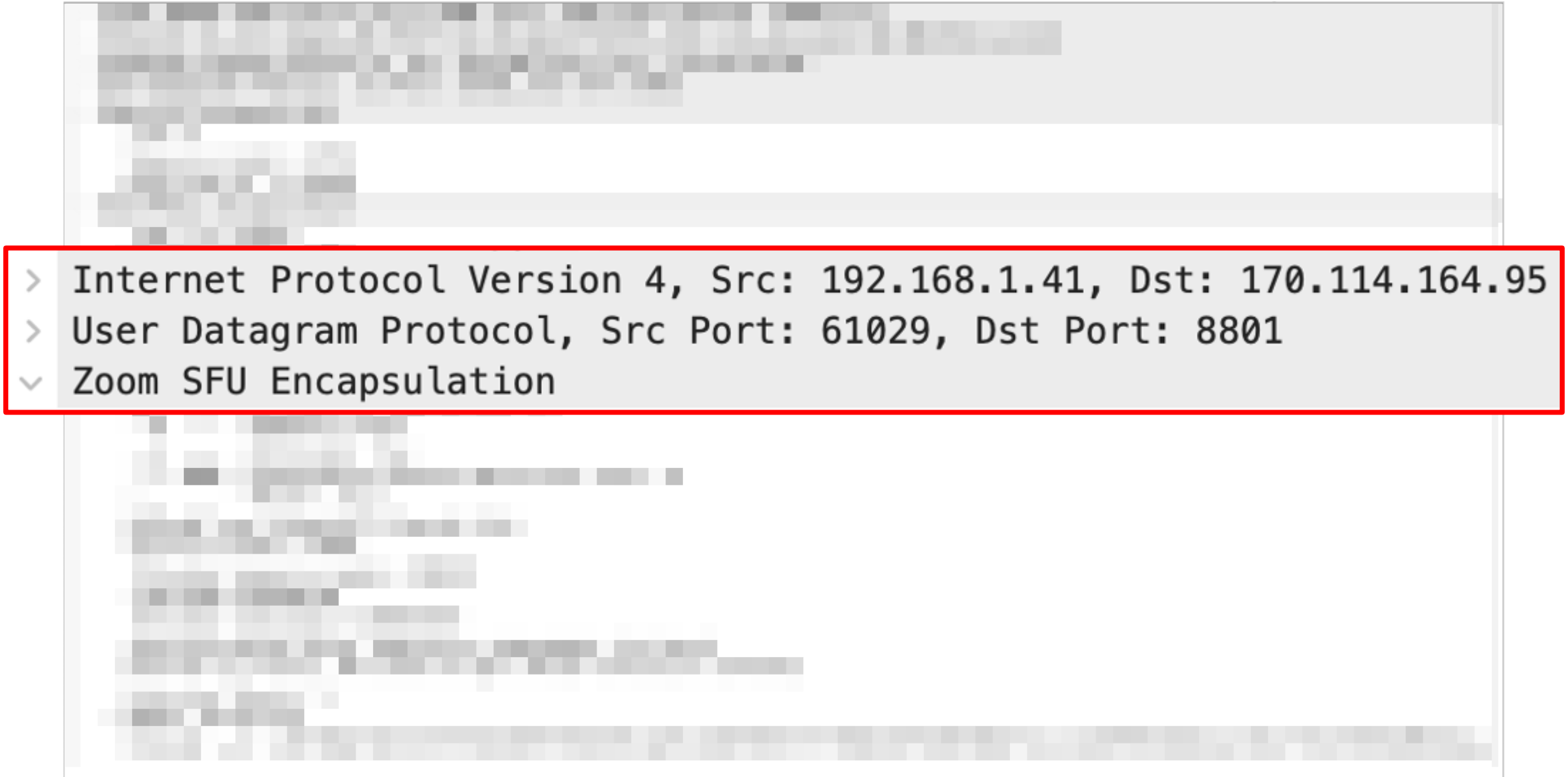


source

Reverse Engineering Zoom

```
> Internet Protocol Version 4, Src: 192.168.1.41, Dst: 170.114.164.95
> User Datagram Protocol, Src Port: 61029, Dst Port: 8801
v Zoom SFU Encapsulation
    Type: 5
    Sequence number: 1278
    Direction: 0 (to Zoom)
v Zoom Media Encapsulation
    Type: 16 (Video)
    Sequence number: 1261
    Timestamp: 106179922
    Frame number: 57
    Packets in frame: 2
v Real-Time Transport Protocol
  > [Stream setup by DECODE AS (frame 28373)]
    10.. .... = Version: RFC 1889 Version (2)
    ..0. .... = Padding: False
    ...1 .... = Extension: True
    .... 0000 = Contributing source identifiers count: 0
    1... .... = Marker: True
    Payload type: DynamicRTP-Type-98 (98)
    Sequence number: 24484
    [Extended sequence number: 90020]
    Timestamp: 894589134
    [Extended timestamp: 5189556430]
    Synchronization Source identifier: 0x01000401 (16778241)
    Defined by profile: RFC 5285 One-Byte Header Extensions (0xbede)
    Extension length: 5
  > Header extensions
    Payload […]: 1c40736b27a5415cf9715dd657876f8c59f14a70c4c6878987c74f26b8123f633690b6ef5ccee1e88f5932228eadc93eefe91c9f23
```

Reverse Engineering Zoom



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```

Building on Existing Work

Enabling Passive Measurement of Zoom Performance in Production Networks



https://dl.acm.org/doi/pdf/10.1145/3517745.3561414

Custom Wireshark Analyzer for Zoom Desktop Media Traffic

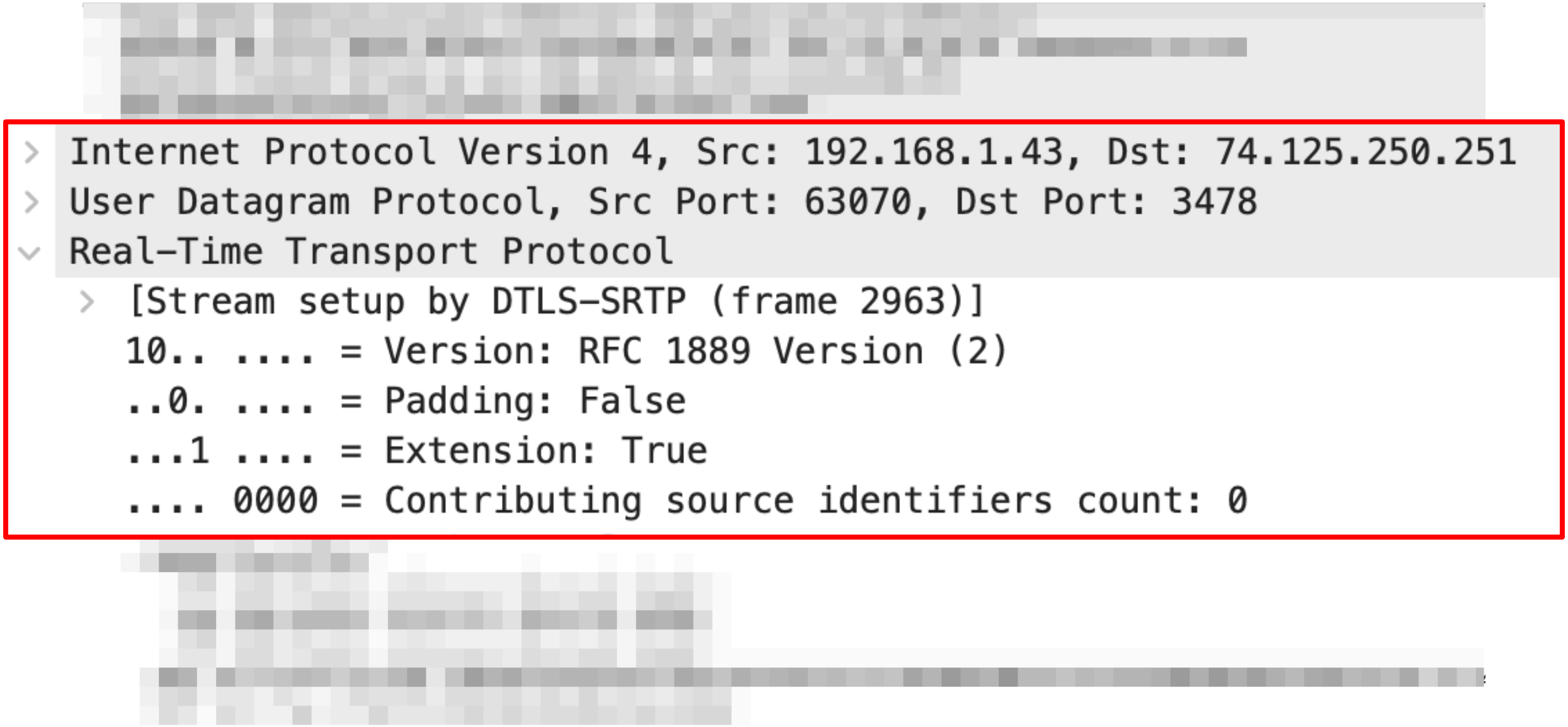


https://github.com/Princeton-Cabernet/zoom-analysis

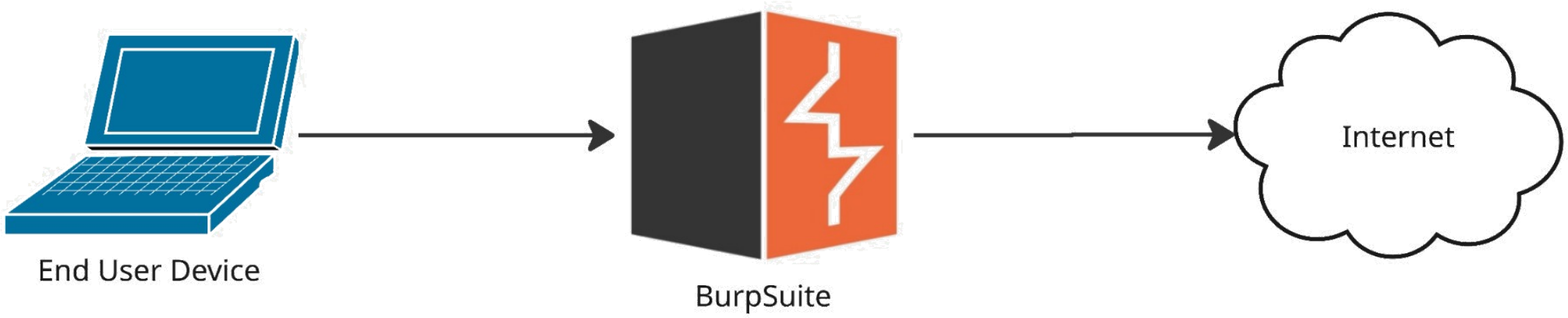
Reverse Engineering Google Meet

```
> Frame 4296: 160 bytes on wire (1280 bits), 160 bytes captured (1280 bits)
> Ethernet II, Src: Apple_d5:f9:5f (14:7d:da:d5:f9:5f), Dst: zte_4c:ac:24 (20:08:89:4c:ac:24)
> Internet Protocol Version 4, Src: 192.168.1.43, Dst: 74.125.250.251
> User Datagram Protocol, Src Port: 63070, Dst Port: 3478
v Real-Time Transport Protocol
  > [Stream setup by DTLS-SRTP (frame 2963)]
    10.. .... = Version: RFC 1889 Version (2)
    ..0. .... = Padding: False
    ...1 .... = Extension: True
    .... 0000 = Contributing source identifiers count: 0
    0... .... = Marker: False
    Payload type: Unassigned (63)
    Sequence number: 24725
    [Extended sequence number: 90261]
    Timestamp: 345165098
    [Extended timestamp: 4640132394]
    Synchronization Source identifier: 0xa11f30c7 (2703175879)
    Defined by profile: RFC 5285 One-Byte Header Extensions (0xbede)
    Extension length: 3
  v Header extensions
    > RFC 5285 Header Extension (One-Byte Header)
    > RFC 5285 Header Extension (One-Byte Header)
    > RFC 5285 Header Extension (One-Byte Header)
    SRTP Encrypted Payload: 56046ee649b15872c7d5a1f0b3604bf7ee71d42d8d55062dc3c6a639ae063054d04ea8469f2495cf5c34
    SRTP Auth Tag: 175d3f6ef64838a438b484a7dee2dbbc
```

Reverse Engineering Google Meet



Case Study in Egress Resilience



Example Zoom Desktop Egress Attempts



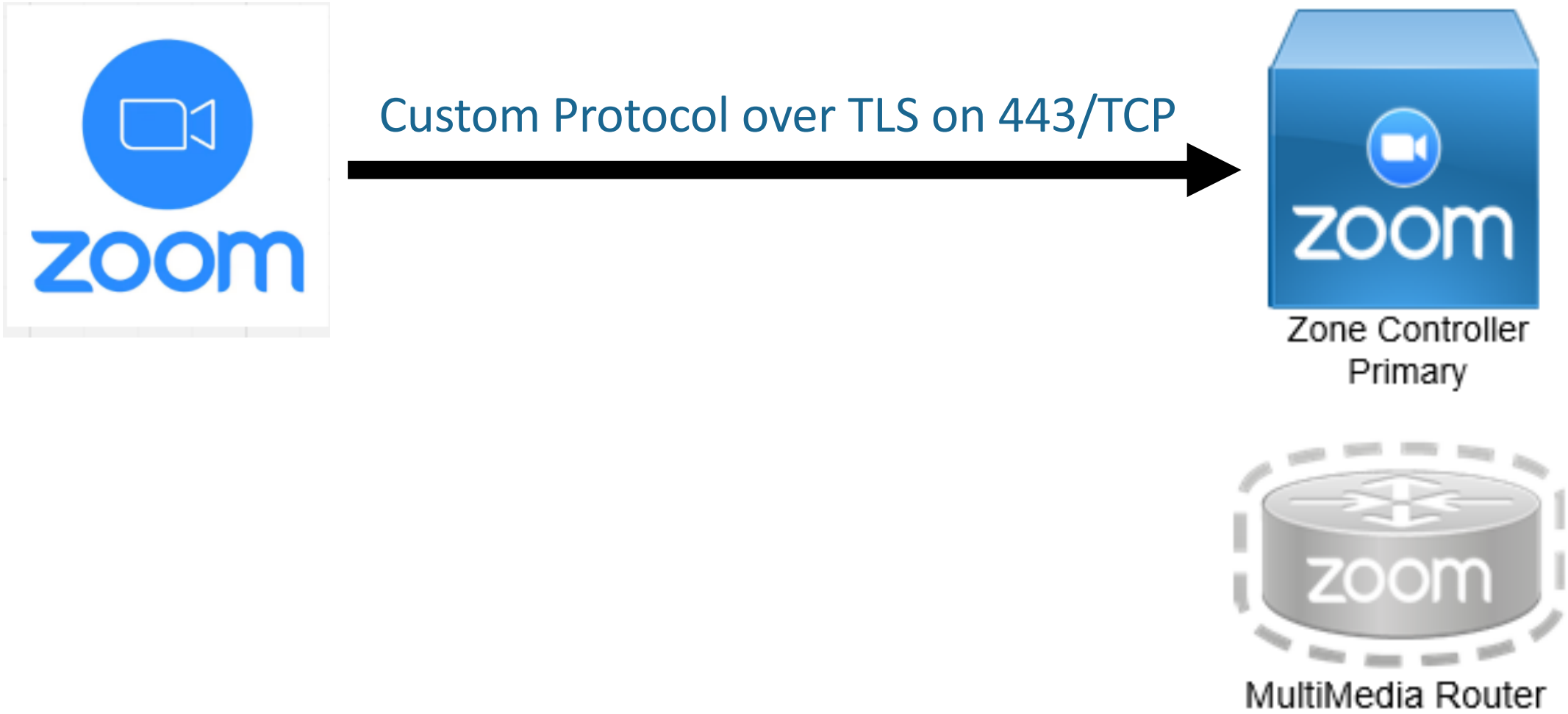


Zone Controller
Primary



MultiMedia Router

Example Zoom Desktop Egress Attempts



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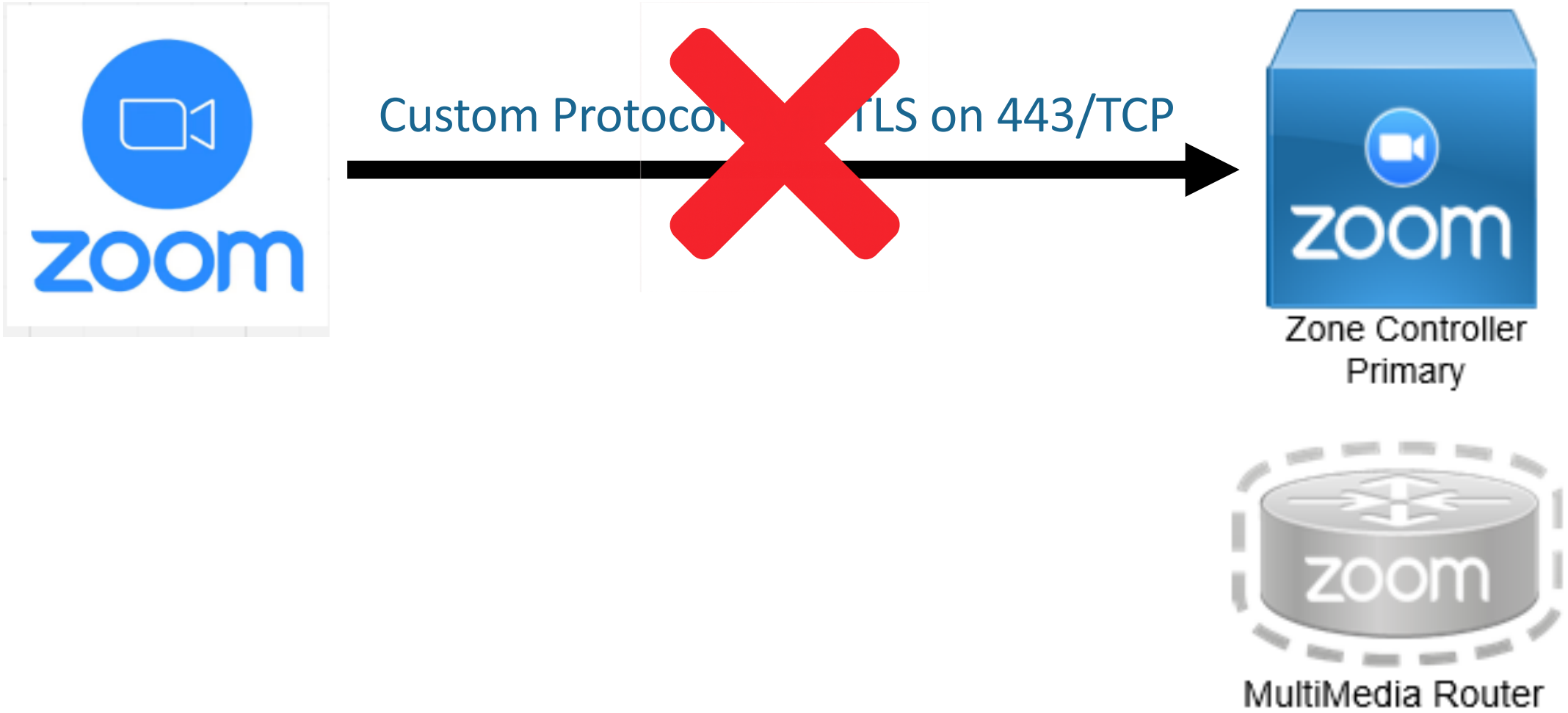

