Domain Fronting is Dead, Long Live Domain Fronting

Using TLS 1.3 to evade censors, bypass network defenses, and blend in with the noise

Erik Hunstad

SIXGEN | A Full-Spectrum Cyber Solutions Company

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Outline

0| **Domain Fronting 101**
- **HTTP Basics**
- **HTTPS Basics**
- **Classic Domain Fronting**

1| **TLS 1.3 + ESNI for Domain Hiding**
- **DNS over TLS/HTTPS**
- **TLS 1.3 with ESNI**
- **Domain Hiding**

2| **Demos**
- **ESNI for Domain Hiding**
- **Bypassing SNI and full decrypt firewalls**
- **Alternate protocols**

3| **What is Blue to do?**

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Domain Fronting 101

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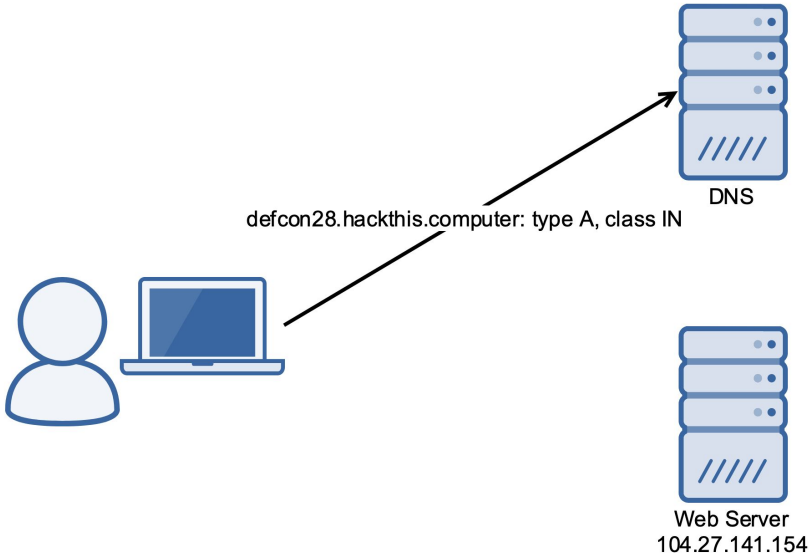
Domain Fronting 101

- ~~If you wish to make an apple pie from scratch, you must first invent the universe~~
- To understand Domain Fronting, you must first understand HTTP over TLS (aka HTTPS)
- Server Name Indication (SNI) allows multiple sites to be hosted on the same IP
- TLS 1.3 enables encrypted certificates and encrypted Server Name Identification (ESNI)
- DNS over TLS or HTTPS + TLS 1.3 = domain fronting 2.0 or “domain hiding”

HTTP Basics

- First, a user requests the IP of a server via DNS
- This is an unencrypted packet sent to UDP port 53



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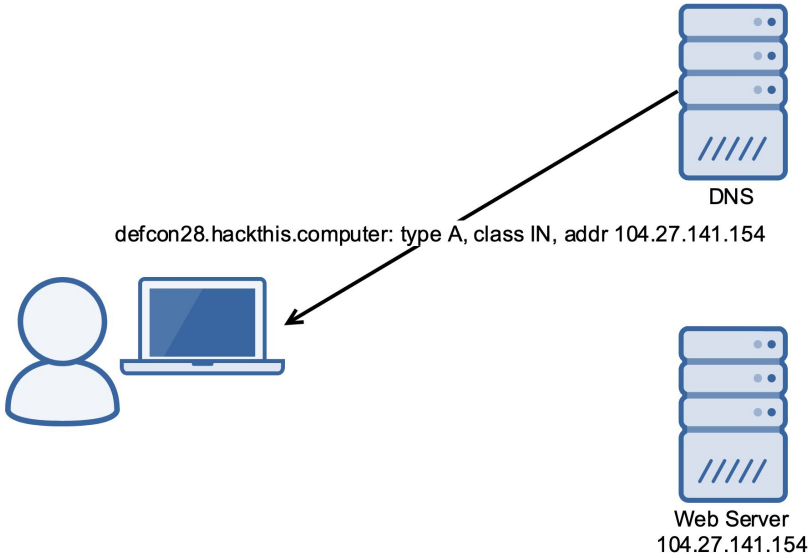
HTTP Basics

- The DNS server responds with an IP address
- The response is also unencrypted



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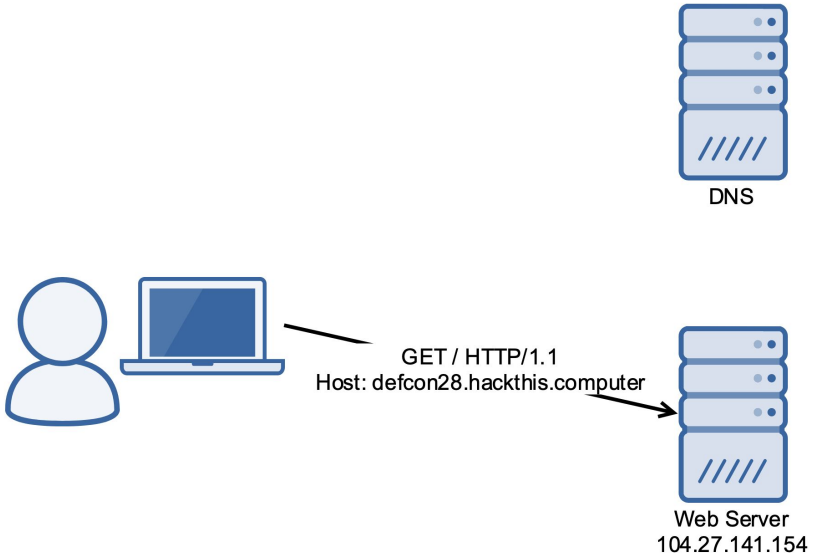
HTTP Basics

- The user sends a GET request, using the domain in the “Host” header
- TCP port 80 - unencrypted



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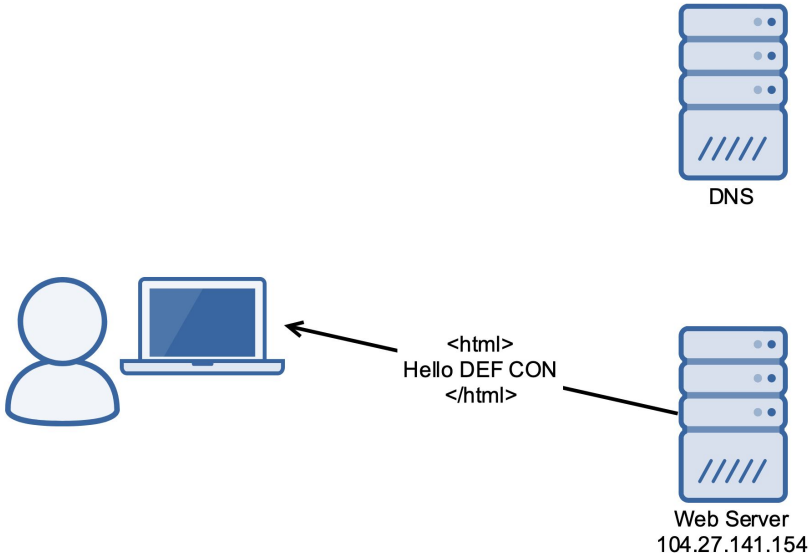
HTTP Basics

- The server responds with HTML content



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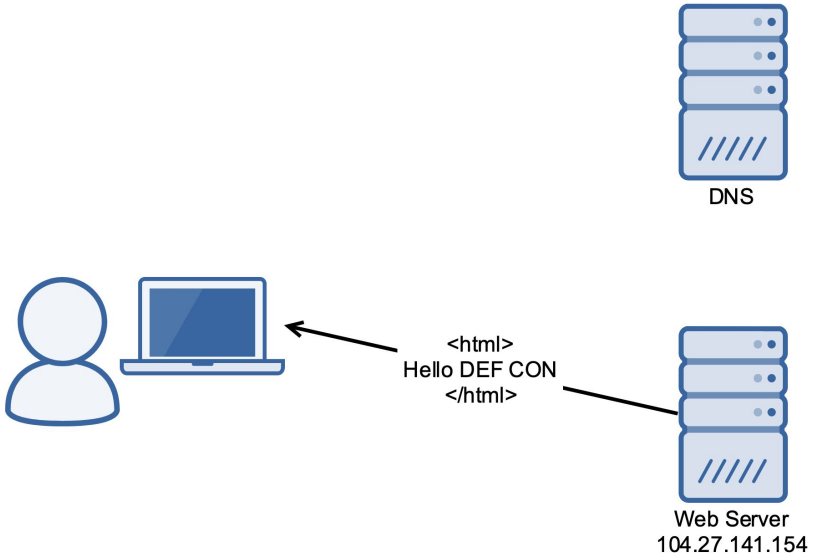
HTTP Basics

- Obviously bad because nothing is encrypted
- Both the DNS and HTTP request and response are in plaintext



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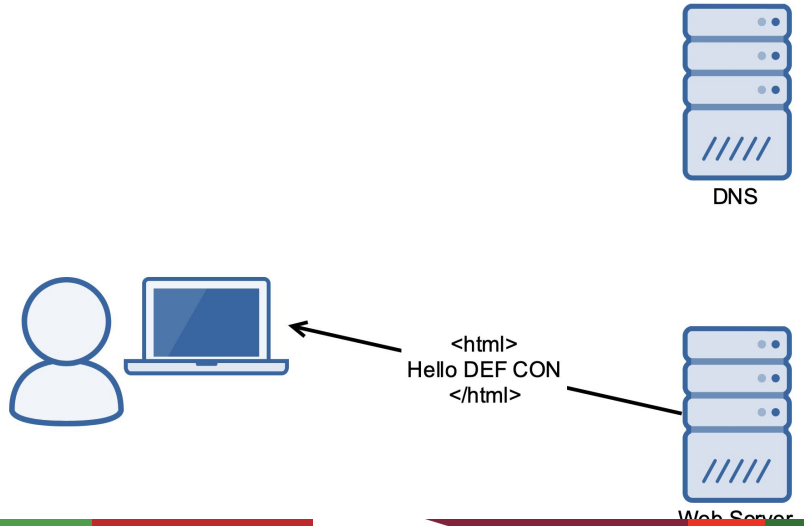
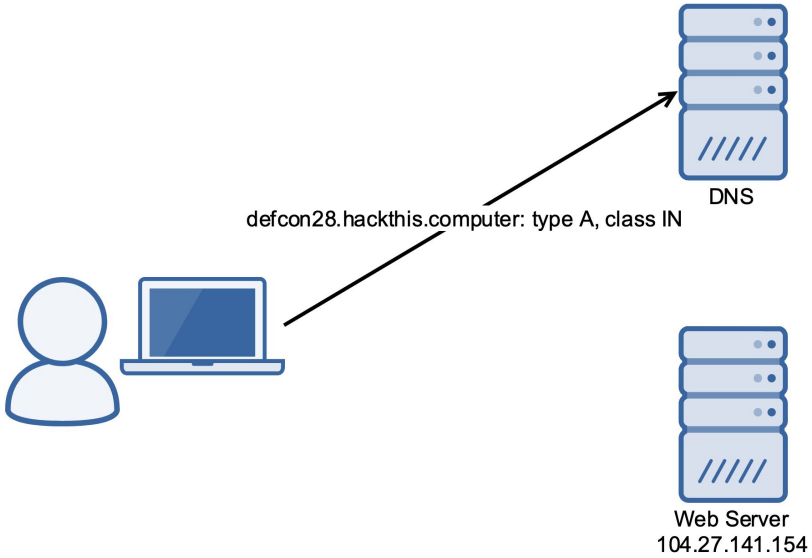