Example Zoom Desktop Egress Attempts



WebSockets over HTTPS on 443/TCP



Zone Controller
Primary



MultiMedia Router

Example Zoom Desktop Egress Attempts



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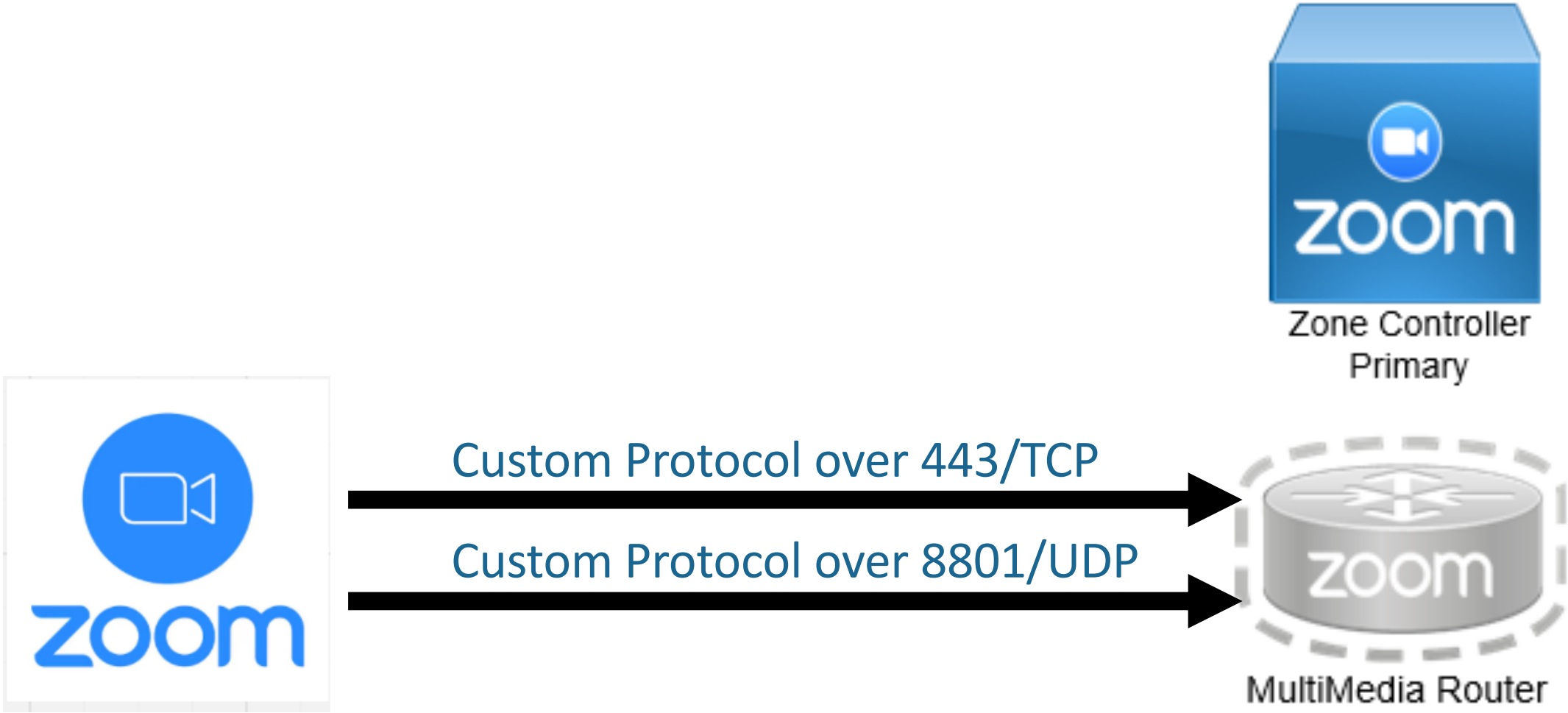

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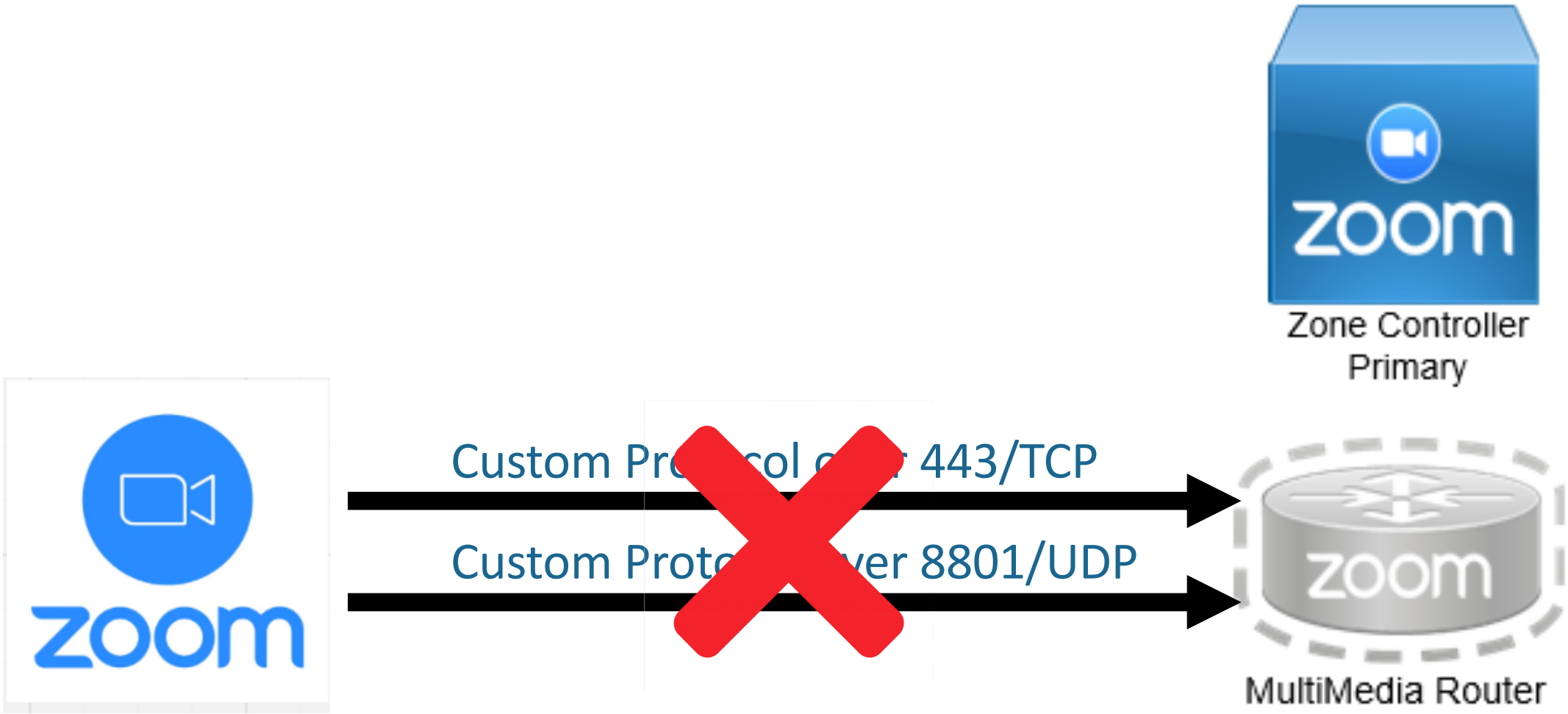


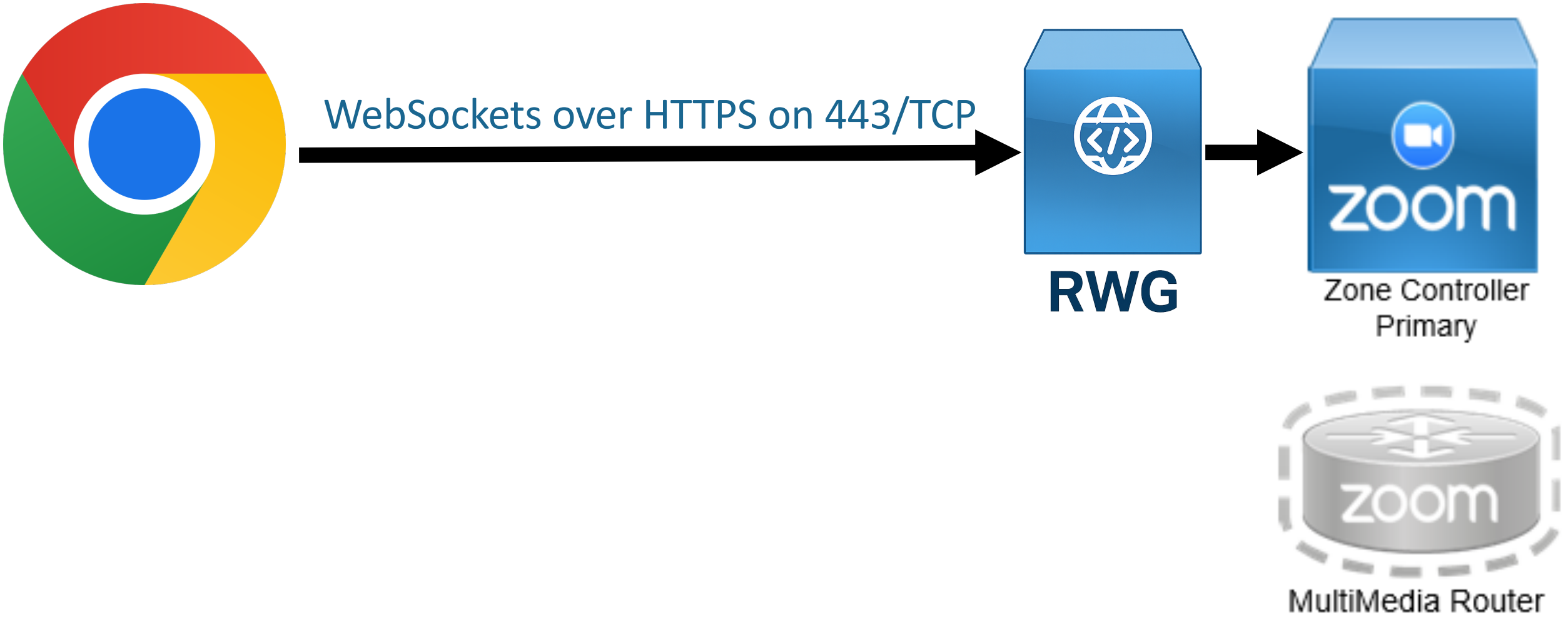
Example Zoom Desktop Egress Attempts



Example Zoom Desktop Egress Attempts



Example Zoom Web Client Egress Attempts



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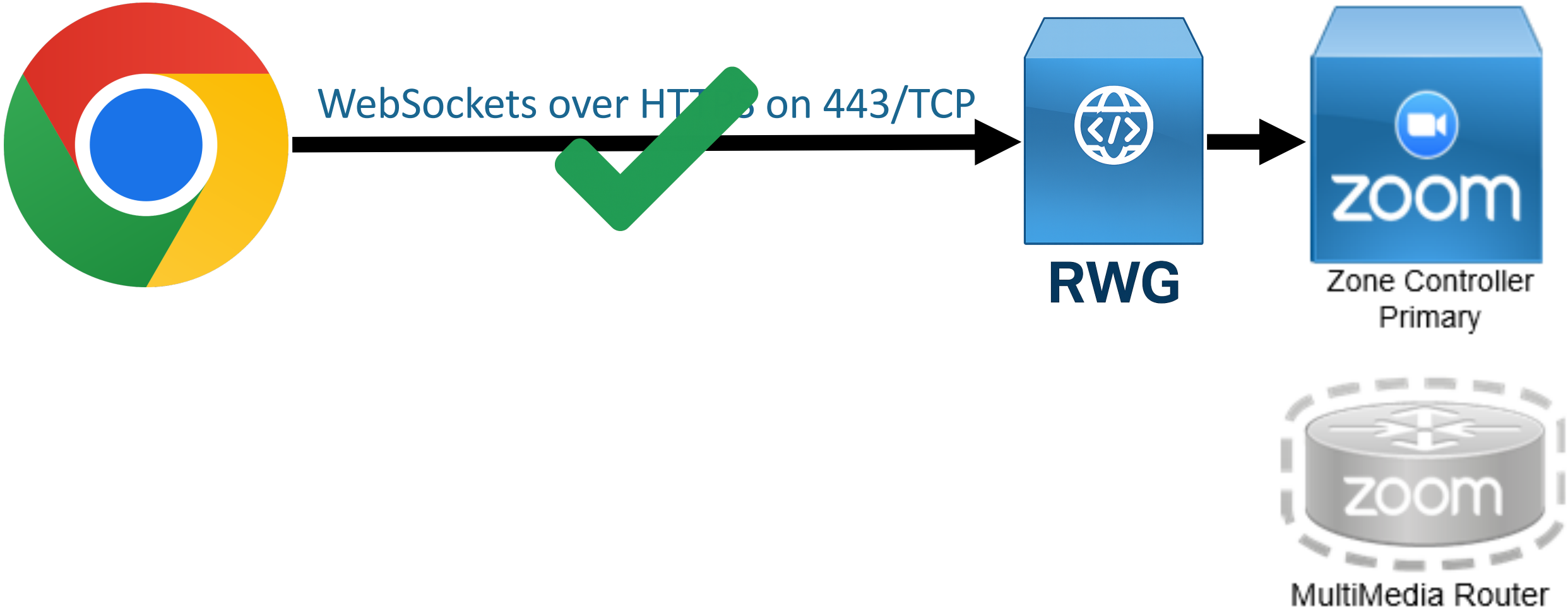