HTTPS Basics

- Starts off the same way, a user requests the IP of a server via DNS
- This is an unencrypted connection on UDP port 53



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HTTPS Basics

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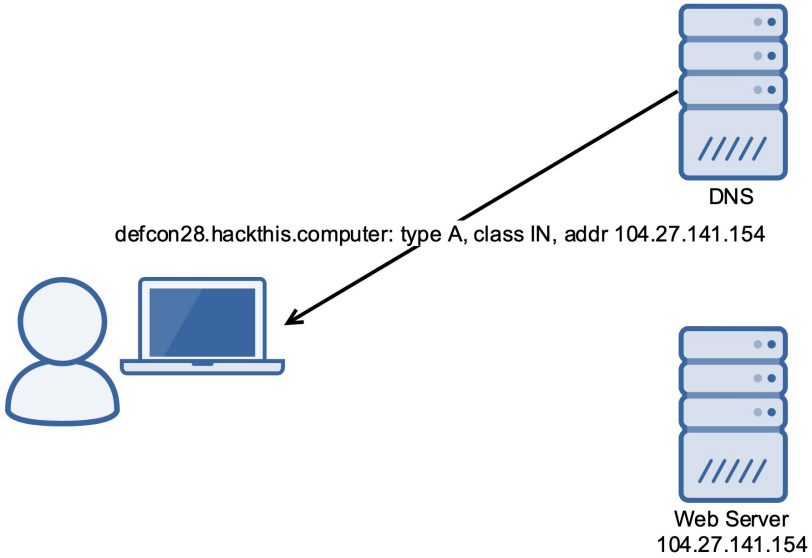

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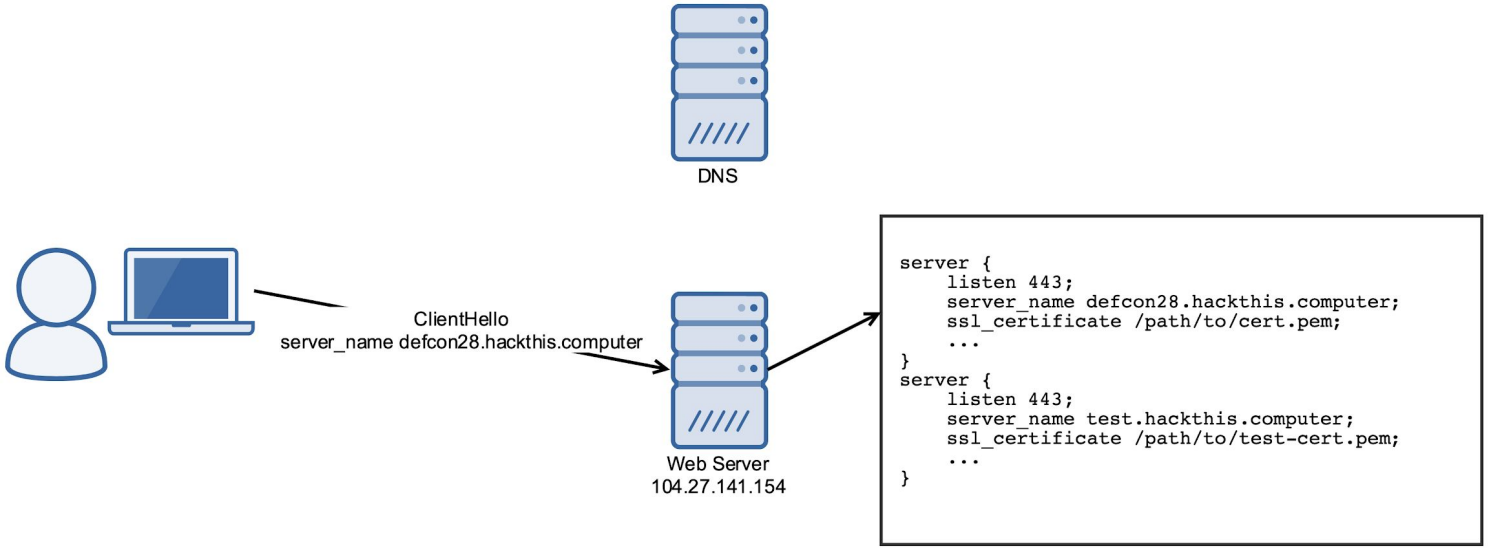
HTTPS Basics

- The user sends a ClientHello to start the TLS handshake
- Server uses the “server_name” field (plaintext) to lookup how to respond



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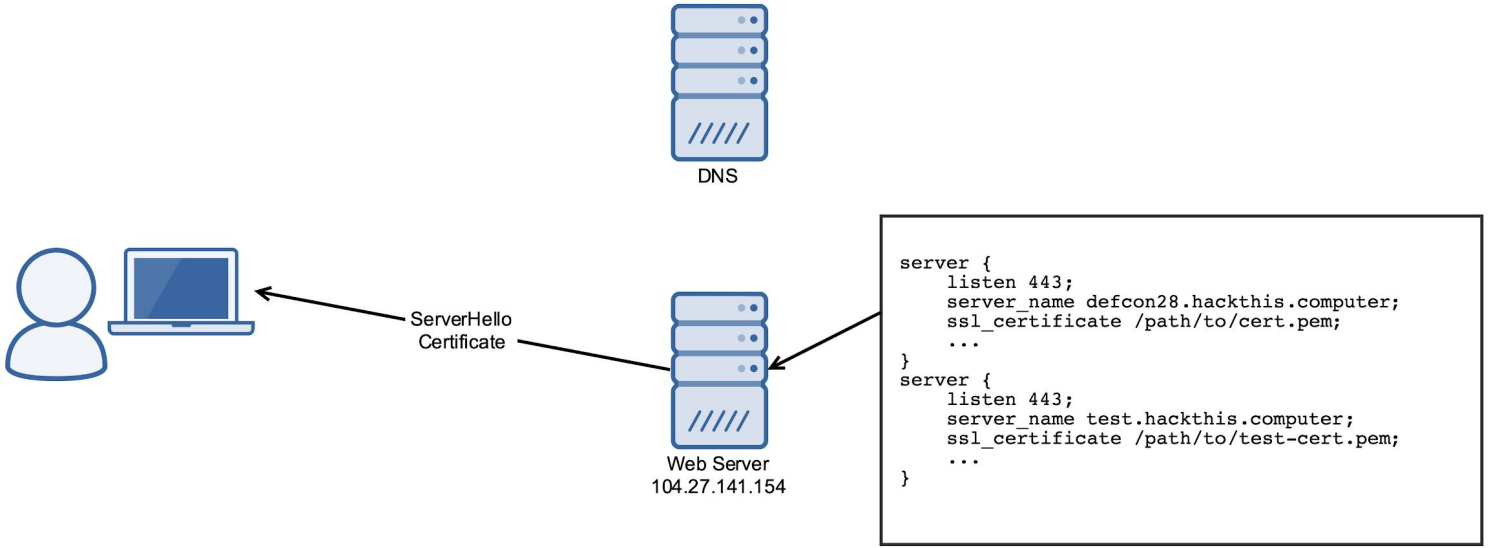
HTTPS Basics

- The server responds with a certificate (in plaintext unless TLS 1.3) and completes the handshake
- All data after the handshake is encrypted



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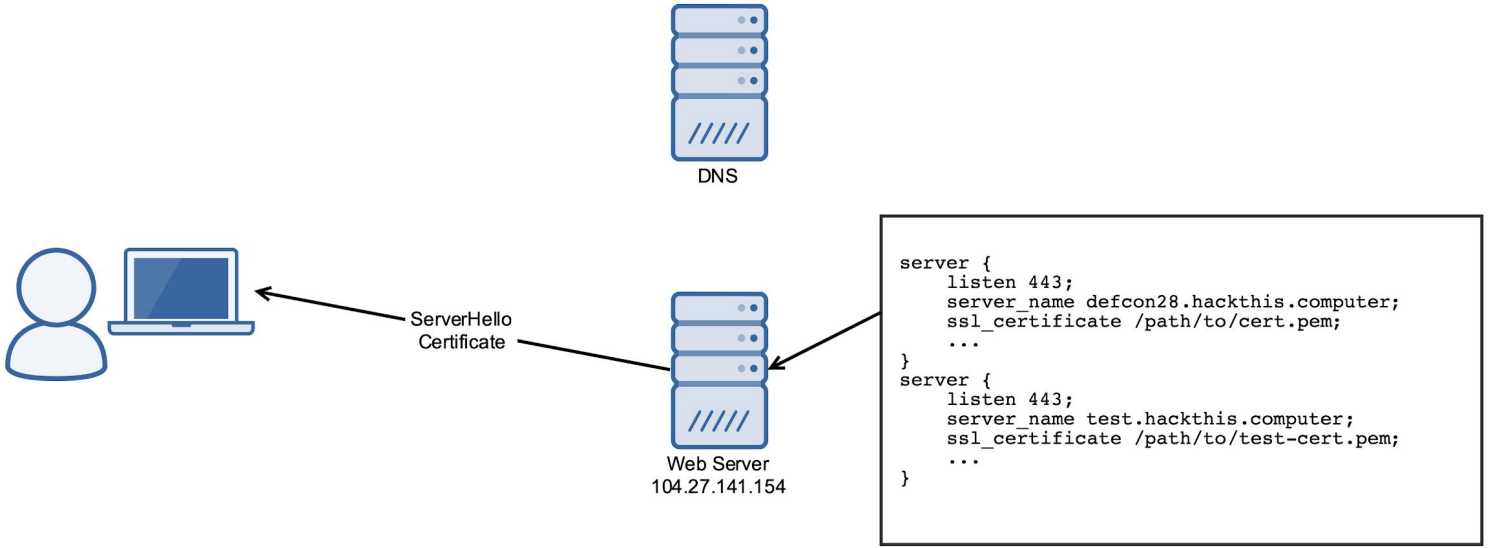
HTTPS Basics

- Much better than HTTP
- Entire DNS process and the certificate exchange process are still unencrypted