Example Zoom Web Client Egress Attempts



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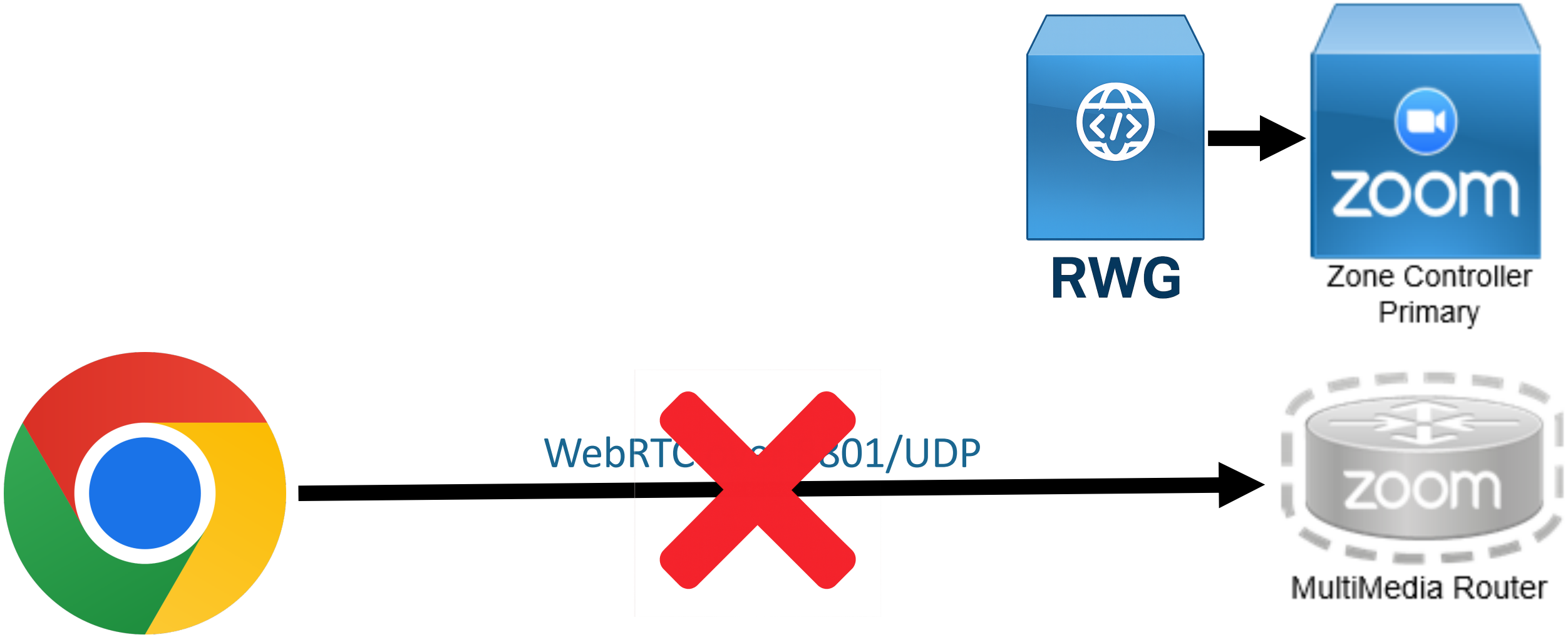

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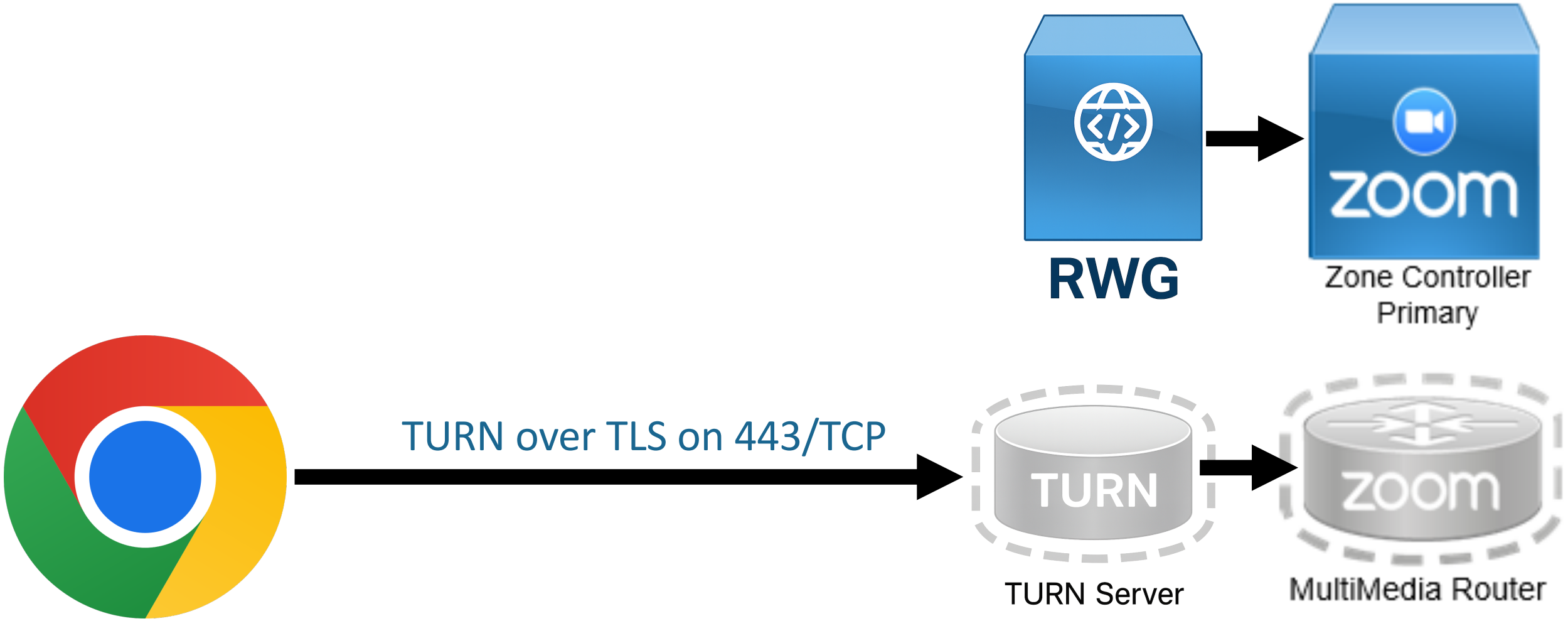

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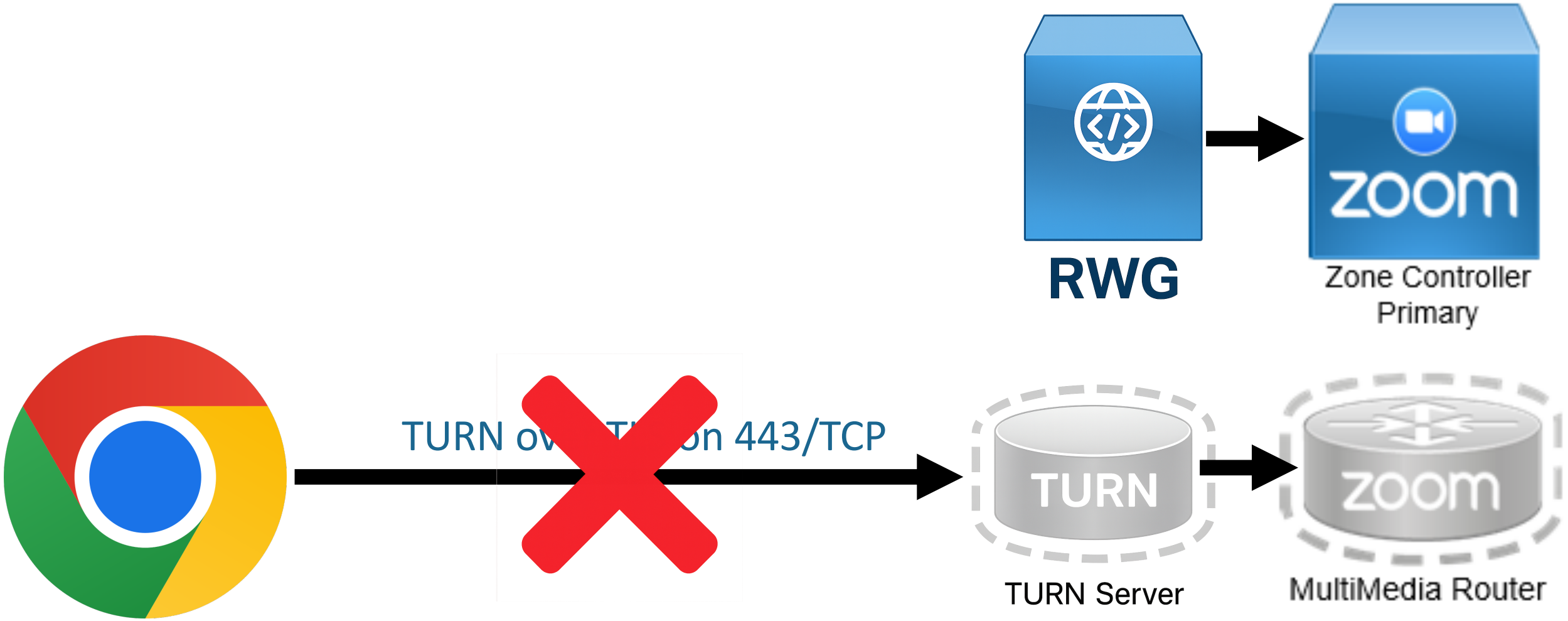

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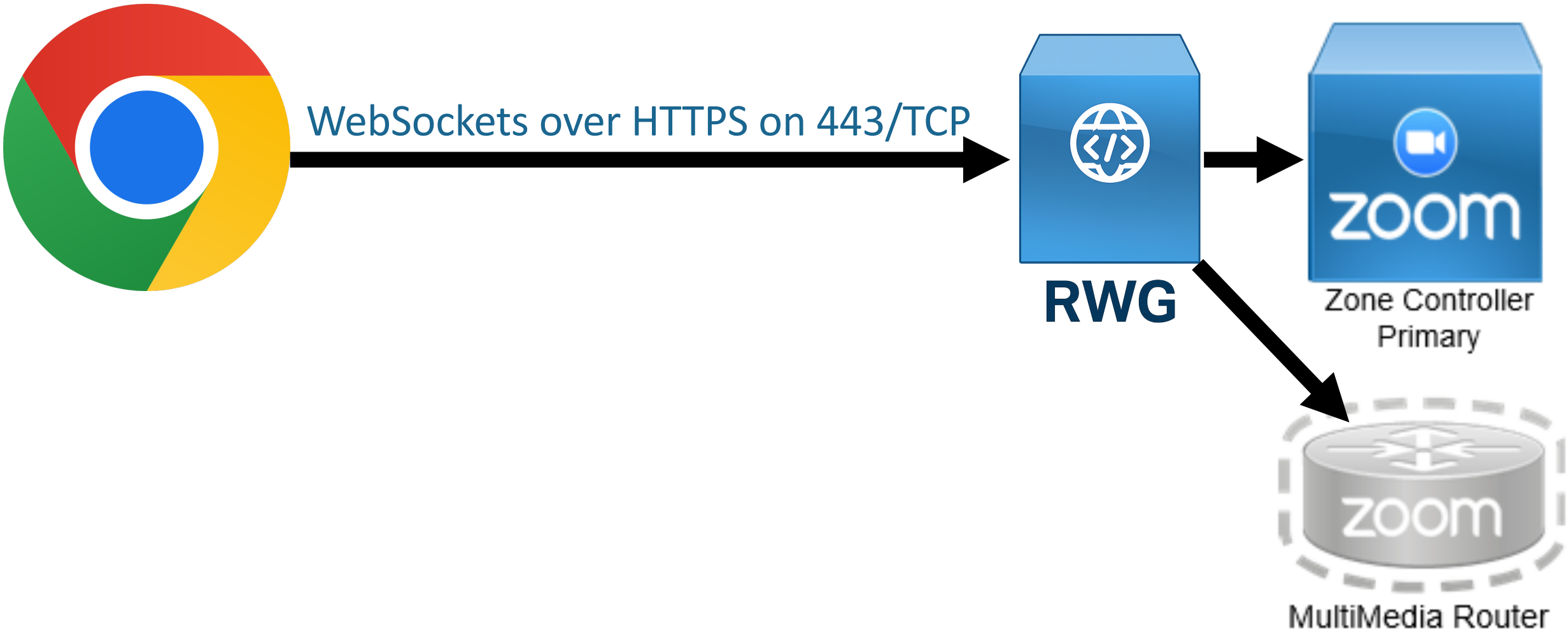

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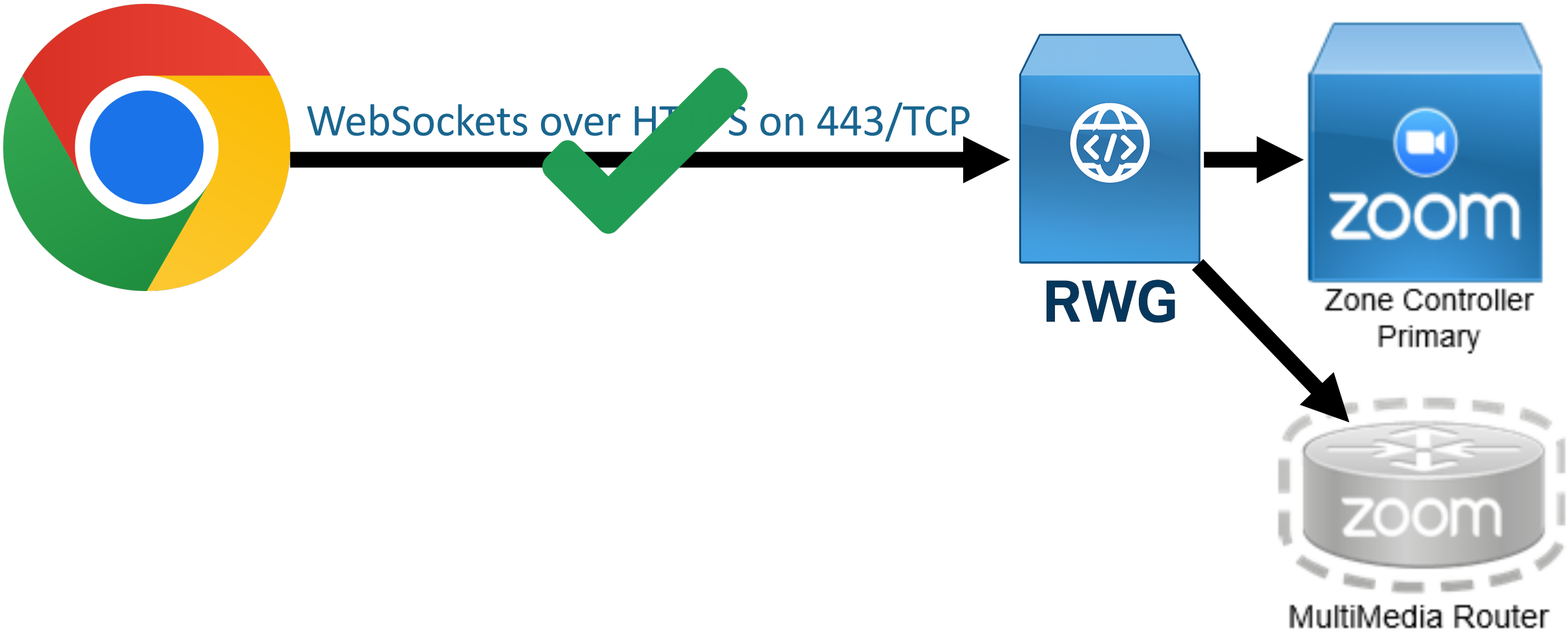

Highly Adaptable to Changing Environments





Developing the Capability

Analyzing Vendor Market Share

Videoconferencing Software	Market Share
Zoom	55.91%
Microsoft Teams	32.29%
GoToMeeting	8.81%
Google Meet	5.52%
WebEx	7.61%
RingCentral	5.31%
FaceTime	2.16%
Skype	1.41%
Facebook Messenger	0.75%
Bluejeans	0.31%

Source: Statista

https://www.demandsage.com/microsoft-teams-statistics/

Analyzing Vendor Market Share

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https://www.demandsage.com/microsoft-teams-statistics/

Reverse Engineering Zoom


```
{
  "body":{
    "ABtoken":"3C45E3C9-7F73-2CD4-0C2A-61B0665E2AA7",
    "conID":"81423846-9F1F-D9EF-72D7-1265B18A9BBA",
    "confID":"0C71C7D6-C040-4363-94C1-3175DA4475F7",
    "e2eEncrypt":true,
    "elapsed":0,
    "encType":2,
    "hugeBO":true,
    "mediasdkConfig":{
      "iceServers":[
        {
          "credential":"rlYnbcRe9d5IqRiU/Ukst9QY0C2lidMWRmUQoWVvFoc=",
          "urls":"turns:turnsg02.cloud.zoom.us:443?transport=tcp",
          "username":"81423846-9F1F-D9EF-72D7-1265B18A9BBA:1741859664289"
        },
        {
          "credential":"y7rK3BSihbZ33NQeVtUsgynrdvJZpYRkUuukI6LaUpU=",
          "urls":"turns:turnsg01.cloud.zoom.us:443?transport=tcp",
          "username":"81423846-9F1F-D9EF-72D7-1265B18A9BBA:1741859664289"
        }
      ]
    },
    "meetingTopic":"Y29sYnkuZWxvdGVzdEBnbWFpbC5jb20ncyBab29tIE1lZXRpbmc",
    "mmrFeature":3204447728,
    "mmrFeatureEx":4501601879980014,
    "mmrFeatureExStr":"46161876203073679 18",
    "mn":"97774758416",
    "participantID":238757,
    "participantIDStr":"238757",
    "reportDomain":"zoomsg134224146206rwg.cloud.zoom.us",
```

Reverse Engineering Zoom


```
"mediasdkConfig":{
  "iceServers":[
    {
      "credential":"rlYnbcRe9d5IqRiU/Ukst9QY0C2lidMWRmUQoWVvFoc=",
      "urls":"turns:turnsg02.cloud.zoom.us:443?transport=tcp",
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      "credential":"y7rK3BSihbZ33NQeVtUsgynrdvJZpYRkUuukI6LaUpU=",
      "urls":"turns:turnsg01.cloud.zoom.us:443?transport=tcp",
      "username":"81423846-9F1F-D9EF-72D7-1265B18A9BBA:1741859664289"
    }
  ]
},
```