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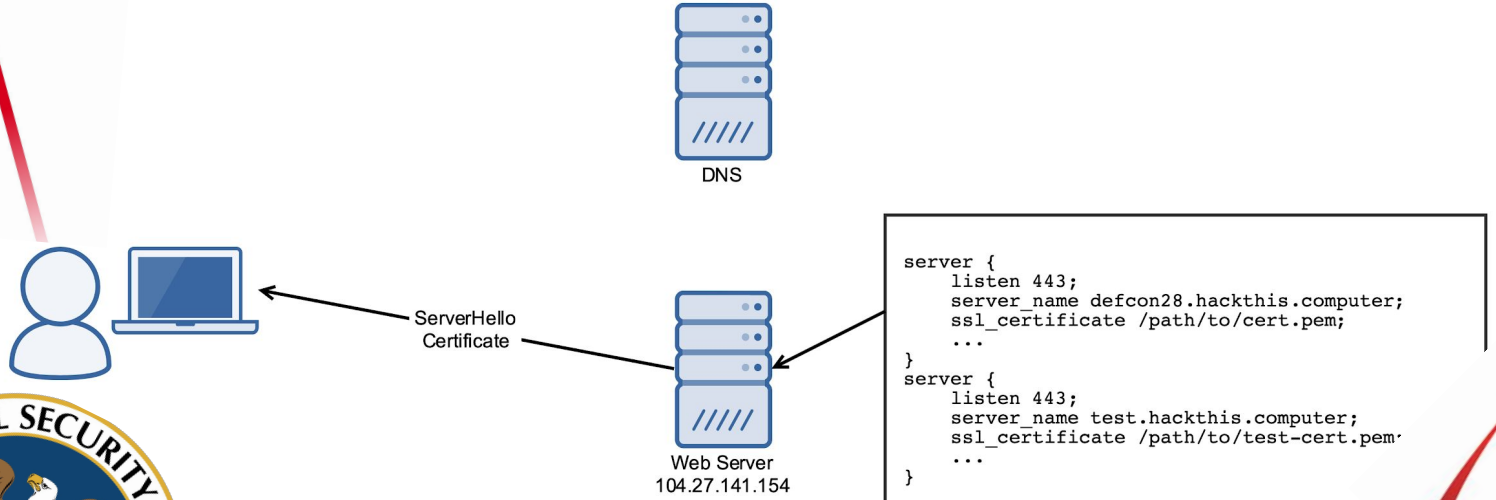

Domain Fronting

- Circumvent censorship by obfuscating the domain of an HTTPS connection
- Connect to an approved server, but send an HTTP request for the actual destination
- Uses a hosting service to host the true destination - false destination must be on the same service
  - Google App Engine
  - Amazon S3/CloudFront
  - Microsoft Azure CDN
  - Others

App Engine

Azure

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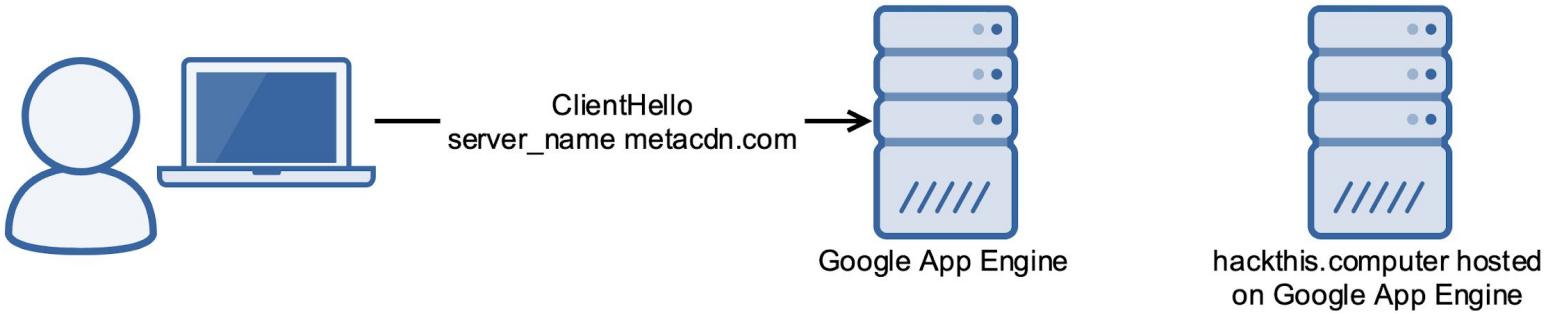
Domain Fronting

- DNS lookup as before for any site hosted by the hosting service
- Client and Server handshake as usual



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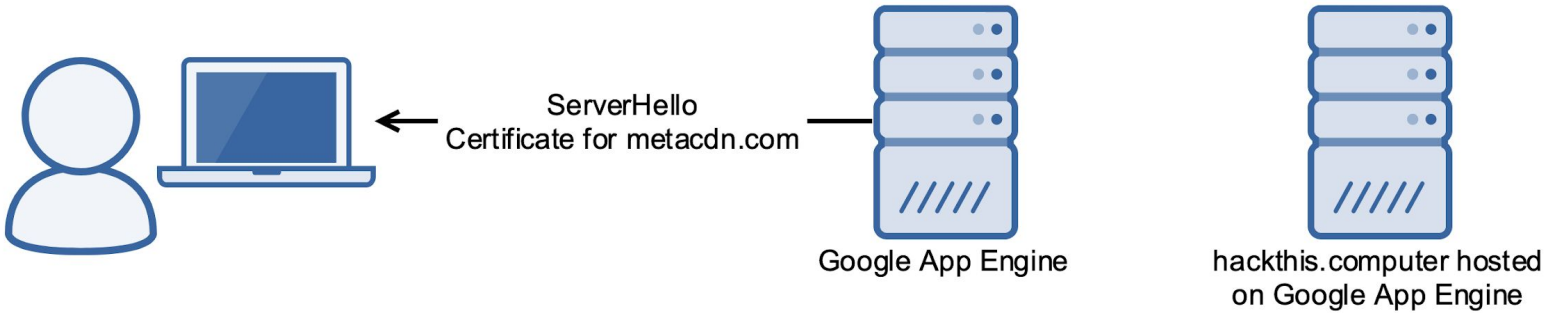
Domain Fronting

- Client and Server handshake as usual



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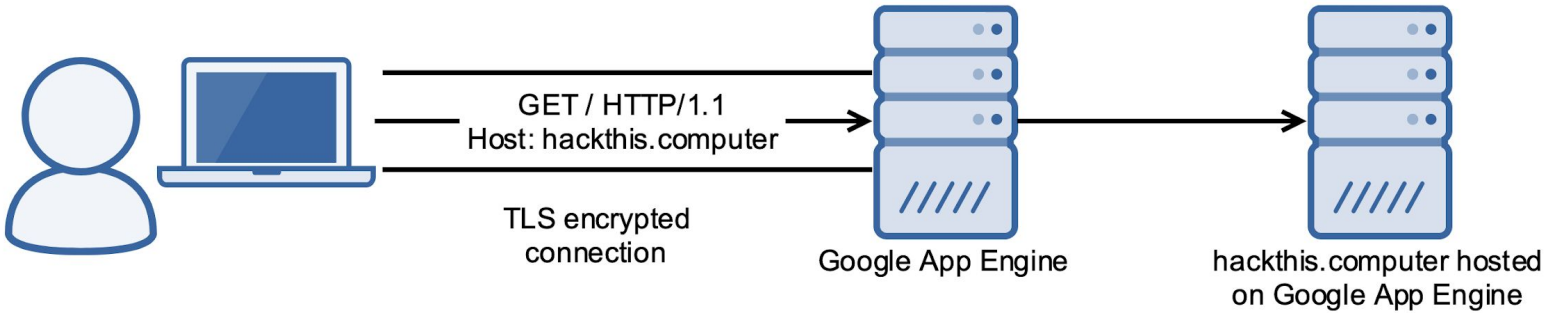
Domain Fronting

- Client sends an HTTP request with the Host header set to the actual destination
- The CDN forwards the request as long as the destination is hosted by the service
  - Any site on GAE could be used to front for an otherwise censored GAE server



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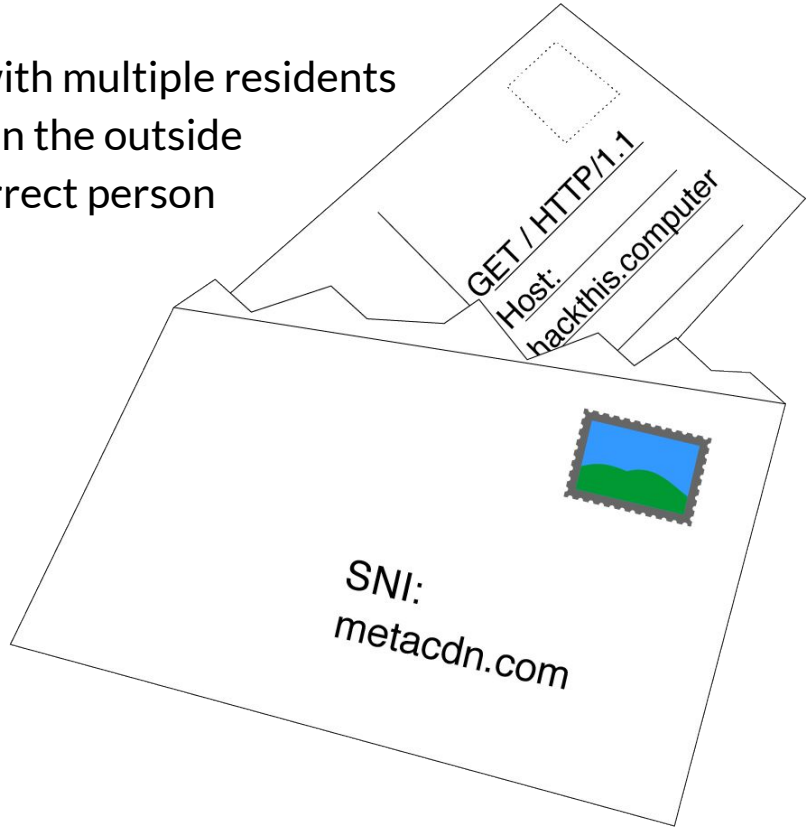
Domain Fronting

- Like a letter delivered to a house with multiple residents
- The mailman can see the address on the outside
- Letter on the inside goes to the correct person



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Domain Fronting

- April 2018 - The music stops
- Google
  - “Domain fronting has never been a supported feature at Google”[1]
- Amazon
  - Implemented “Enhanced Domain Protections”
  - “no customer ever wants to find that someone else is masquerading as their innocent, ordinary domain”[2]
  - Think of the innocent ~~children~~ ordinary domains!
- Cloudflare
  - Only HTTP works
- Azure
  - Still works... For now

[1] A Google update just created a big problem for anti-censorship tools
[2] Enhanced Domain Protections for Amazon CloudFront Requests

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Domain Fronting - Issues

- Major providers shut it down
- Limited fronting options
  - Only sites hosted on the same provider can be used to front
- Must host an “app” or have an account with the provider
  - Not free
    - Bandwidth
    - CPU time
  - Complex sign up requirements
    - Identity checks
    - Phone required
    - Credit card required

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TLS 1.3 + ESNI for “Domain Hiding”

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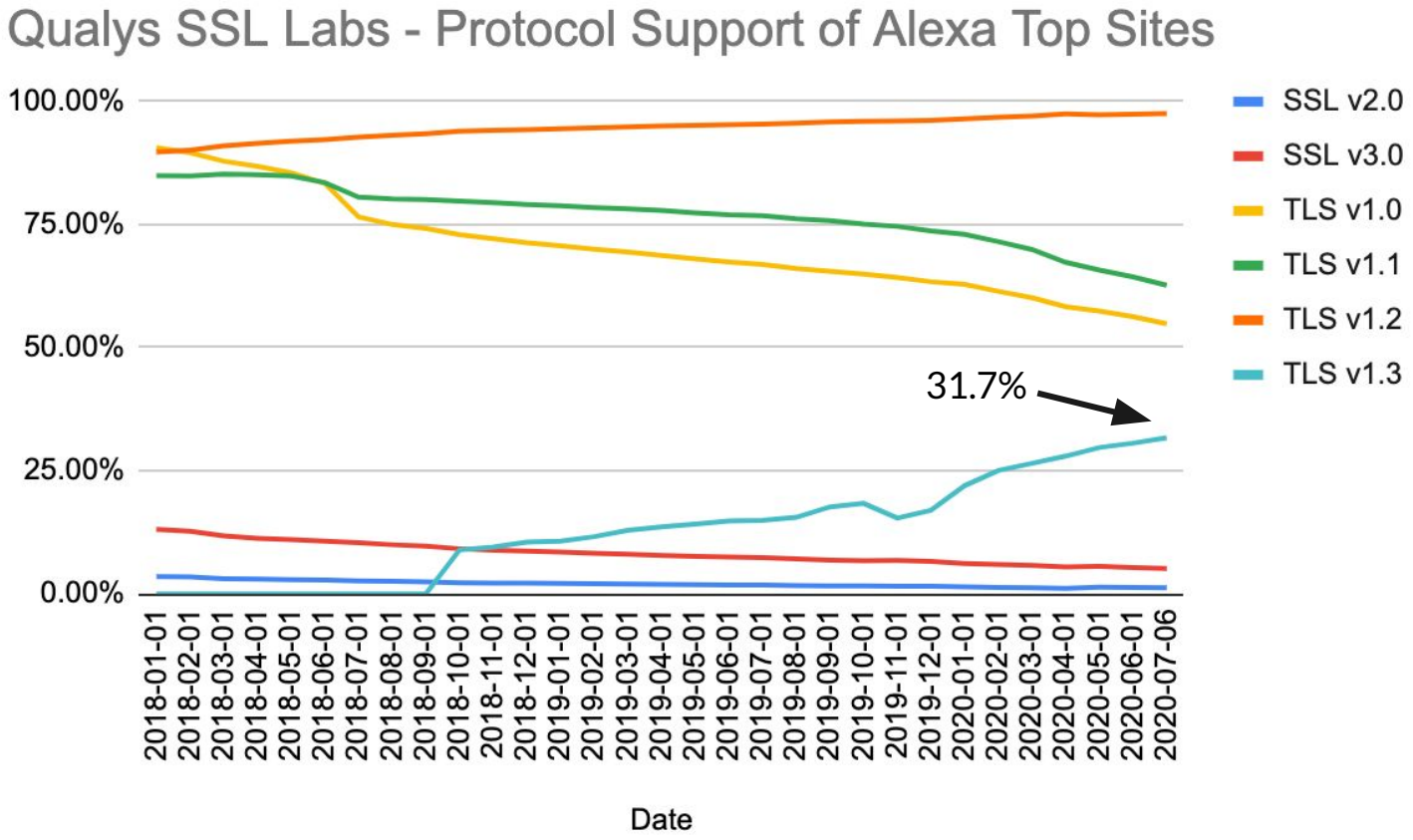
The Growth of TLS 1.3



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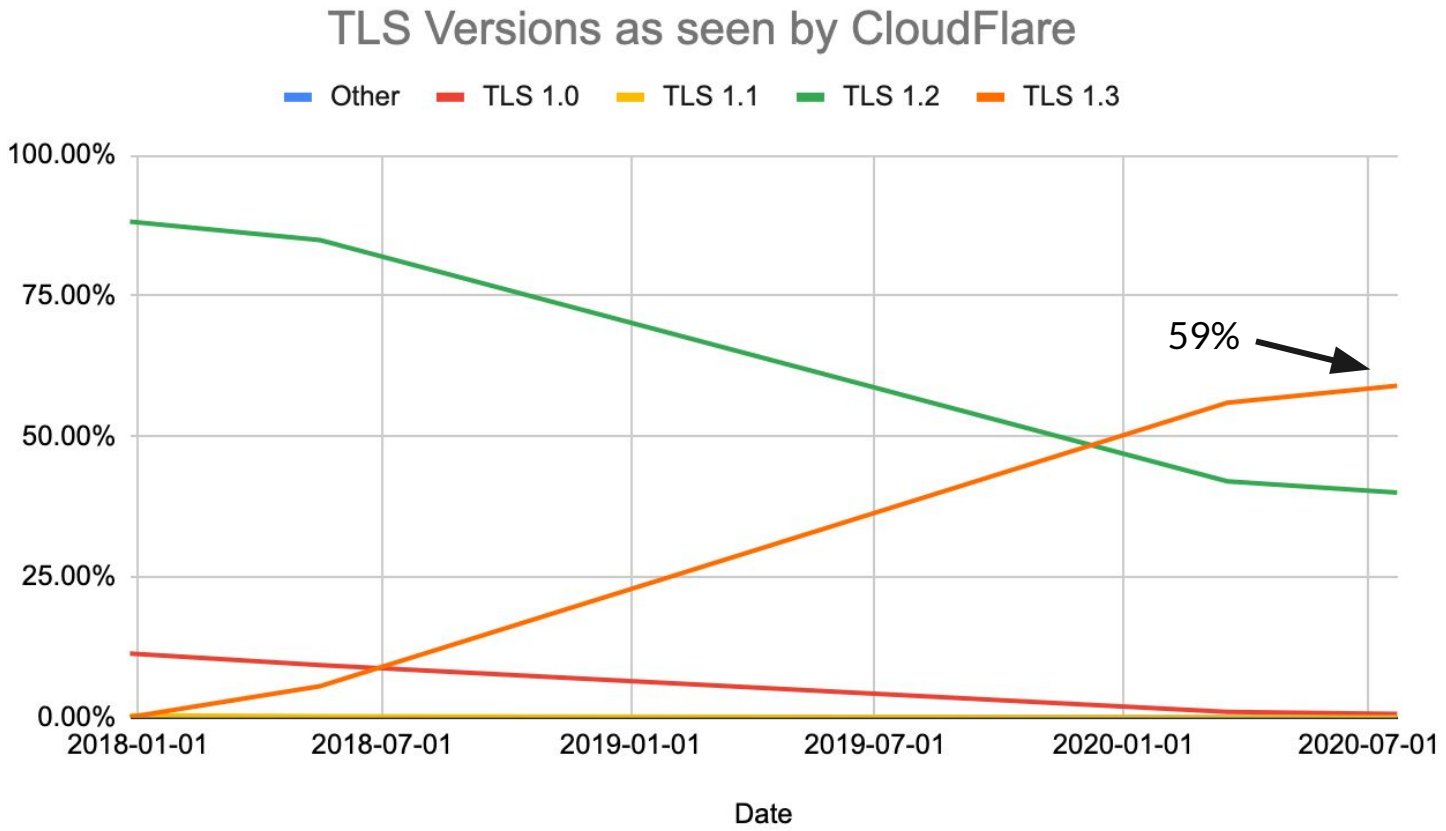
The Growth of TLS 1.3



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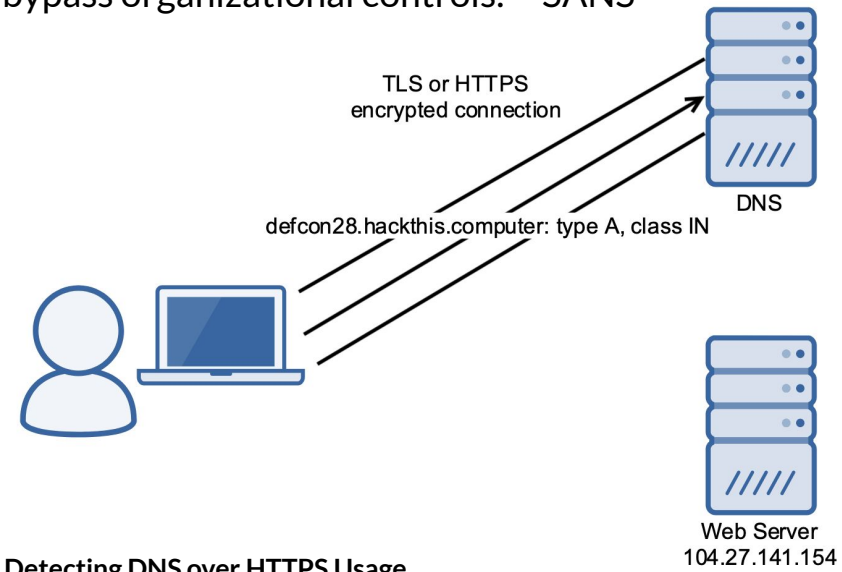
DNS - Fixing the Problem

- What if you wrap a DNS request in TLS?
- How about HTTPS? (RFC 8484)
- "The unmitigated usage of encrypted DNS, particularly DNS over HTTPS, could allow attackers and insiders to bypass organizational controls." - SANS[3]
    - Great!