Zooming in on TURN

Firewall rules for Zoom Meetings and Webinars

Protocol	Ports	Source	Destination
			115.110.154.192/26
			115.114.56.192/26
			115.114.115.0/26
			115.114.131.0/26
			120.29.148.0/24
			121.244.146.0/27
			134.224.0.0/16
			137.66.128.0/17
			144.195.0.0/16
			147.124.96.0/19
			149.137.0.0/17
			156.45.0.0/17
			159.124.0.0/16
			160.1.56.128/25
			161.199.136.0/22
			162.12.232.0/22
			162.255.36.0/22
			165.254.88.0/23

```
→  ~ nslookup turnsg02.cloud.zoom.us
Server:         192.168.1.1
Address:        192.168.1.1#53

Non-authoritative answer:
Name:   turnsg02.cloud.zoom.us
Address: 134.224.147.10
```

source

Reverse Engineering Microsoft Teams

Response

Pretty Raw Hex Render \n

```
HTTP/2 200 OK
Cache-Control: no-cache, no-store
Content-Length: 186
Content-Type: application/json; charset=utf-8
Ms-Cv: lHKzC4UNR0280SVyWrqm+g.0
Strict-Transport-Security: max-age=31536000; includeSubDomains
Api-Supported-Versions: 1.0, 2.0
Server-Timing: reqlatency;dur=2
X-Cache: CONFIG_NOCACHE
X-Msedge-Ref: Ref A: C58D8123B9144A1CA7727C9B8DCD5BC8 Ref B: BKK30EDGE0511 Ref C: 2025-03-18T14:10:21Z
Date: Tue, 18 Mar 2025 14:10:21 GMT

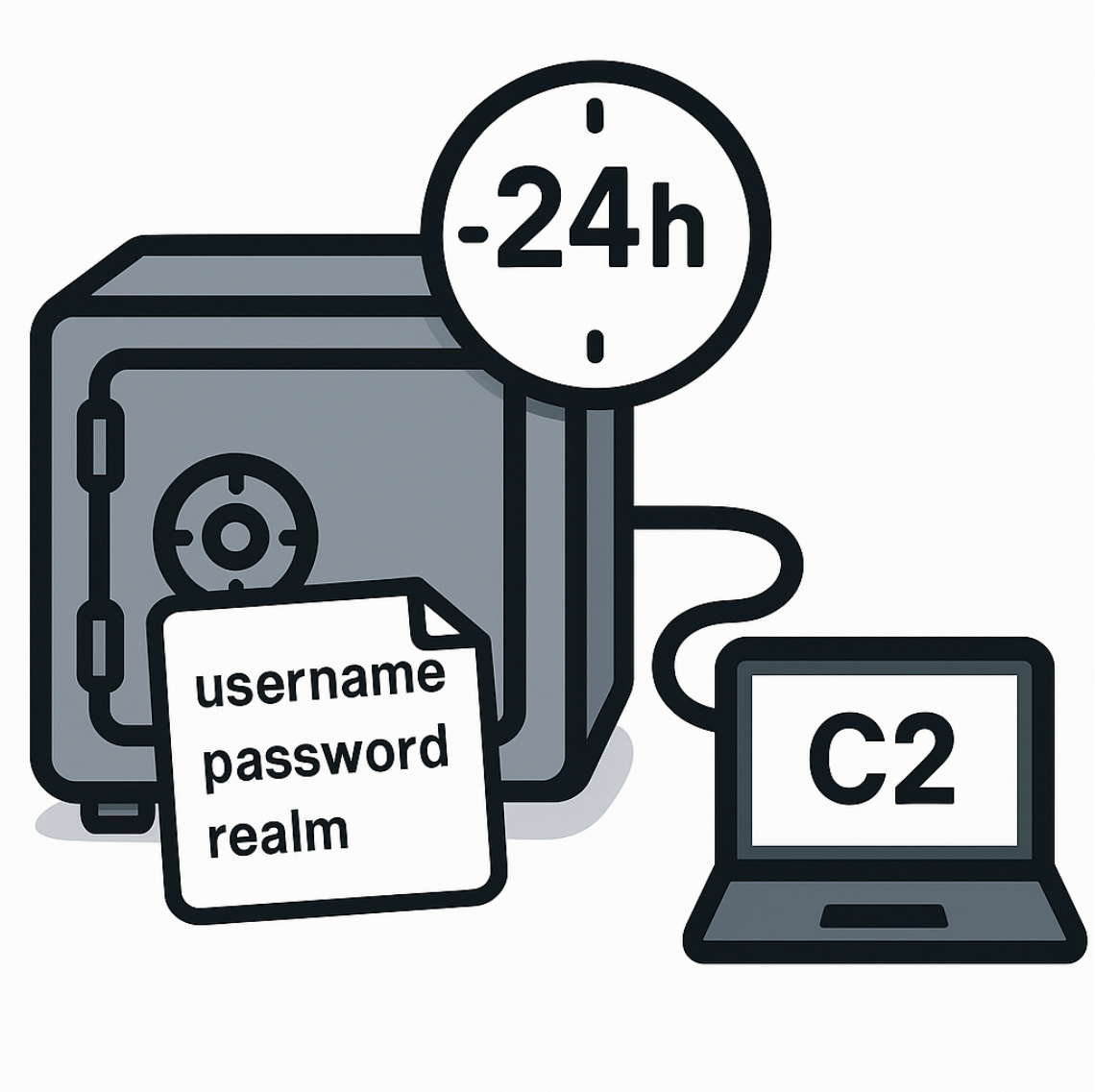
{
  "tokens":[
    {
      "realm":"\"rtcmedia\"",
      "username":"AgAAJKTmRIAB252Px+6sqQkexkR0PUDm73PwpkvWP3IAAAAAdg8G7t0lFUabmHtcNlO6RCa8OuA=",
      "password":"InNEjcnomvcTOpPEgPsA8OOmMkE="
    }
  ],
  "expires":604800
}
```

Reverse Engineering Microsoft Teams



Observations Regarding TURN Credentials

- Usually valid for a couple of days
- Complements an existing long-term channel
- Not tied to specific calls and credentials persist post-session
- Applies to common platforms like Zoom and Teams
- No install or meeting required on the victim side





What do we want to build?

- A short-lived tunnel launched from an existing implant
- Used briefly and mimics activity like a video-call
- Runs in parallel with long-term infrastructure
- Lightweight enough to avoid clogging that primary channel
- Disguised among high-traffic destinations (e.g., Zoom, Teams)

Most Visited Sites

Domain	Request Volume
google.com	82.450
microsoft.com	67.813
amazon.com	52.209
somebank.com	47.652

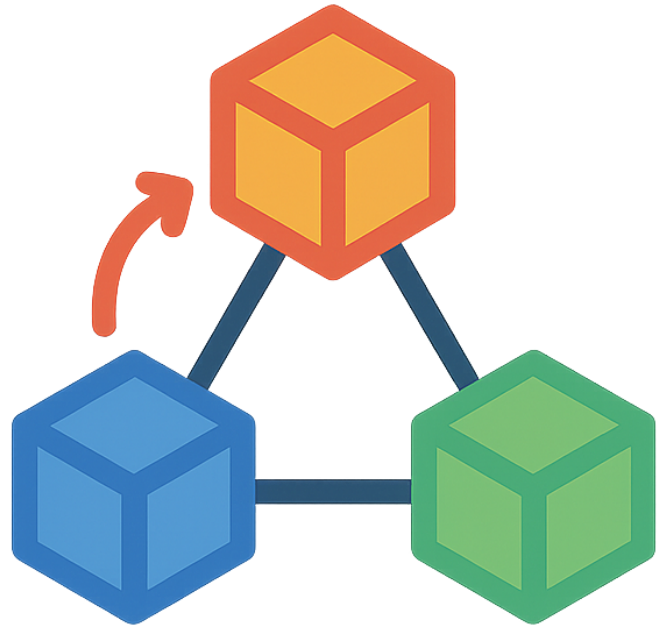
TURNt (TURN tunneler): A Tool for Short-Term C2



https://github.com/praetorian-inc/turnt

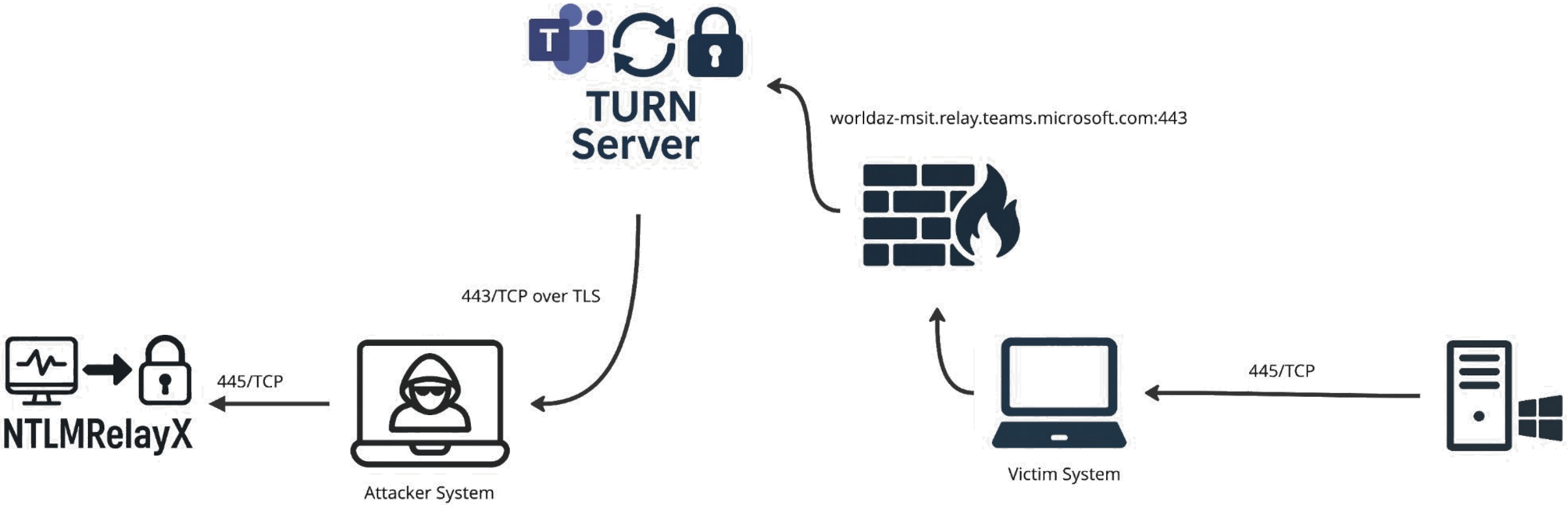
Use-Cases and Capabilities

- Fast tunnel setup during assumed breach scenarios
- No need to provision infrastructure in advance
- Operates from operator laptop or disposable VDI
- Ideal for decentralized red team operations
- Lightweight, flexible, and serverless by design

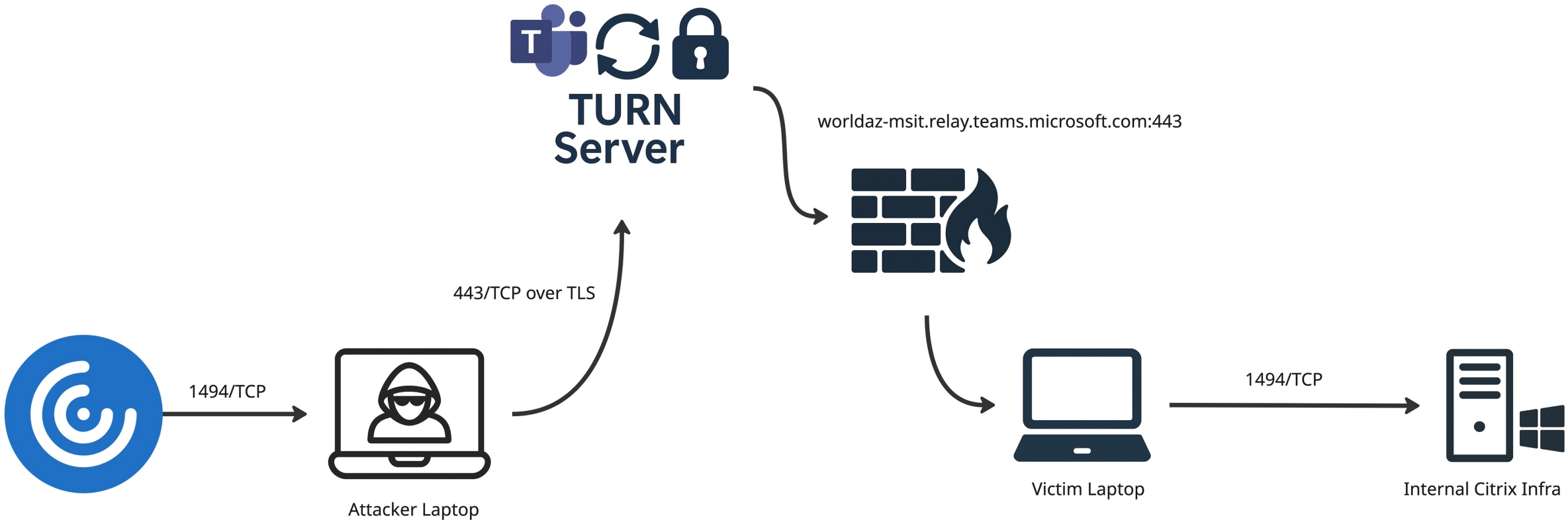


Decentralized C2

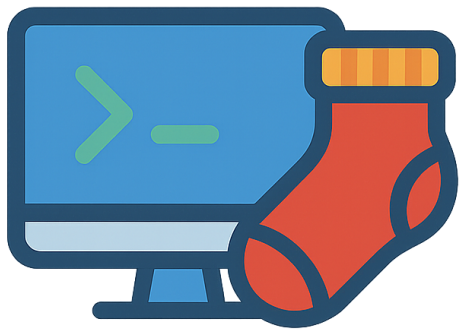
Remote Port Forwarding



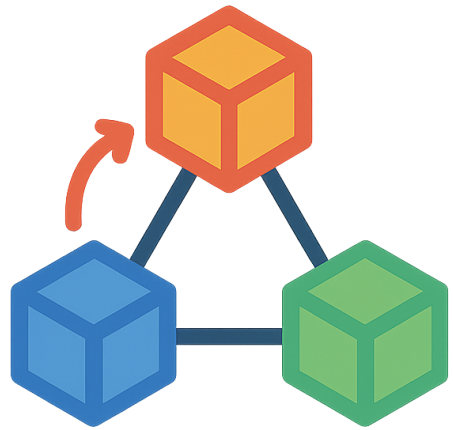
Local Port Forwarding



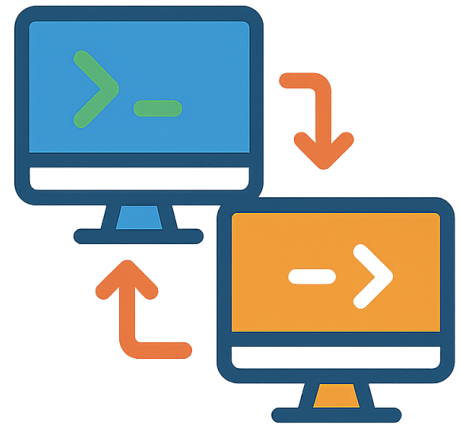
Use-Cases and Capabilities



SOCKS Proxying



Decentralized C2



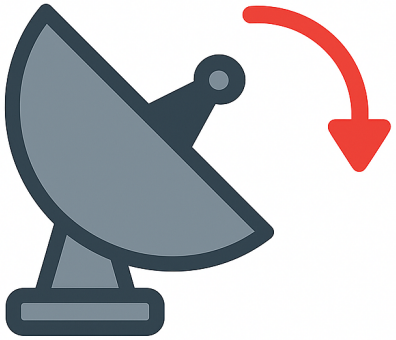
Local & Remote Port-Forwarding

Zoom Demo Example Scenario

- Obtaining credentials from Zoom
- Victim doesn’t need to do anything
- Laptop is the operator laptop
- Example victim system is GCP virtual machine
- Demo downloading a file through the channel