[3] A New Needle and Haystack: Detecting DNS over HTTPS Usage

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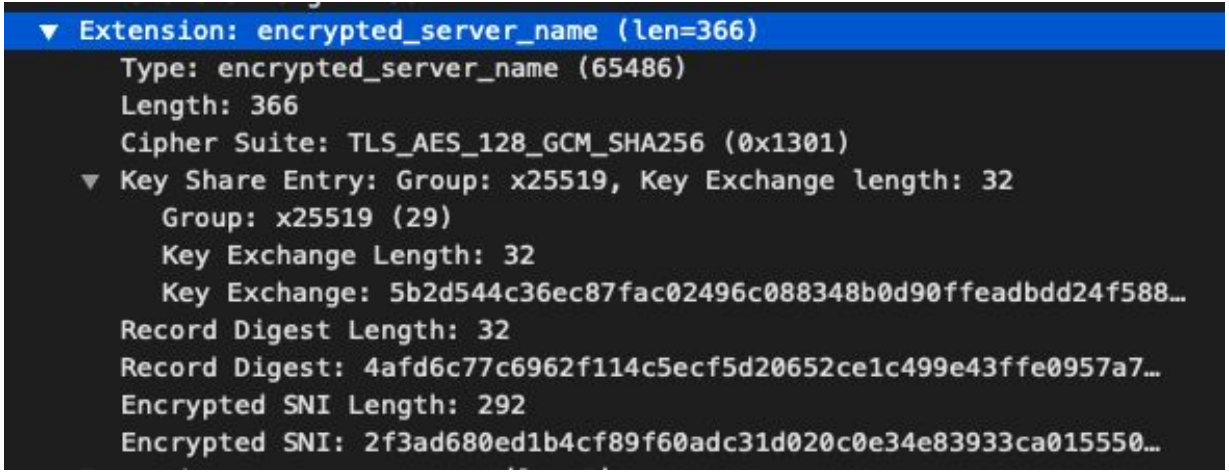
TLS 1.3 and ESNI

- Now that DNS is encrypted, it can be used to fetch a public key before an HTTPS connection is started
- Classic Diffie-Hellman key exchange to symmetrically encrypt the server_name
    - All data required is sent in a single Client Hello (the client's public key + extras)



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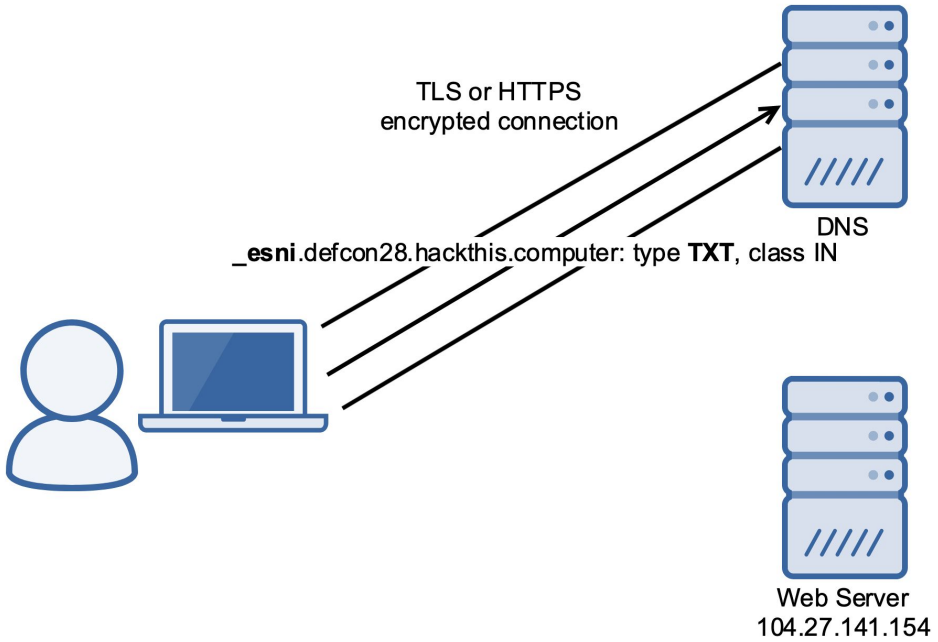
TLS 1.3 and ESNI - Step by Step

- Client requests the IP address and ESNI public key via DNS over TLS or HTTPS



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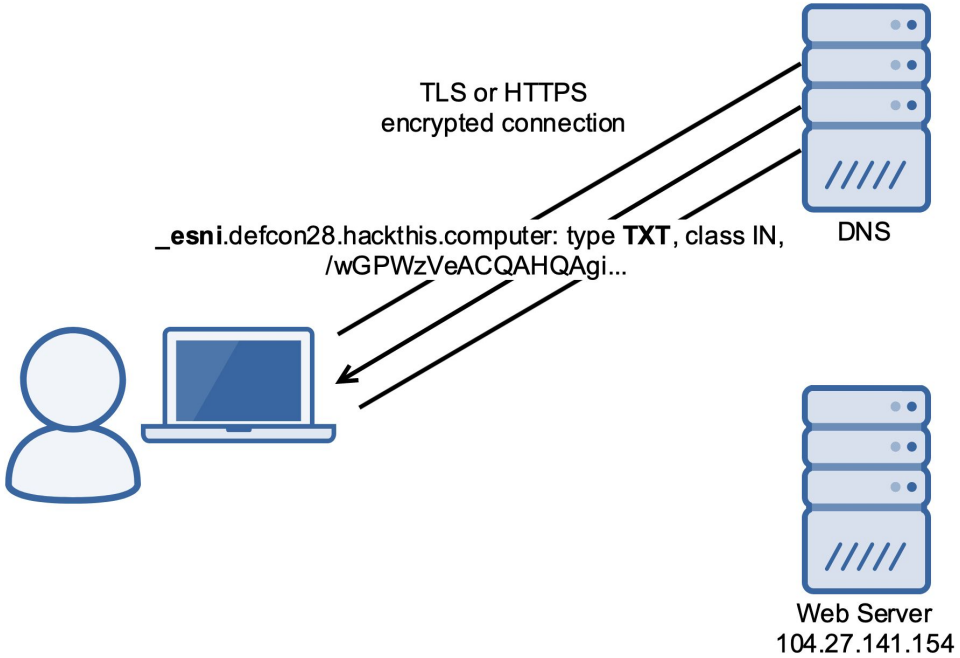
TLS 1.3 and ESNI - Step by Step

- DNS server returns the IP address and ESNI public key via DNS over TLS or HTTPS
- Cloudflare rotates their key every ~1 hour (with a few hours of buffer allowed by the servers)



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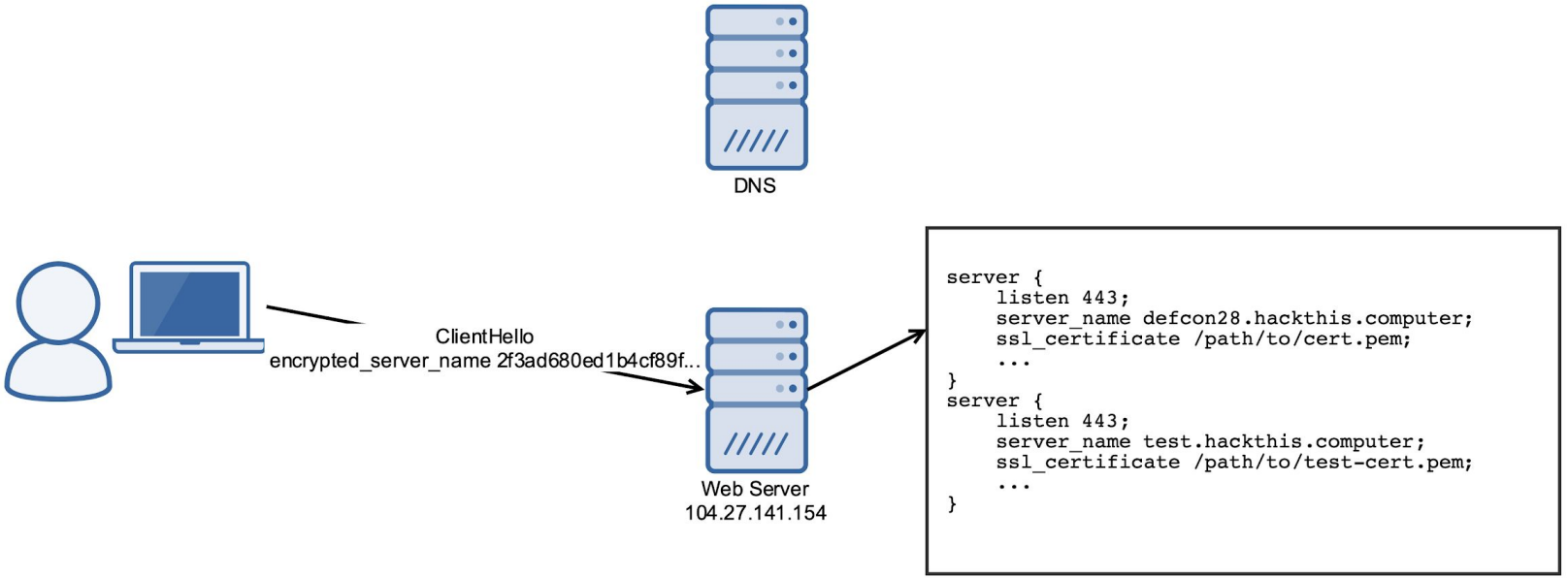
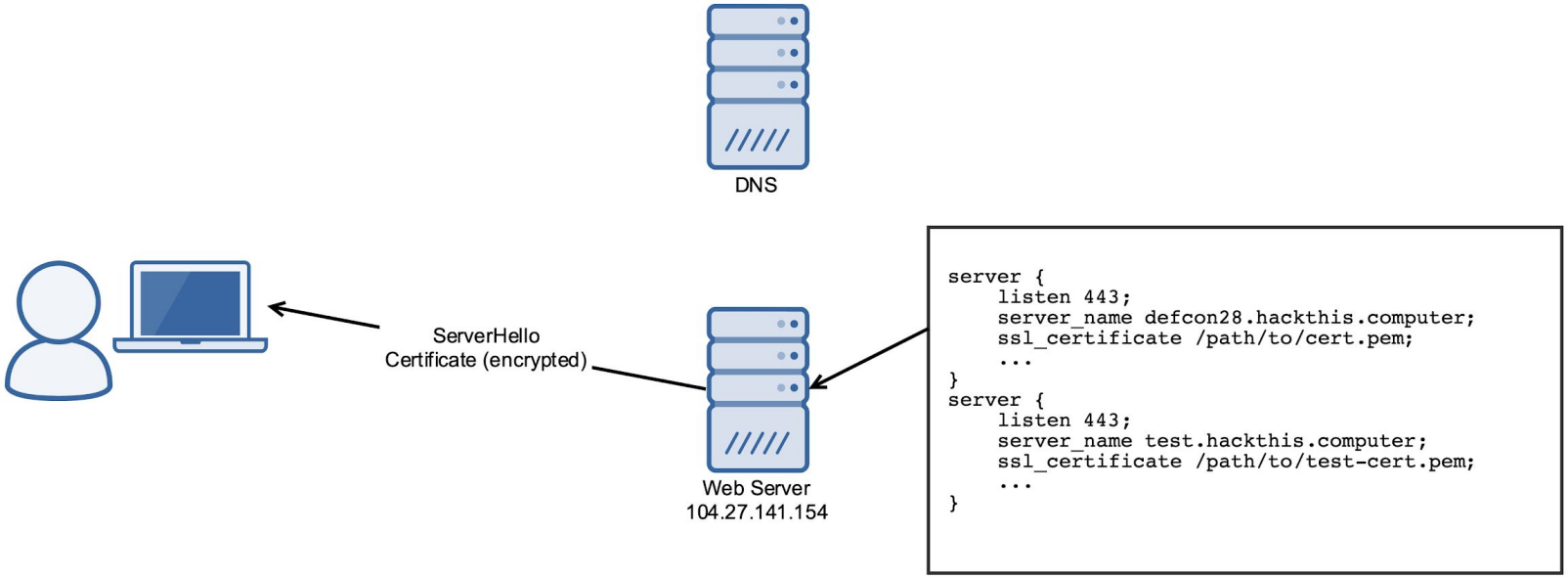
TLS 1.3 and ESNI - Step by Step