TURNt Controller



TURNt Relay

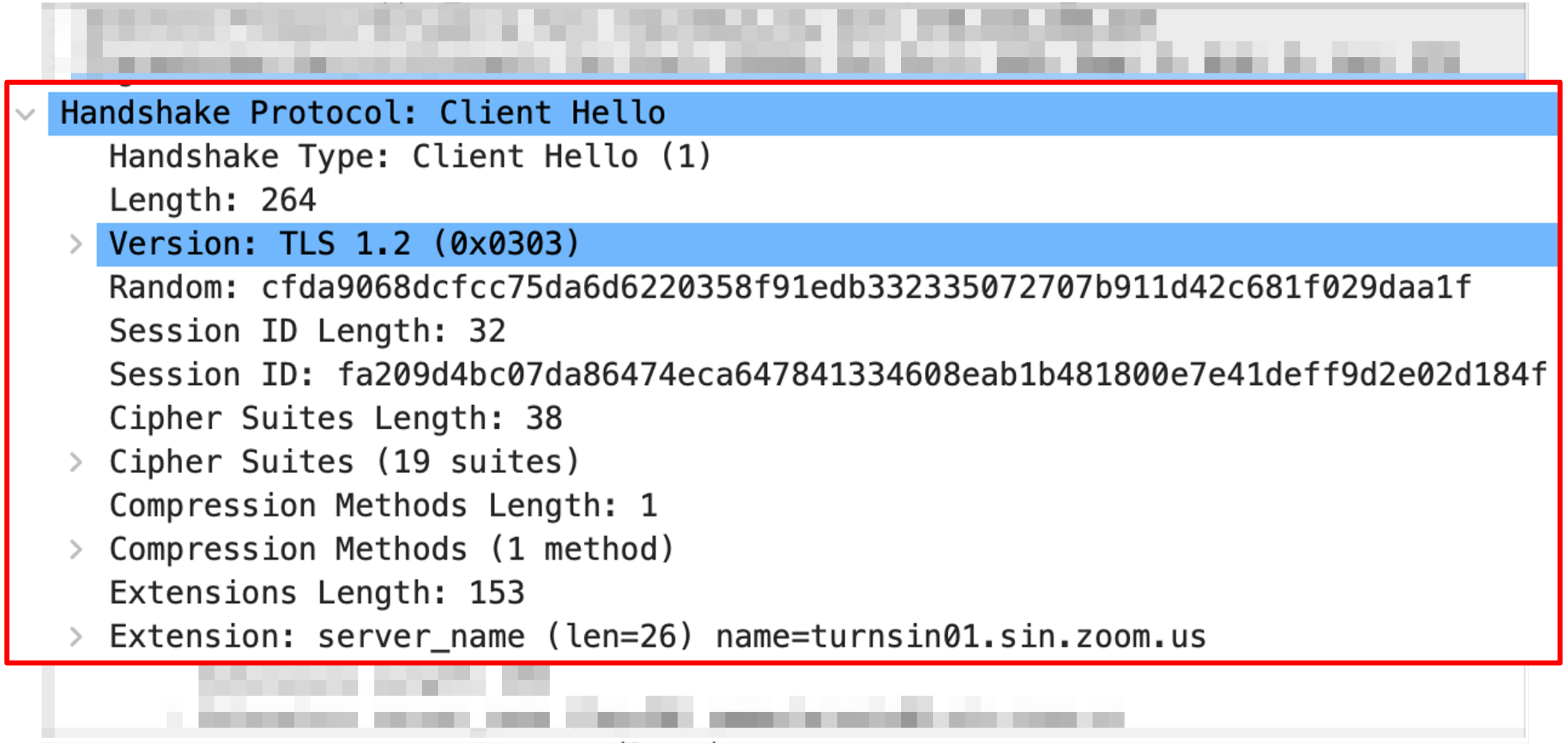
Zoom Video Demo

demo video

Examining Wireshark Traffic (Zoom)

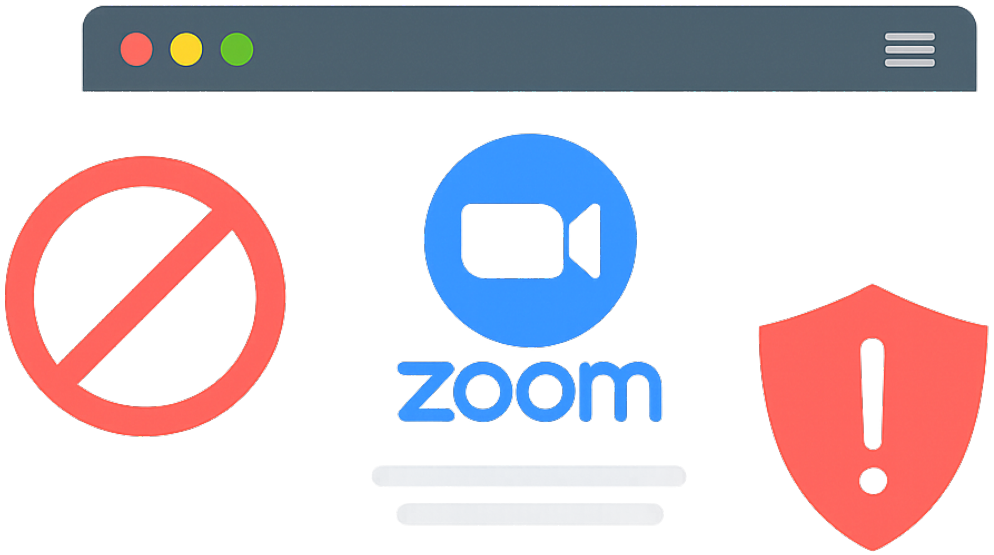
```
> Internet Protocol Version 4, Src: 192.168.1.43, Dst: 170.114.166.217
> Transmission Control Protocol, Src Port: 61862, Dst Port: 443, Seq: 1, Ack: 1, Len: 273
v Transport Layer Security
  v TLSv1.3 Record Layer: Handshake Protocol: Client Hello
      Content Type: Handshake (22)
      Version: TLS 1.0 (0x0301)
      Length: 268
    v Handshake Protocol: Client Hello
        Handshake Type: Client Hello (1)
        Length: 264
      > Version: TLS 1.2 (0x0303)
        Random: cfda9068dcfcc75da6d6220358f91edb332335072707b911d42c681f029daa1f
        Session ID Length: 32
        Session ID: fa209d4bc07da86474eca647841334608eab1b481800e7e41deff9d2e02d184f
        Cipher Suites Length: 38
      > Cipher Suites (19 suites)
        Compression Methods Length: 1
      > Compression Methods (1 method)
        Extensions Length: 153
      > Extension: server_name (len=26) name=turnsin01.sin.zoom.us
```

Examining Wireshark Traffic (Zoom)



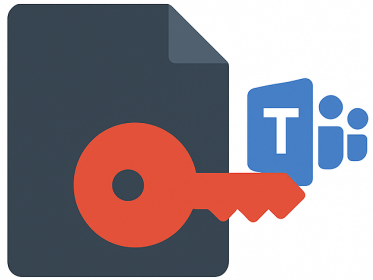
Zoom Recent Mitigations

- Pushed out a mitigation on Sunday
- Prevents peer-to-peer connections via TURN infra
- Restricted to client and media server ranges
- Haven’t dug into potential bypasses
- Feasibility depends on the provider

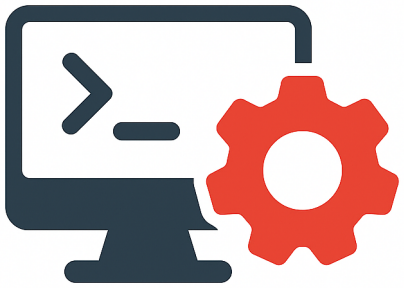


Microsoft Teams Demo

- Show automated retrieval of TURN credentials from Microsoft
- Demonstrate a speed test showing a 100 MB file download
- Demonstrate remote port-forwarding capability
- Lab uses my local laptop and a demo virtual machine in GCP

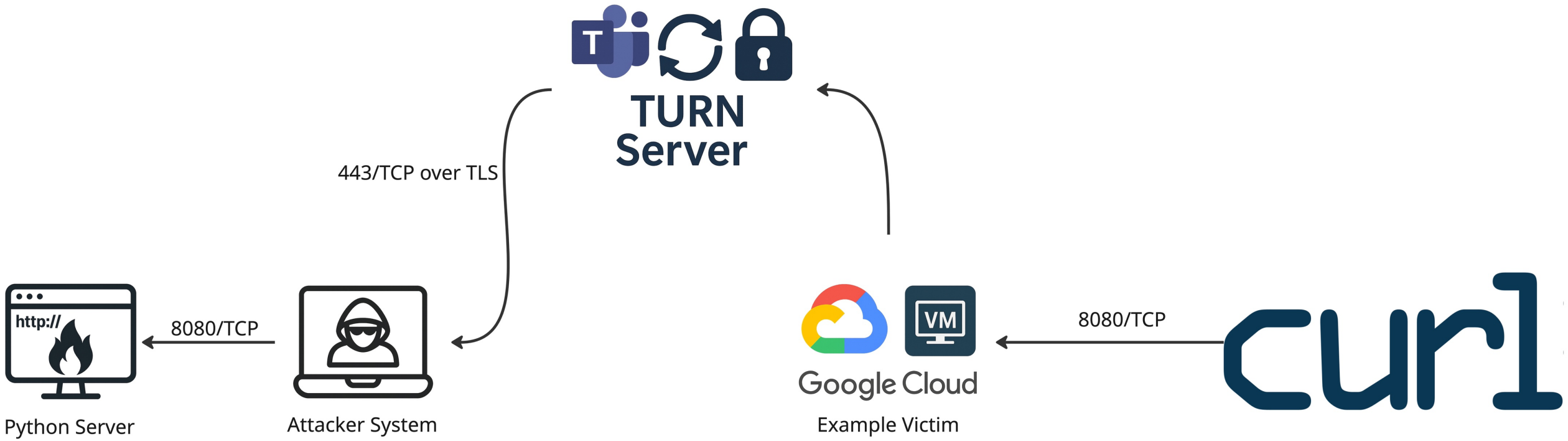


TURNt Credentials



TURNt Admin

Microsoft Teams Demo



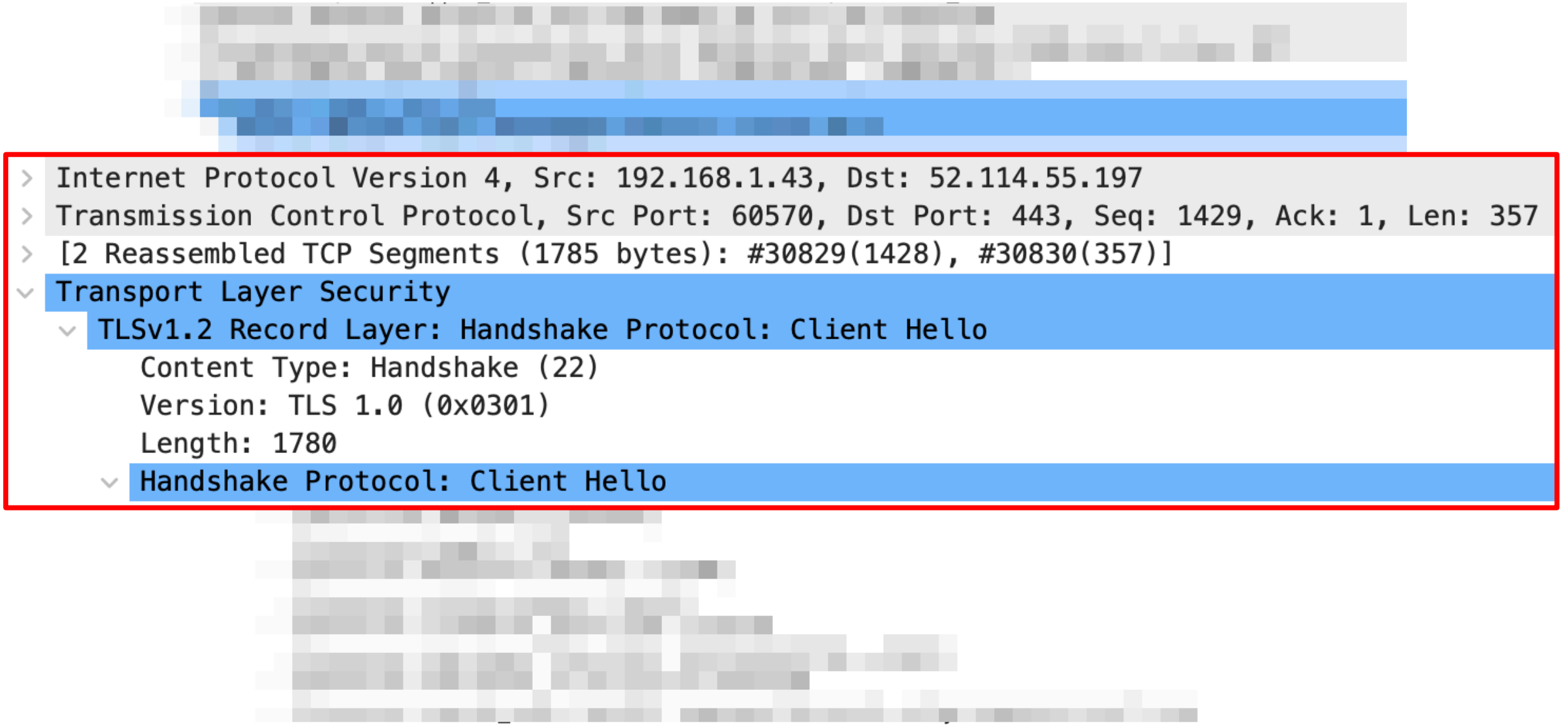
Microsoft Teams Video Demo

demo video

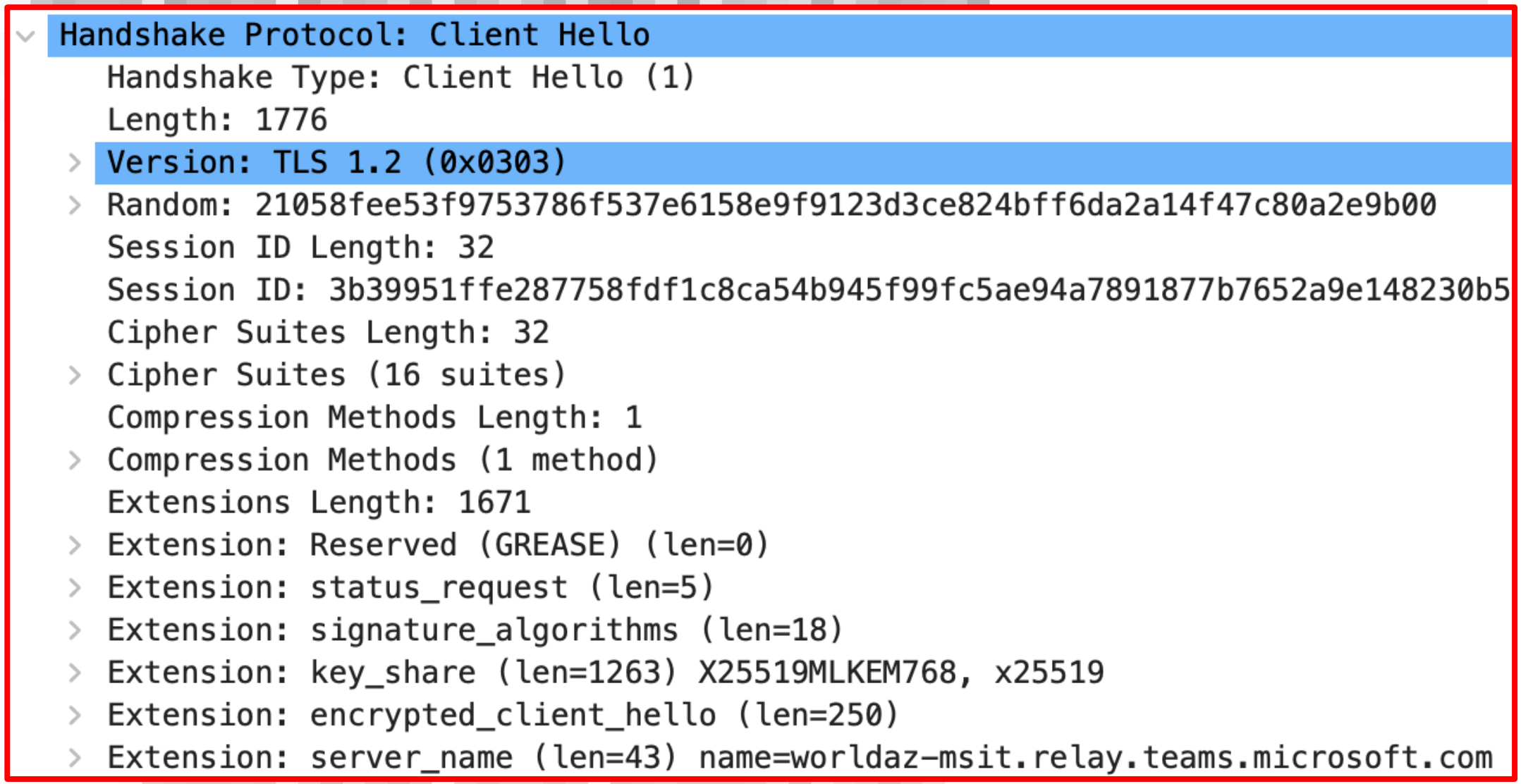
Examining Wireshark Traffic (Microsoft Teams)

```
> Internet Protocol Version 4, Src: 192.168.1.43, Dst: 52.114.55.197
> Transmission Control Protocol, Src Port: 60570, Dst Port: 443, Seq: 1429, Ack: 1, Len: 357
> [2 Reassembled TCP Segments (1785 bytes): #30829(1428), #30830(357)]
v Transport Layer Security
  v TLSv1.2 Record Layer: Handshake Protocol: Client Hello
      Content Type: Handshake (22)
      Version: TLS 1.0 (0x0301)
      Length: 1780
    v Handshake Protocol: Client Hello
        Handshake Type: Client Hello (1)
        Length: 1776
      > Version: TLS 1.2 (0x0303)
      > Random: 21058fee53f9753786f537e6158e9f9123d3ce824bff6da2a14f47c80a2e9b00
        Session ID Length: 32
        Session ID: 3b39951ffe287758fdf1c8ca54b945f99fc5ae94a7891877b7652a9e148230b5
        Cipher Suites Length: 32
      > Cipher Suites (16 suites)
        Compression Methods Length: 1
      > Compression Methods (1 method)
        Extensions Length: 1671
      > Extension: Reserved (GREASE) (len=0)
      > Extension: status_request (len=5)
      > Extension: signature_algorithms (len=18)
      > Extension: key_share (len=1263) X25519MLKEM768, x25519
      > Extension: encrypted_client_hello (len=250)
      > Extension: server_name (len=43) name=worldaz-msit.relay.teams.microsoft.com
```