- Client sends a TLS 1.3 ClientHello with an encrypted_server_name extension



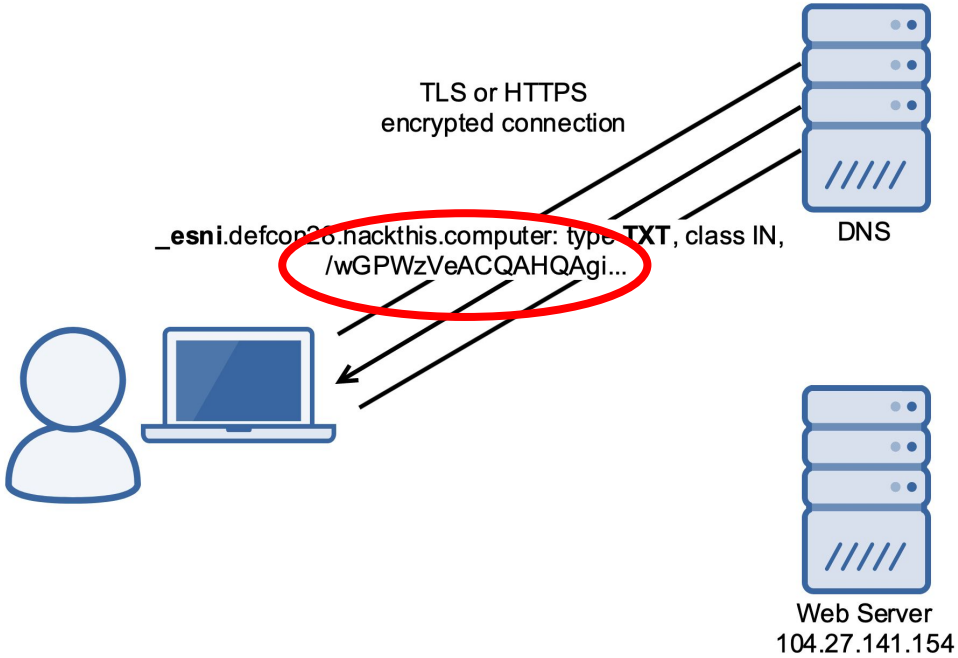
TLS 1.3 and ESNI - Step by Step

- Web server responds with a ServerHello that includes the encrypted certificate



TLS 1.3 and ESNI - Weak Spots

- DNS response for IP or _esni could be tampered with (poisoned resolver cache)
- DNSSEC![4]



[4] How DNSSEC Works

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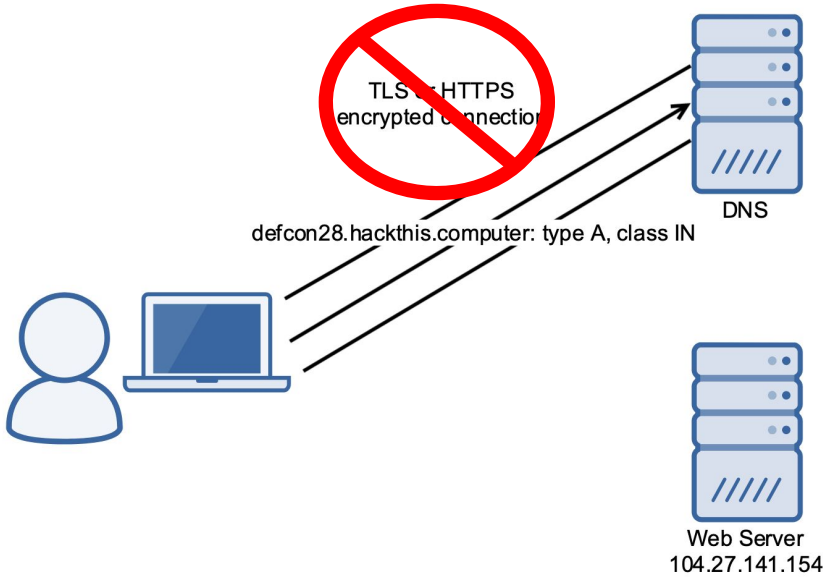
TLS 1.3 and ESNI - Weak Spots

- DNS over TLS or HTTPS is completely blocked
- Preload ESNI keys to bootstrap the connection



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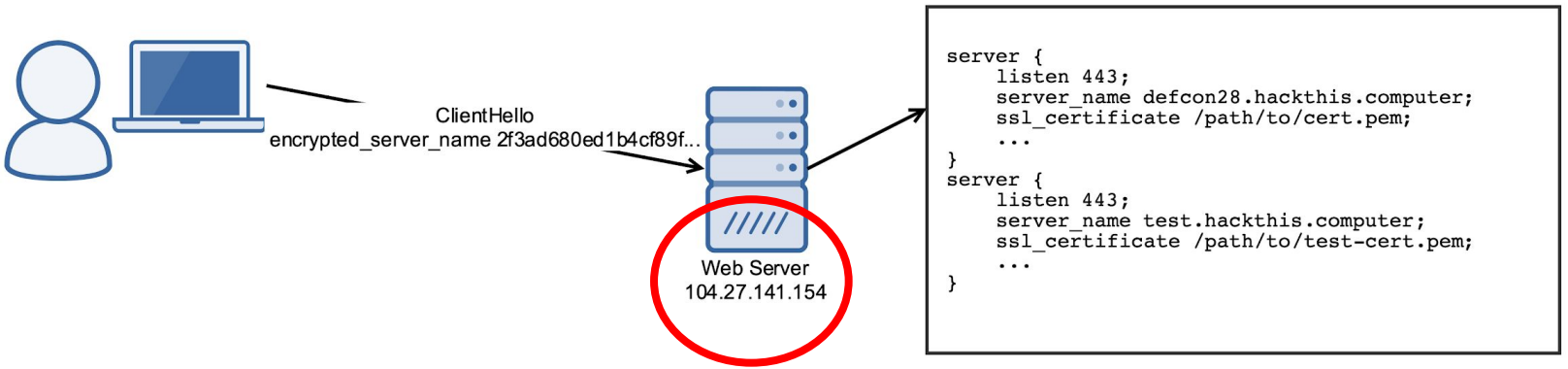
TLS 1.3 and ESNI - Weak Spots

- The TLS connection goes to an IP address
- An IP **may** be shared by many domains, but may not
- Is there a generally applicable way to route to any domain via any other?
  - No, but how close can we get?



Domain Hiding and DNS - Issues

Issue	Solution
DNS is unencrypted	DNS over TLS or HTTPS
DNS is untrustworthy	DNSSEC
Encrypted DNS is blocked	Bootstrap ESNI keys
SNI is unencrypted	ESNI
IPs (or IPs that domains resolve to) are blocked	Domain hiding with the largest CDN!

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Demos

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Cloudflare

- Founded in 2009
- Content Delivery Network (CDN)
  - Highest number of internet exchange points of any network
  - Largest CDN in the world
  - Supports TLS 1.3, ESNI, Websockets, and QUIC
- Authoritative DNS
  - Over 26,000,000 domains
  - Supports DNSSEC

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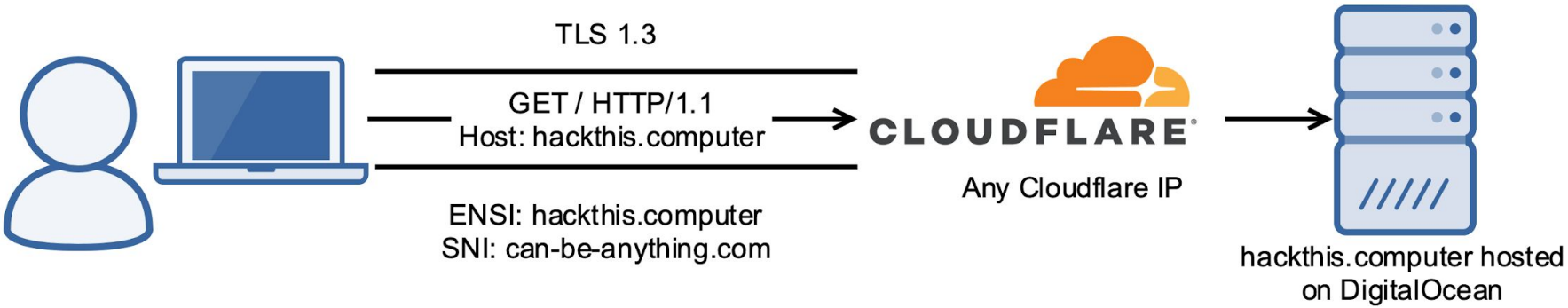
Domain Hiding with Cloudflare

- A TLS 1.3 connection with ESNI is sent to ANY Cloudflare server
  - SNI can be included as well - does not have to match ESNI value
- A HTTP request is sent using that connection can have any Host header
  - True domain must have DNS provided by Cloudflare
- Cloudflare will forward the request to the true destination - just like domain fronting!
- Robin Wood (@digininja) was the first to show this was possible



Noctilucent

- Go (Golang) rewrite of crypto/tls based on Cloudflare's tls-tris project
- TLS 1.3 support
  - Config options specific for domain hiding
    - ESNIServerName - does not need to match the SNI extension or Host header
    - PreserveSNI - Allows the sending of a ClientHello with both SNI and ESNI extensions
- Drop in replacement for standard crypto/tls - backwards compatible
- Test client application
  - Attempts DNS over HTTPS (DoH) - Falls back to DNS over TLS, then system default DNS
  - Allows command line tuning of nearly every part of the TLS and HTTP connection
  - HTTPS and Websocket support
  - Cross platform!

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Normal HTTPS Connection

Normal HTTPS Connection

```
.../esni/client $ ./client-macOS -TLSHost cloudflare.com -serverName cloudflare.com -HostHeader
cloudflare.com
[=] TLS 1.3 with TLS_CHACHA20_POLY1305_SHA256
[=] ESNI host has not been set
[=] SNI host set to: cloudflare.com
[+] Connecting to https://cloudflare.com:443
[+] TLS handshake complete
[+] Sending GET request: GET / HTTP/1.1
Host: cloudflare.com
User-Agent: ESNI_FRONT_TEST
Accept: */*
Connection: close

[+] GET request sent
[=] Reponse:
HTTP/1.1 301 Moved Permanently
Date: Tue, 24 Mar 2020 00:23:42 GMT
Transfer-Encoding: chunked
Connection: close
Cache-Control: max-age=3600
Expires: Tue, 24 Mar 2020 01:23:42 GMT
Location: https://www.cloudflare.com/
Expect-CT: max-age=604800, report-uri="https://report-uri.cloudflare.com/cdn-cgi/beacon/expect-ct"
Set-Cookie: __cf_bm=166e3a90f25654e23ea8574aef6e0cac3fc530e4-1585009422-1800-
AQQvEoF8e21eEE7TrueGnj4E3aeOFv38ZtFA2iBp3Dxl8Vv+5qaljvAEDCy5kqcTMj0VSs2fgaVUrSDCQjZv+nU=; path=/;
expires=Tue, 24-Mar-20 00:53:42 GMT; domain=.cloudflare.com; HttpOnly; Secure; SameSite=None
Strict-Transport-Security: max-age=15780000; includeSubDomains
Server: cloudflare
CF-RAY: 578c3eb81d10740d-IAD
alt-svc: h3-27=":443"; ma=86400, h3-25=":443"; ma=86400, h3-24=":443"; ma=86400, h3-23=":443"; ma=86400

0
[=] TLS 1.3 => Read 819 bytes
```

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TLS 1.3 + ESNI HTTPS Connection

TLS1.3 + ESNI HTTPS Connection

```
.../esni/client $ ./client-macOS -TLSHost cloudflare.com -esni -ESNIServerName cloudflare.com -HostHeader
cloudflare.com
[+] Using resolver: https://doh-2.seby.io/dns-query
[+] Successfully queried _ensi TXT record for host: cloudflare.com
[=] TLS 1.3 with TLS_CHACHA20_POLY1305_SHA256
[=] ENSI host set to: cloudflare.com
[=] SNI host has been unset
[+] Connecting to https://cloudflare.com:443
[+] TLS handshake complete
[+] Sending GET request: GET / HTTP/1.1
Host: cloudflare.com
User-Agent: ESNI_FRONT_TEST
Accept: */*
Connection: close

[+] GET request sent
[=] Reponse:
HTTP/1.1 301 Moved Permanently
Date: Tue, 24 Mar 2020 23:41:52 GMT
Transfer-Encoding: chunked
Connection: close
Cache-Control: max-age=3600
Expires: Wed, 25 Mar 2020 00:41:52 GMT
Location: https://www.cloudflare.com/
Expect-CT: max-age=604800, report-uri="https://report-uri.cloudflare.com/cdn-cgi/beacon/expect-ct"
Set-Cookie: __cf_bm=47e9c445d7f4ffdeec643bbe8bb7e0e65ed24bfd-1585093312-1800-
AezT9reipfUk2D9ZS6D2s4Ml7fC/Lo/sVCpGQE3nDmLqByRKS9kuJ23NAXIw3lFaASr1e2MNV5OUNuRL8OVLQ84=; path=/;
expires=Wed, 25-Mar-20 00:11:52 GMT; domain=.cloudflare.com; HttpOnly; Secure; SameSite=None
Strict-Transport-Security: max-age=15780000; includeSubDomains
Server: cloudflare
CF-RAY: 57943ed30b4f747e-IAD
alt-svc: h3-27=":443"; ma=86400, h3-25=":443"; ma=86400, h3-24=":443"; ma=86400, h3-23=":443"; ma=86400

0
[=] TLS 1.3 => Read 819 bytes
```

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Hidden Request (no SNI)

TLS1.3 + ESNI HTTPS Connection

```
.../esni/client $ ./client-macOS -TLSHost cloudflare.com -esni -ESNIServerName defcon28.hackthis.computer
-HostHeader defcon28.hackthis.computer
[+] Using resolver: https://dns.rubyfish.cn/dns-query
[+] Successfully queried _ensi TXT record for host: cloudflare.com
[=] TLS 1.3 with TLS_CHACHA20_POLY1305_SHA256
[=] ENSI host set to: defcon28.hackthis.computer
[=] SNI host has been unset
[+] Connecting to https://cloudflare.com:443
[+] TLS handshake complete
[+] Sending GET request: GET / HTTP/1.1
Host: defcon28.hackthis.computer
User-Agent: ESNI_FRONT_TEST
Accept: */*
Connection: close

[+] GET request sent
[=] Reponse:
HTTP/1.1 200 OK
Date: Tue, 24 Mar 2020 23:47:47 GMT
Content-Type: text/plain; charset=utf-8
Content-Length: 14
Connection: close
Set-Cookie: __cfduid=d4f30bc8fdaaaa9f40faea6ad776822a71585093667; expires=Thu, 23-Apr-20 23:47:47 GMT;
path=/; domain=.hackthis.computer; HttpOnly; SameSite=Lax
CF-Cache-Status: DYNAMIC
Expect-CT: max-age=604800, report-uri="https://report-uri.cloudflare.com/cdn-cgi/beacon/expect-ct"
Server: cloudflare
CF-RAY: 5794477ebfd7745d-IAD

Hello DEF CON!
[=] TLS 1.3 => Read 488 bytes
```

Fronted Request (with SNI)

TLS1.3 + ESNI HTTPS Connection

```
.../esni/client $ ./client-macOS -TLSHost cloudflare.com -esni -ESNIServerName defcon28.hackthis.computer
-HostHeader defcon28.hackthis.computer -serverName cloudflare.com -preserveSNI
[+] Using resolver: https://dns.rubyfish.cn/dns-query
[+] Successfully queried _ensi TXT record for host: cloudflare.com
[=] TLS 1.3 with TLS_CHACHA20_POLY1305_SHA256
[=] ENSI host set to: defcon28.hackthis.computer
[=] SNI host set to: cloudflare.com
[+] Connecting to https://cloudflare.com:443
[+] TLS handshake complete
[+] Sending GET request: GET / HTTP/1.1
Host: defcon28.hackthis.computer
User-Agent: ESNI_FRONT_TEST
Accept: */*
Connection: close

[+] GET request sent
[=] Reponse:
HTTP/1.1 200 OK
Date: Tue, 24 Mar 2020 23:53:26 GMT
Content-Type: text/plain; charset=utf-8
Content-Length: 14
Connection: close
Set-Cookie: __cfduid=db2a920903e1a64ddd9a144770c84265d1585094006; expires=Thu, 23-Apr-20 23:53:26 GMT;
path=/; domain=.hackthis.computer; HttpOnly; SameSite=Lax
CF-Cache-Status: DYNAMIC
Expect-CT: max-age=604800, report-uri="https://report-uri.cloudflare.com/cdn-cgi/beacon/expect-ct"
Server: cloudflare
CF-RAY: 57944fc418b4ceec-IAD

Hello DEF CON!
[=] TLS 1.3 => Read 488 bytes
```

So what?

- Any domain protected by Cloudflare is able to arbitrarily front to any IP
  - Target IP can be hosted anywhere
  - DNS must be run via Cloudflare
- Cloudflare Managed DNS is free
- Signup requirements?
  - Email (disposable is ok)
  - Password
  - That's it!

What Can You Hide With?

- Source: Alexa top 100,000 domains
- HTTPS GET request looking for cloudflare cookies, Expect-CT header, or Server
- Results:
  - At least **21% of the top 100,000 domains** are available to front (21,298)
  - A few examples:
    - myshopify.com
    - medium.com
    - **discordapp.com (on the PA whitelist)**[5]
    - udemy.com
    - zendesk.com
    - **coinbase.com (on the PA whitelist)**[5]
    - **hdfcbank.com**
    - **mozilla.org (on the PA whitelist)**[5]
    - teamviewer.com
    - blackboard.com
    - **okta.com**
    - **bitdefender.com**
    - **ny.gov**
    - mlb.com
    - **stanford.edu**
    - plex.tv
    - coronavirus.gov.hk
    - So much porn...

[5] List of Domains and Applications Excluded from SSL Decryption

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Just doing some Single Sign On...

Fronting via www.okta.com

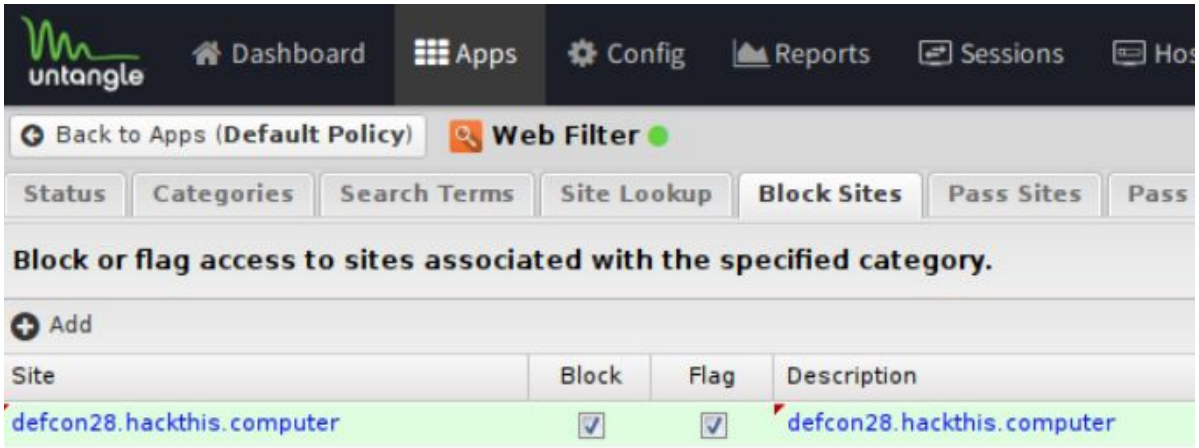
```
.../esni/client $ ./client-macOS -TLSHost www.okta.com -esni -ESNIServerName defcon28.hackthis.computer -
HostHeader defcon28.hackthis.computer -serverName www.okta.com -preserveSNI
[+] Using resolver: https://dns.rubyfish.cn/dns-query
[+] Successfully queried _ensi TXT record for host: www.okta.com
[=] TLS 1.3 with TLS_CHACHA20_POLY1305_SHA256
[=] ENSI host set to: defcon28.hackthis.computer
[=] SNI host set to: www.okta.com
[+] Connecting to https://www.okta.com:443
[+] TLS handshake complete
[+] Sending GET request: GET / HTTP/1.1
Host: defcon28.hackthis.computer
User-Agent: ESNI_FRONT_TEST
Accept: */*
Connection: close

[+] GET request sent
[=] Reponse:
HTTP/1.1 200 OK
Date: Wed, 25 Mar 2020 00:51:16 GMT
Content-Type: text/plain; charset=utf-8
Content-Length: 14
Connection: close
Set-Cookie: __cfduid=d8f3c3cba363e375baa558d574687b5891585097476; expires=Fri, 24-Apr-20 00:51:16 GMT;
path=/; domain=.hackthis.computer; HttpOnly; SameSite=Lax
CF-Cache-Status: DYNAMIC
Expect-CT: max-age=604800, report-uri="https://report-uri.cloudflare.com/cdn-cgi/beacon/expect-ct"
Server: cloudflare
CF-RAY: 5794a47a8a5bcedc-IAD

Hello DEF CON!
[=] TLS 1.3 => Read 488 bytes
```