Examining Wireshark Traffic (Microsoft Teams)



Examining Wireshark Traffic (Microsoft Teams)




IXP
BGP
BGP
DATA
CENTER
TIER 2 ISP
TIER 3 ISP



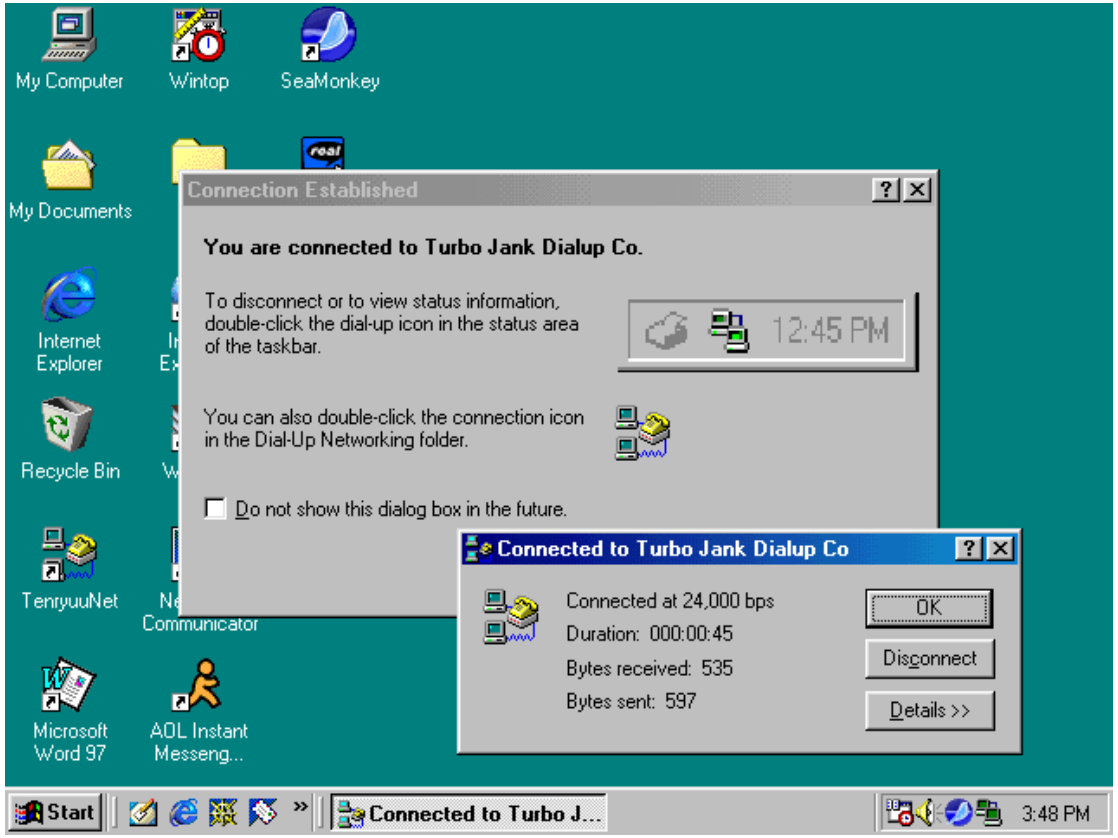
DISCLAIMER

Compromising the Helpdesk

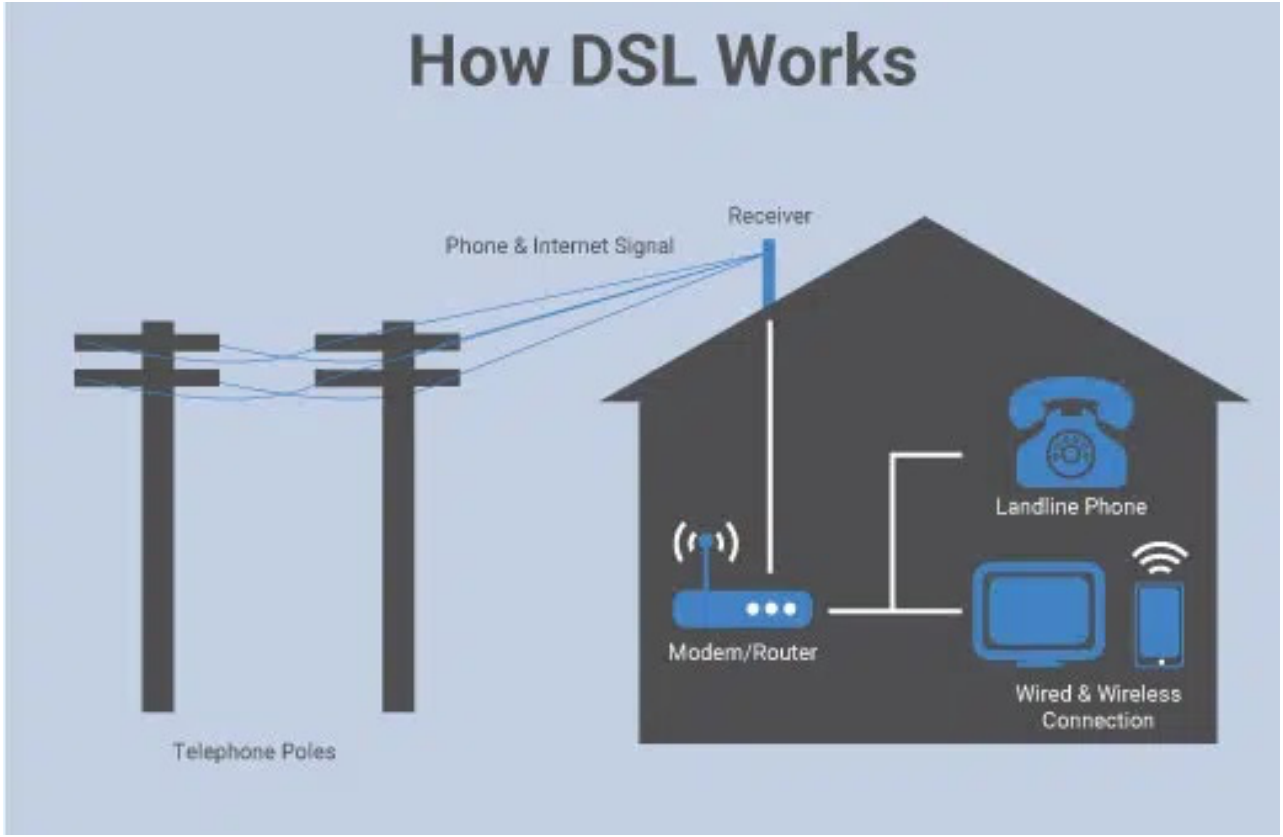
- Helpdesk accounts are often privileged easy targets
- Common red team foothold especially in large orgs
- Frequently outsourced overseas locations
- Ran into slow unreliable tunnel from compromised users
- Example: Slow tunneling through helpdesk employee in India



Last Mile Delivery is the Traditional Bottleneck



source



source

Fiber to the Home Build Out

Best **1 Gbps** broadband plans for you

₹50 / Month, one-time benefit

₹ 4200 / Month

X 3 Months = ₹ 12600 + Gst

Upload/Download = **1 Gbps**

Unlimited Data, Unstoppable Speed

Enjoy Entertainment Bundle

OTTs - ALL



& More

Channels - 200+



More Details

Get Started

₹50 / Month, one-time benefit

~~₹4200~~

₹ 3900 / Month

X 6 Months = ₹ 23400 + Gst

Upload/Download = **1 Gbps**

Unlimited Data, Unstoppable Speed

Enjoy Entertainment Bundle

OTTs - ALL



& More

Channels - 200+



Free Wi-Fi 6 router

More Details

Get Started

₹50 / Month, one-time benefit

~~₹4200~~

₹ 3600 / Month

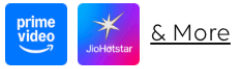
X 12 Months = ₹ 43200 + Gst

Upload/Download = **1 Gbps**

Unlimited Data, Unstoppable Speed

Enjoy Entertainment Bundle

OTTs - ALL



& More

Channels - 200+

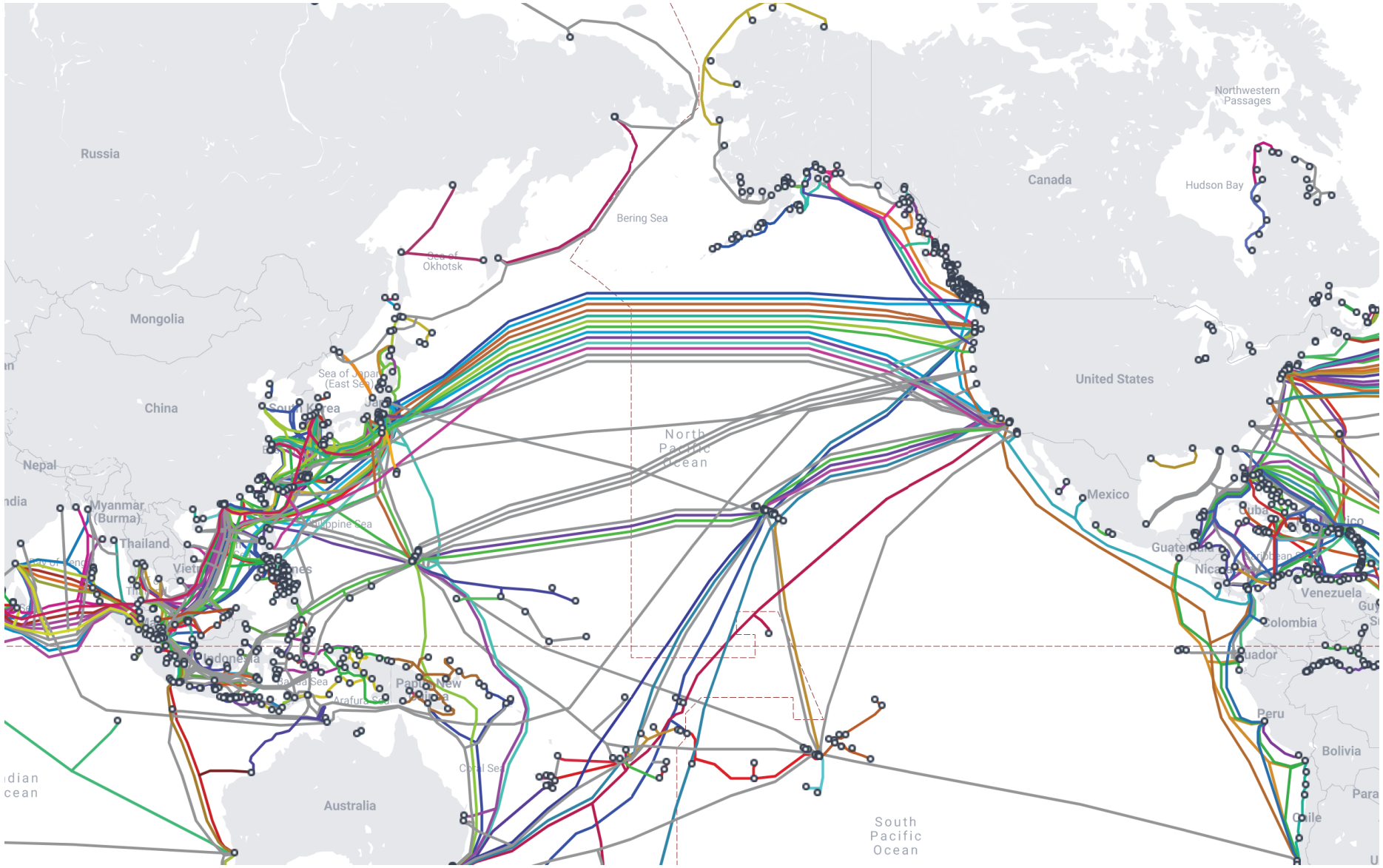


Free Wi-Fi 6 + Mesh router

More Details

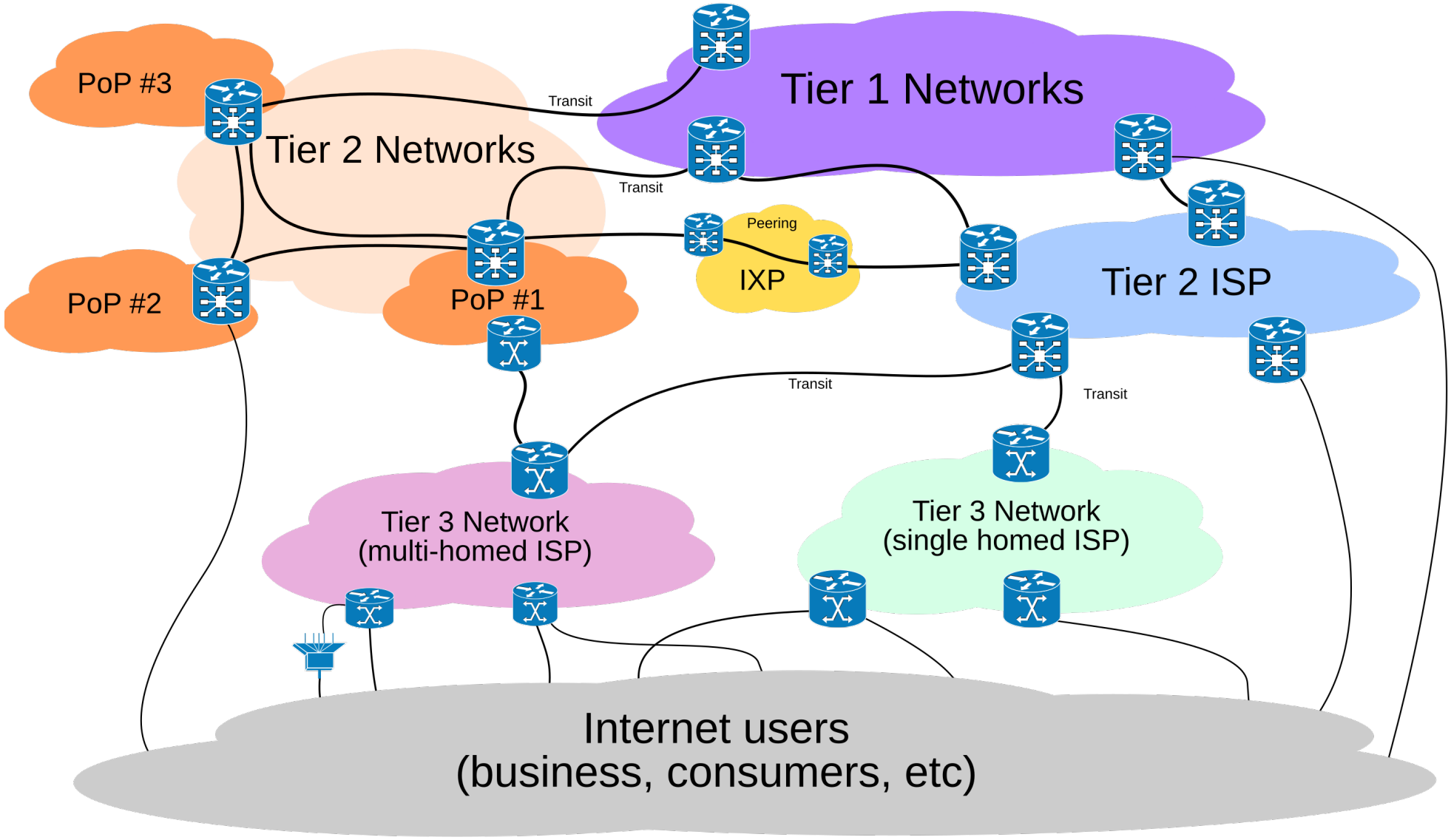
Get Started

Global Fiber Connectivity Map



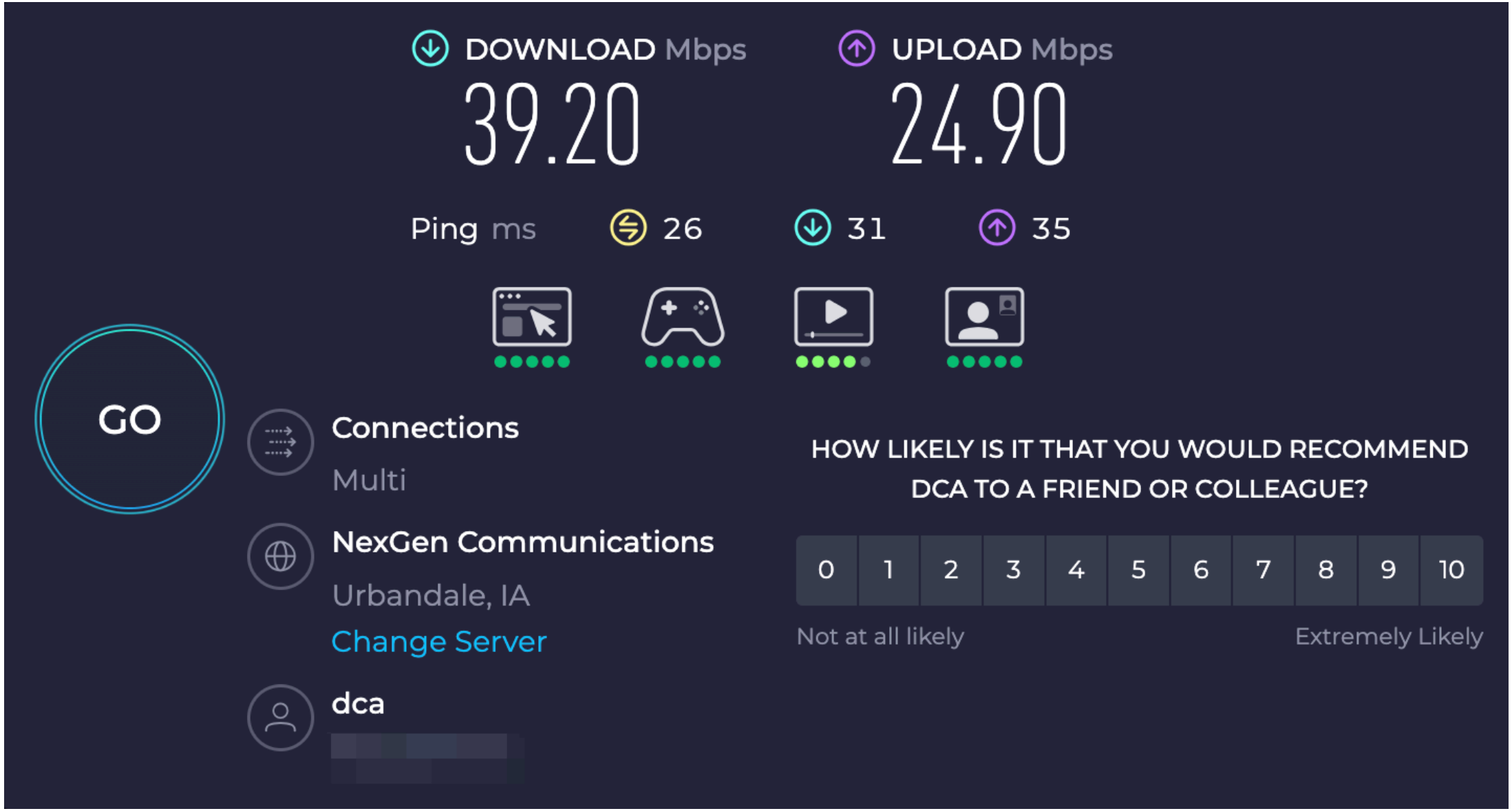
source

Internet Routing is a Lot Messier Than Expected

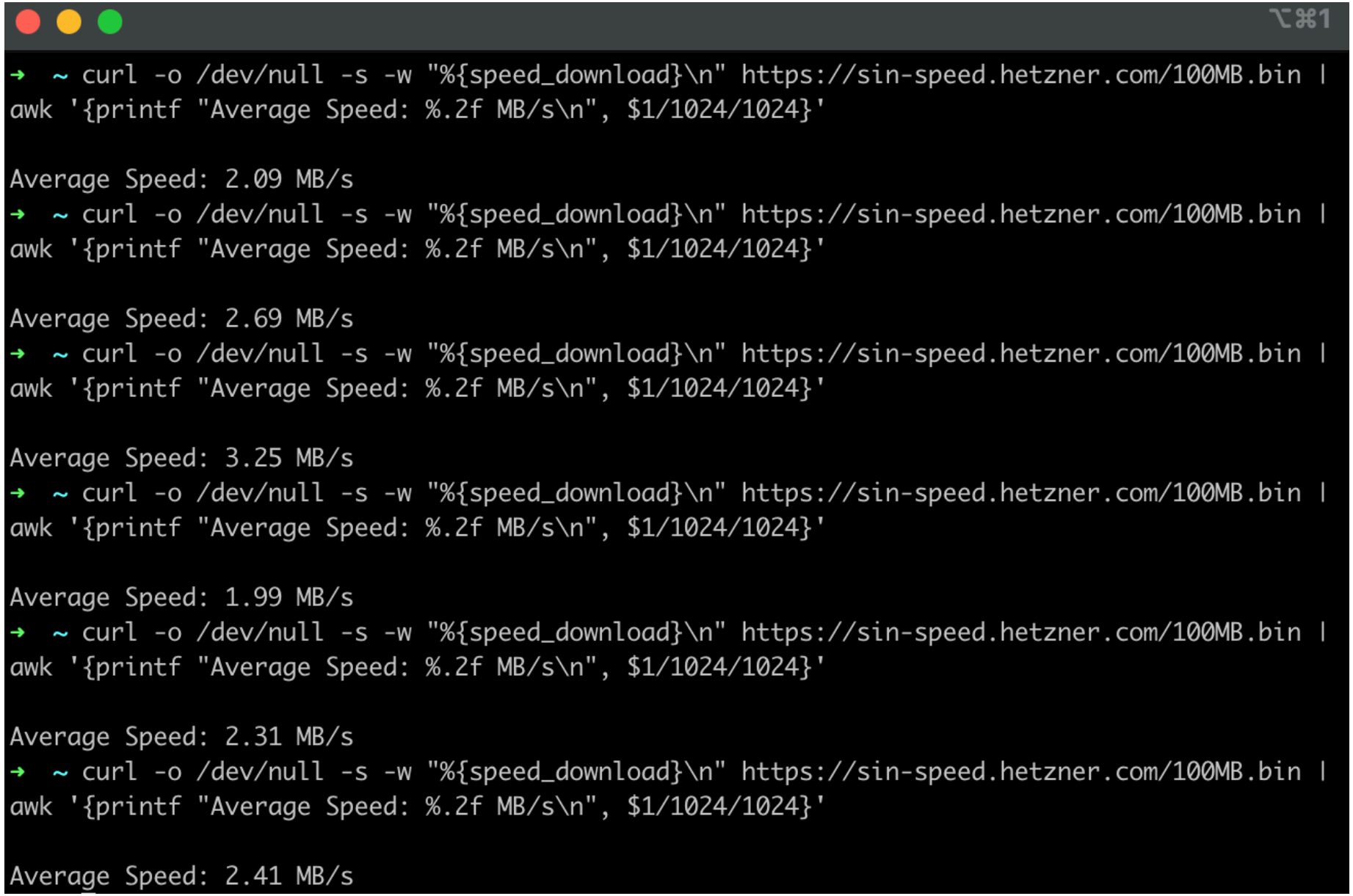


source

Routing Can Impact Performance Significantly (ExpressVPN)



Routing Can Impact Performance Significantly (ExpressVPN)



Routing Can Impact Performance Significantly (ExpressVPN)

```
→  ~ curl -o /dev/null -s -w "%{speed_download}\n" https://sin-speed.hetzner.com/100MB.bin |
awk '{printf "Average Speed: %.2f MB/s\n", $1/1024/1024}'

Average Speed: 4.11 MB/s
→  ~ curl -o /dev/null -s -w "%{speed_download}\n" https://sin-speed.hetzner.com/100MB.bin |
awk '{printf "Average Speed: %.2f MB/s\n", $1/1024/1024}'

Average Speed: 4.52 MB/s
→  ~ curl -o /dev/null -s -w "%{speed_download}\n" https://sin-speed.hetzner.com/100MB.bin |
awk '{printf "Average Speed: %.2f MB/s\n", $1/1024/1024}'

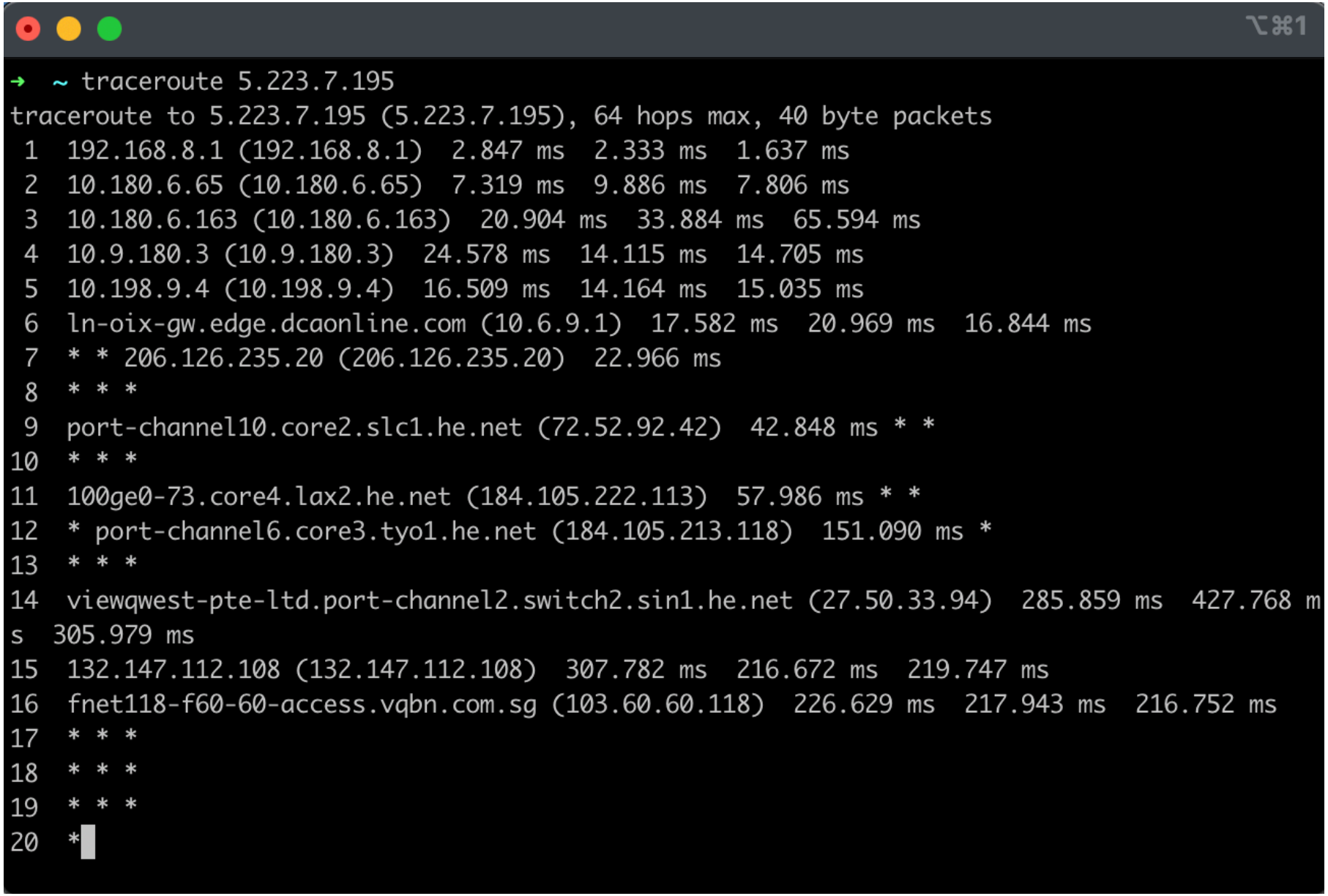
Average Speed: 4.14 MB/s
→  ~ curl -o /dev/null -s -w "%{speed_download}\n" https://sin-speed.hetzner.com/100MB.bin |
awk '{printf "Average Speed: %.2f MB/s\n", $1/1024/1024}'

Average Speed: 4.15 MB/s
→  ~ curl -o /dev/null -s -w "%{speed_download}\n" https://sin-speed.hetzner.com/100MB.bin |
awk '{printf "Average Speed: %.2f MB/s\n", $1/1024/1024}'

Average Speed: 4.13 MB/s
→  ~ curl -o /dev/null -s -w "%{speed_download}\n" https://sin-speed.hetzner.com/100MB.bin |
awk '{printf "Average Speed: %.2f MB/s\n", $1/1024/1024}'

Average Speed: 3.95 MB/s
```

Routing Can Impact Performance Significantly (ExpressVPN)



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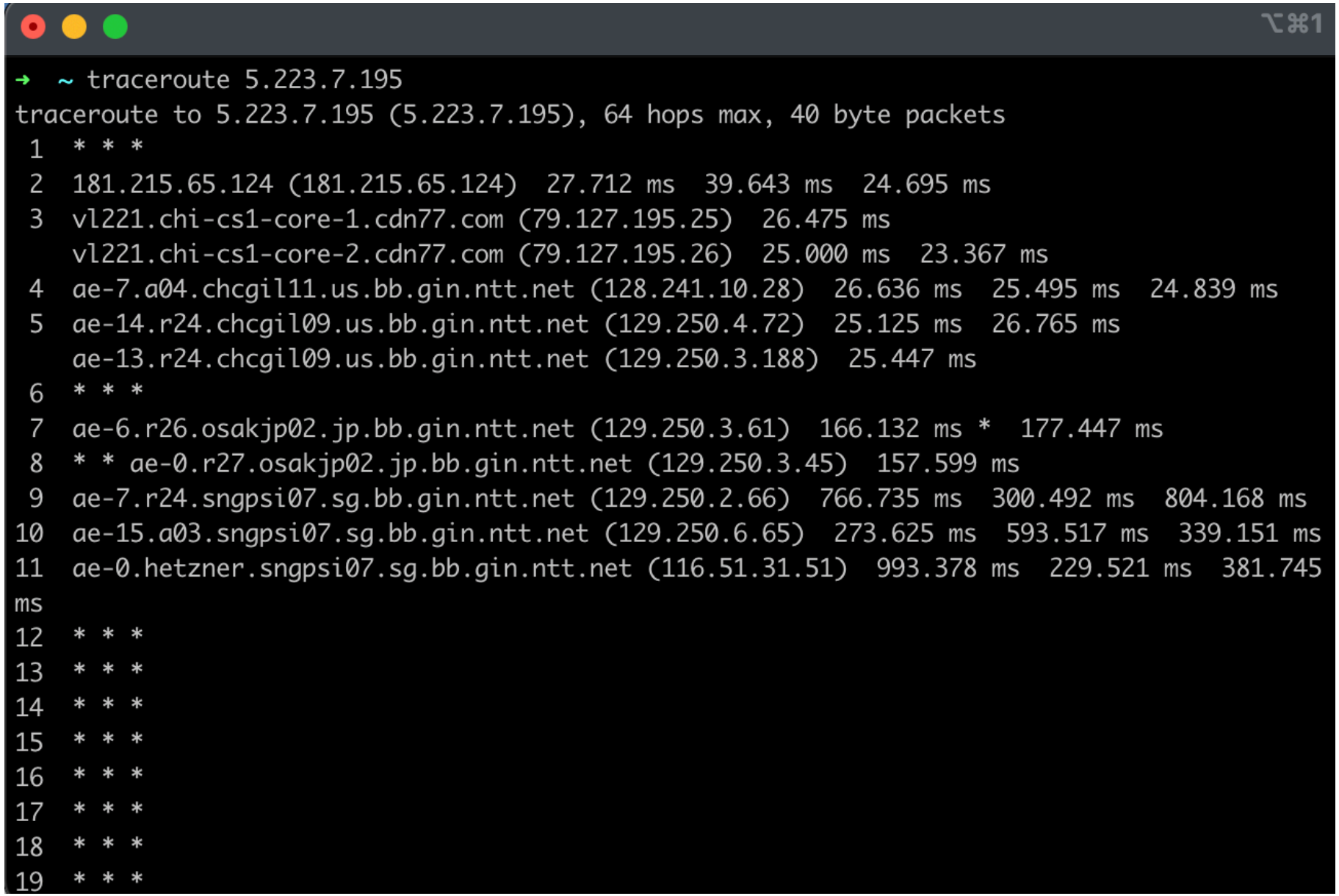
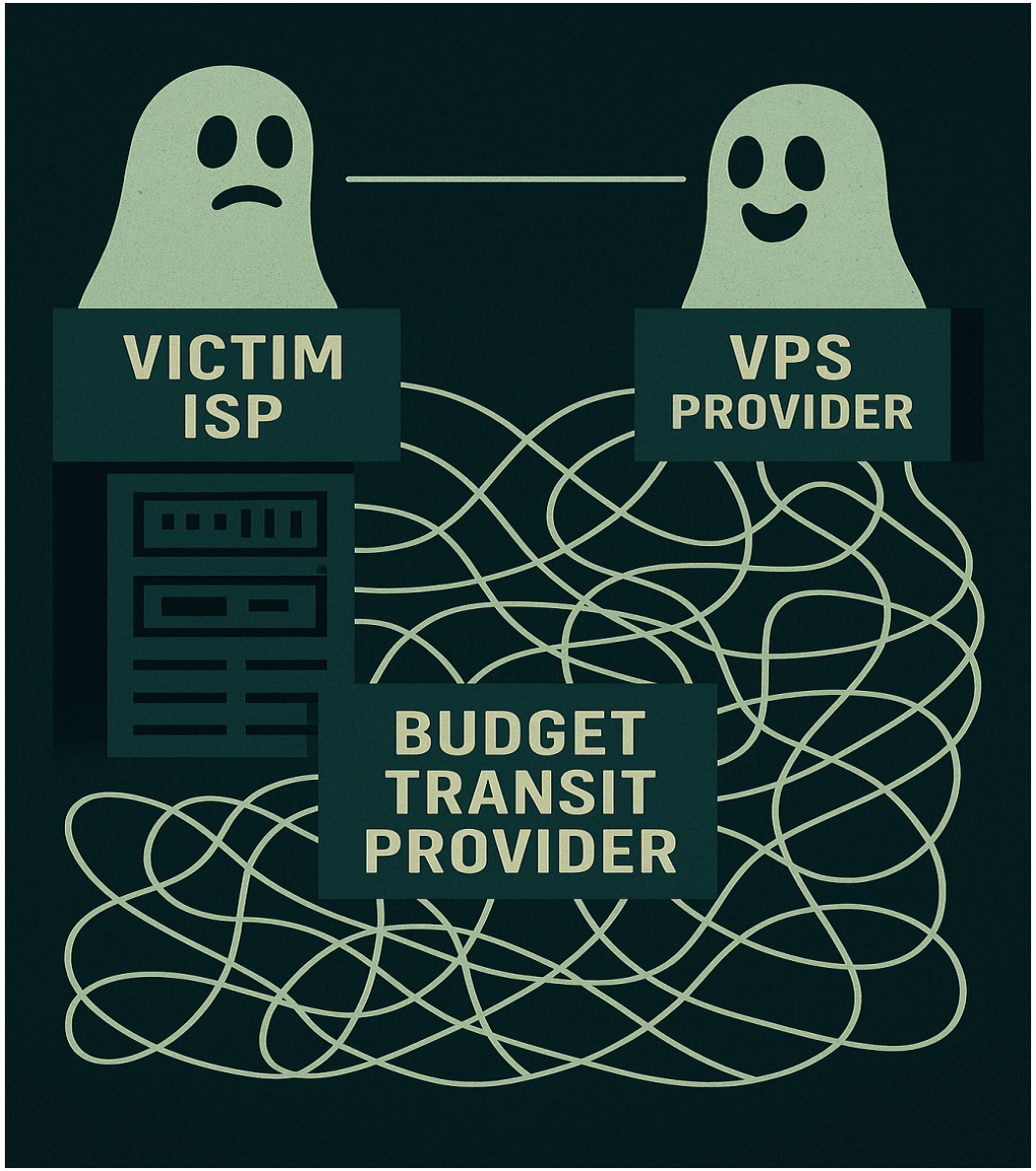