SNI Based Web Filters

- Many products only look at SNI
  - ESNI completely ignored
- By preserving the SNI along with ESNI, filters and analytics can be tricked
- Example: Untangle
  - Installed with strict web filter settings



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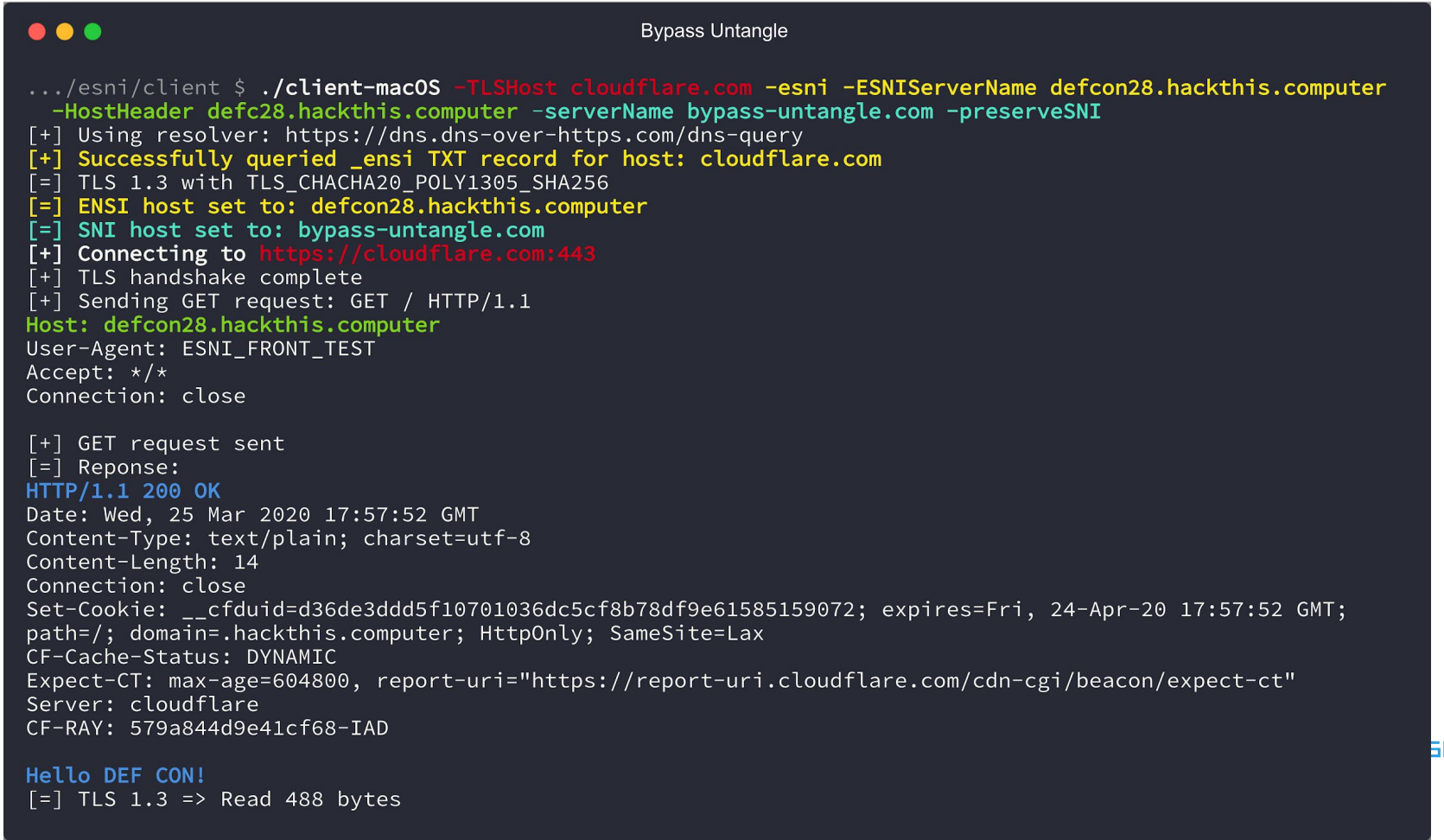
Fooling SNI based Firewalls



Fooling SNI based Firewalls

Web Filter / **Top Domains (by request)**

The number of web requests grouped by domain.

Refresh | Auto (5 sec) | Data View | Download (Image) | Add to Dashboard | Settings

Domain [domain]	value
ubuntu.com	100
firefox.com	91
nextdns.io	68
cloudflare-dns.com	63
digicert.com	56
blahdns.com	46
mozilla.net	42
pki.goog	38
bypass-untangle.com	31
google.com	28
mozilla.com	27
securedns.eu	26

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HTTPS Decrypting Firewalls

- Seen in enterprise environments
  - Install a root certificate on endpoints
  - Break and re-encrypt traffic that passes through
  - Corporate Man-in-the-Middle
- Allows analysis of full packet data!
- Kazakhstan attempted this nation-wide in July 2019[6]
- Does TLS 1.3/ESNI offer a way around these firewalls?

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[6] Kazakhstan government is now intercepting all HTTPS traffic

HTTPS Decrypting Firewalls

- Palo Alto PA-VM 10.0.0
  - Released 2020-06-17
  - Major new feature: TLS 1.3 decryption
  - Default decryption profile does not include TLS 1.3!
    - Allows TLS 1.3 to pass with an error

TLS1.3	Client and decrypt profile version mismatch. Supported client version bitmask: 0x40. Supported decrypt profile version bitmask: 0x38.
TLS1.3	Client and decrypt profile version mismatch. Supported client version bitmask: 0x40. Supported decrypt profile version bitmask: 0x38.
TLS1.3	Client and decrypt profile version mismatch. Supported client version bitmask: 0x40. Supported decrypt profile version bitmask: 0x38.

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[Palo Alto bypass via Mozilla fronting]

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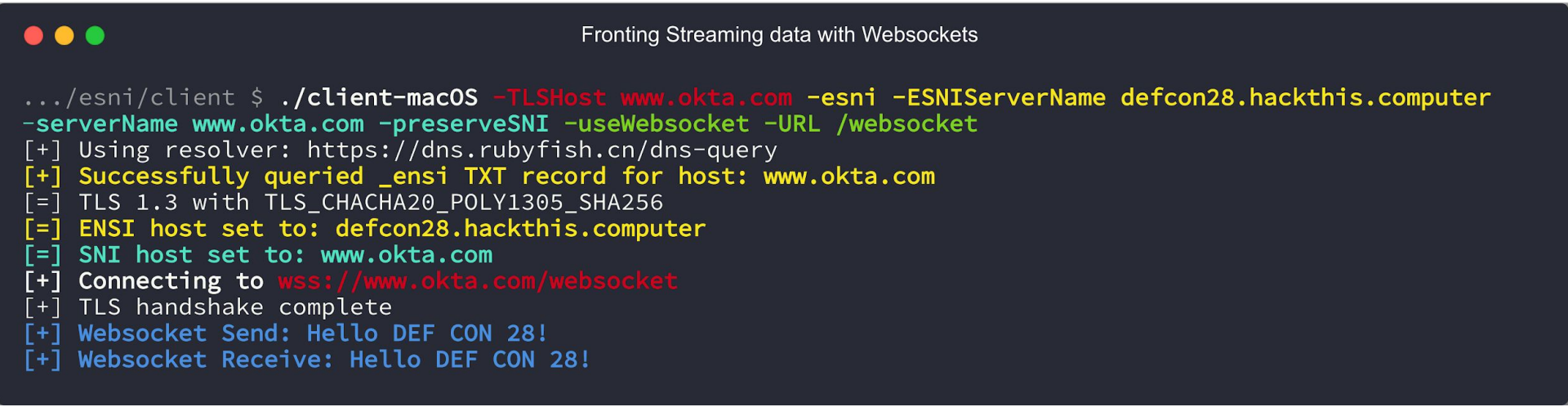
What Else?

- Many connections to a fronted site may be suspicious
  - What protocols can we use?
    - HTTP ✔️
    - Websockets ✔️
    - Arbitrary TCP/UDP via a helper ✔️

Fronting Streaming data with Websockets



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[Cloak Demo]

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[Cloak+CobaltStrike Demo]

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[DeimosC2 Demo]

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3

What is Blue to Do?

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What is Blue to Do?

- Disable TLS 1.3 (25-50% of traffic)
- Block Cloudflare (26 million domains)?
- Block ClientHellos with an encrypted_server_name extension?
  - Technically possible
  - Netsweeper >=6.4.1 (2020-02-25) can block all ESNI traffic
    - Cannot categorize sites
    - All or none
  - No other vendors currently support ESNI blocking as of today

What is Blue to Do?

- Flag on ClientHello packets with both “server_name” and “encrypted_server_name”
  - Snort
    - Possible with custom rules?
    - ssl_state:client_hello
    - tls.version can narrow down to 1.3
    - SNI extension type is `0x0000`
    - ESNI extension type is `0xffce`
  - Securicata
    - Snort with extra features
    - has `tls.sni` but no `tls.esni`

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What is Blue to Do?

- “Good old fashioned police work”
  - Beaconing detection and anomaly network analytics
    - RITA or BeaKer (or fancy AI/ML)
    - How much should a user interact with a site? How often? How much data?
  - JA3 and JA3S mismatches
    - Should svchost.exe have a JA3 fingerprint of Go?
    - Cloak and utls are working to defeat this
  - Well instrumented EDR, application whitelisting, etc
    - Don’t get pwned in the first place!
    - “Server administrators should never allow untrusted code to run on the server” -Microsoft

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Domain Hiding - Noctilucent - The Future

- Latest advancement in censorship resistant communication
- Useable today
  - Go - drop in replacement
  - Cloak fork - use with anything that can be proxied (CobaltStrike, etc)
- Will be harder to block as TLS 1.3 and ESNI adoption grows
- ESNI RFC is in flux (last updated 2020-06-01) - might break tomorrow
  - Actually called ECH as of May 2020
- Currently relies on a single (massive) CDN
  - Cloudflare please don't break this
- Blue Team: Your move!

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Special Thanks

- Robin Wood (@digininja) - freelance pen-tester, researcher and developer
- Andy Wang (cbeuw) - developer of Cloak
- Nick Sullivan (@grittygrease) - Head of Research and Cryptography at Cloudflare

References/Resources

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- Wikipedia: Domain Fronting
- Blocking-resistant communication through domain fronting
- Encrypt it or lose it: how encrypted SNI works
- Encrypted Server Name Indication for TLS 1.3
- Godns - a simple client lib for doing dns over https
- How DNSSEC Works
- SSL Labs - SSL Pulse
- Domain fronting through Cloudflare
- TLS-tris
- RITA (Real Intelligence Threat Analytics)

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Questions

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https://github.com/SixGenInc/Noctilucent