Peering Can Be More Important Than Uplink Speed

- Example: Imagine trying to exfil 10GB of data from a compromise webserver
- Good peering beats raw bandwidth for tunnel speed
- Exfil to servers with good peering with victim internet provider
- Budget hosting providers often cheap on transit
- Some region have fast local fiber but bad global peering
- This could be an entire talk



Performance Killers When Tunneling over TCP

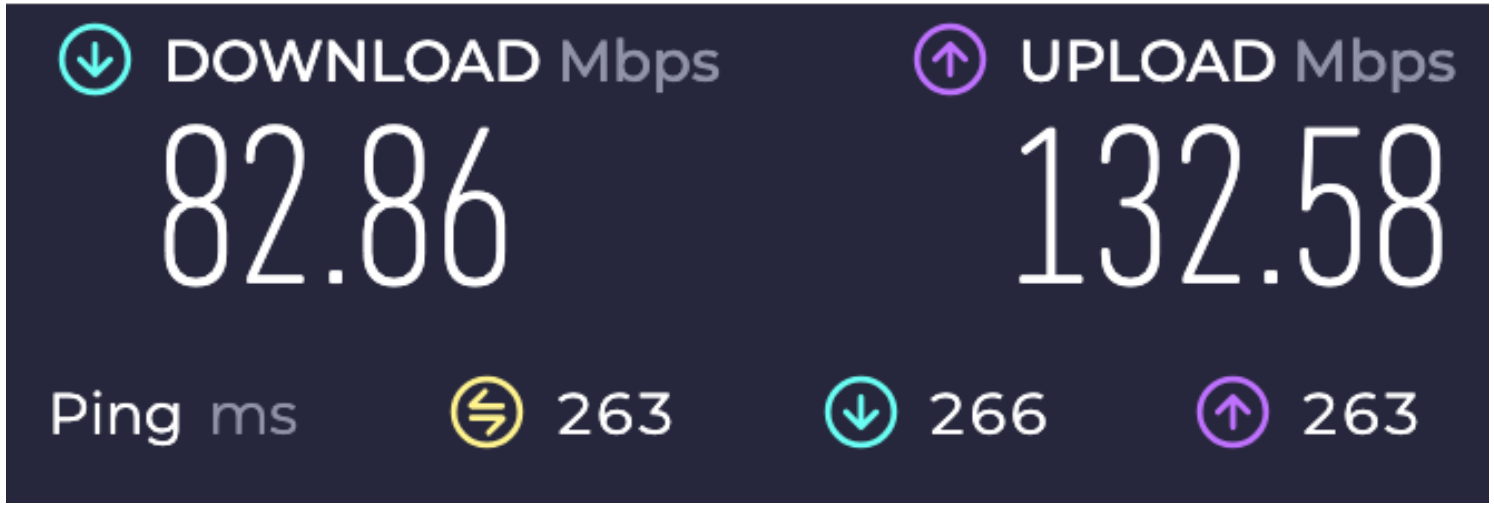


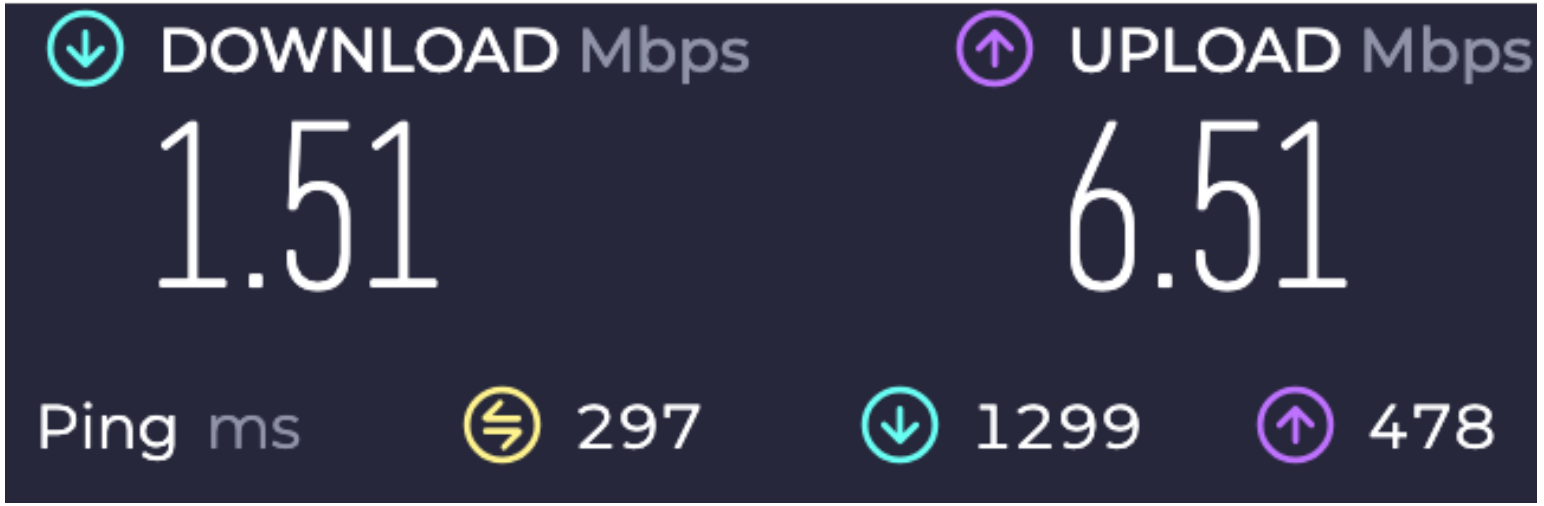
TCP Meltdown



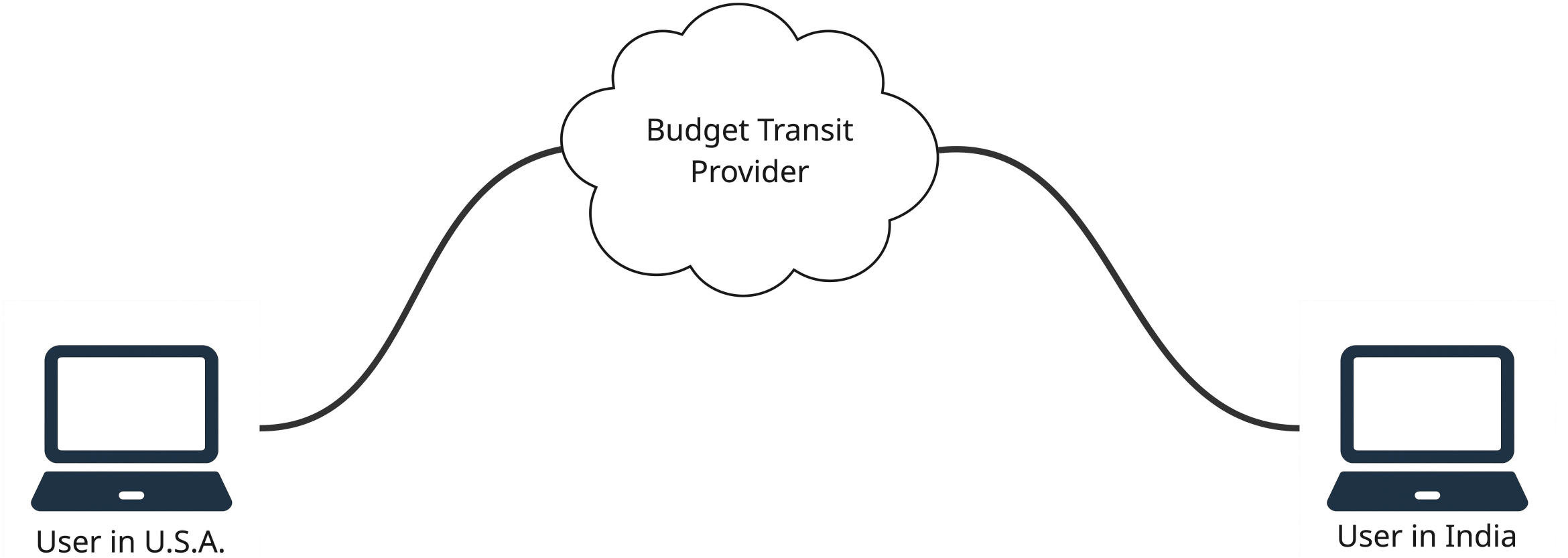
Head-Of-Line Blocking

TCP Meltdown in Action





Peer to Peer Isn't Always the Most Efficient



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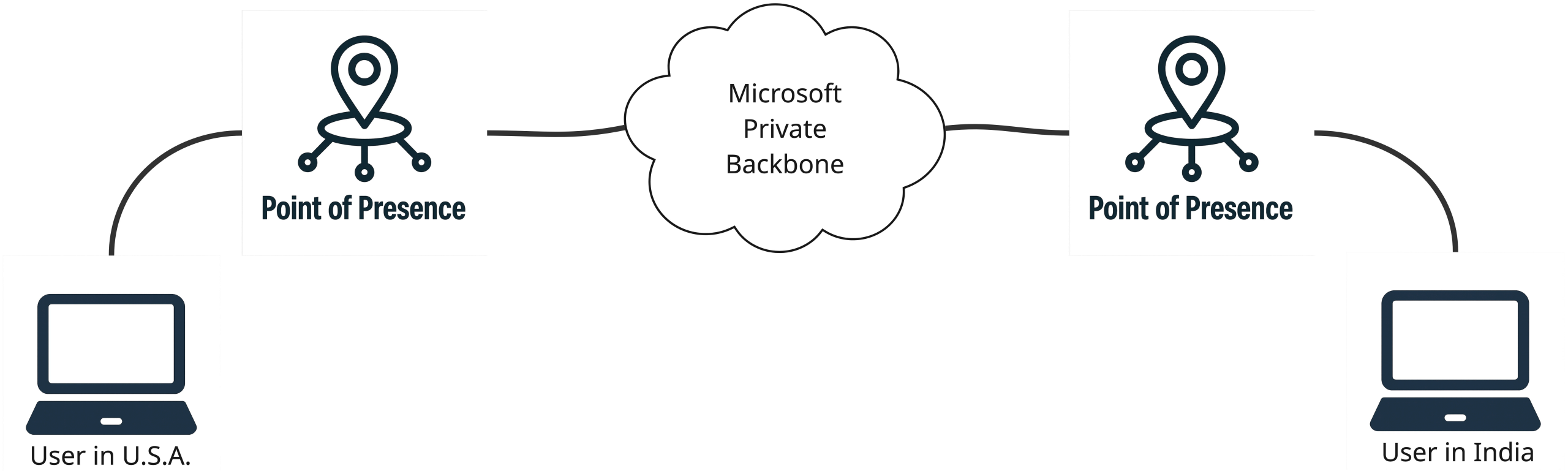
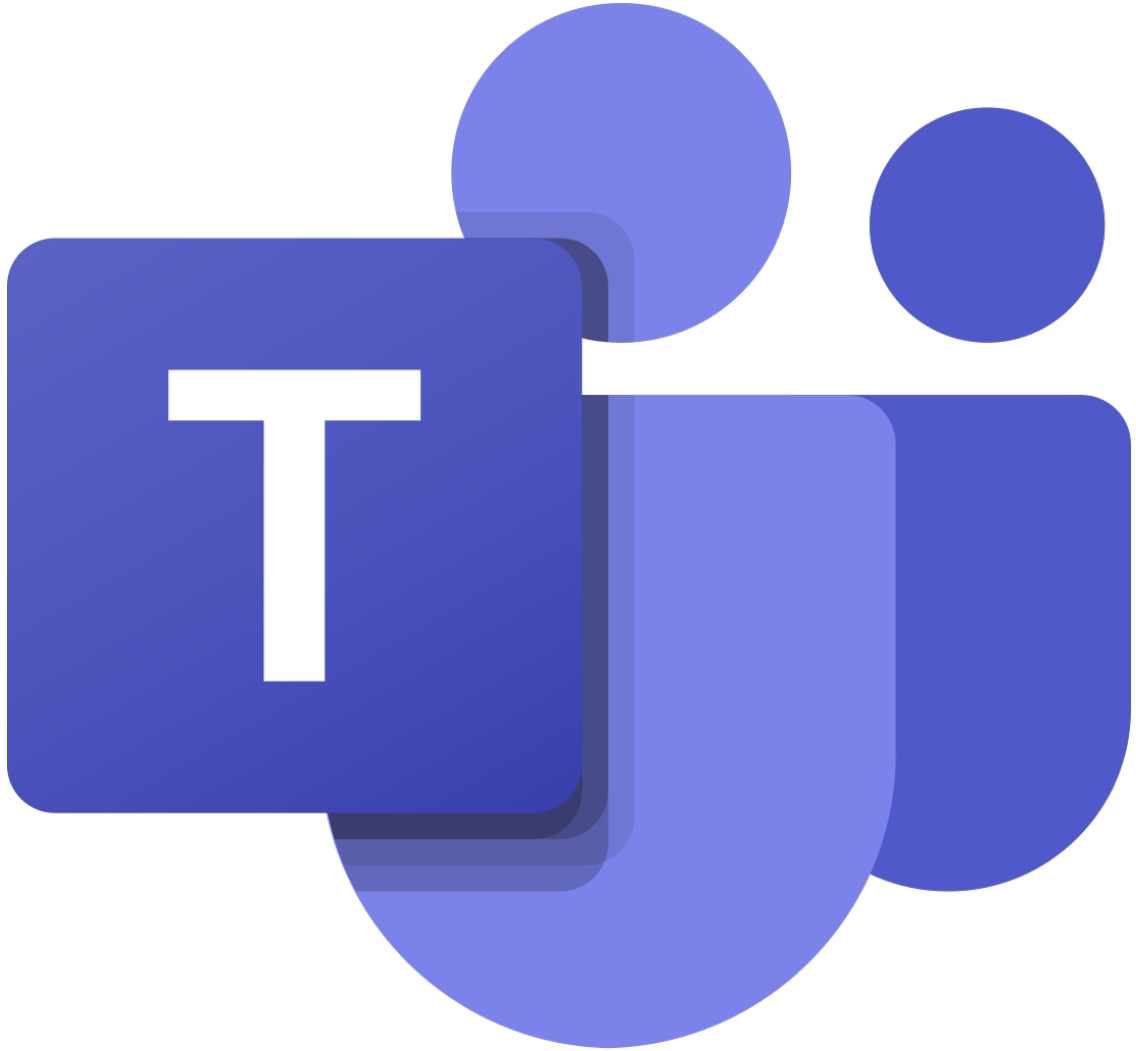


Recommend: Microsoft Teams for Cross Continent Tunneling





Questions?

Blog Post

Tool Release

LinkedIn

Blog Post: https://www.praetorian.com/blog/ghost-calls-abusing-web-conferencing-for-covert-command-and-control-part-1/

GitHub: https://github.com/praetorian-inc/turnt

LinkedIn: https://www.linkedin.com/in/adam-crosser-366263265

X: https://x.com/UNC1739