CSE508 Network Security

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Core Protocols: DNS

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Domain Name System

DNS maps domain names to IP addresses

"Phonebook" for the internet

Client: I want to connect to: `www.cs.stonybrook.edu`

DNS server: here is its IP address: `130.245.27.2`

Distributed, hierarchical, reliable database

Replaced the manually maintained /etc/`hosts` file

Domain names are assigned by *registrars* accredited by ICANN

Not always a one-to-one mapping

Virtual hosting: many names hosted on a single IP address

Load balancing/fault tolerance: single name hosted on many IP addresses

DNS Server Hierarchy

Hierarchically divided name space

`.edu` ➔ `stonybrook.edu` ➔ `cs.stonybrook.edu` ➔ `www.cs.stonybrook.edu`

Root name servers

Responsible for top-level domains (TLDs): `.com`, `.edu`, `.net`, …

Point to the *authoritative name server* of each TLD ➔ managed by government or commercial organizations

```
$ curl http://data.iana.org/TLD/tlds-alpha-by-domain.txt |wc -l
1504
```

Authoritative name servers are responsible for a set of names belonging into a *zone*

A leaf node in the DNS hierarchy manages the zone of a single domain

DNS Resolvers

Query DNS servers and resolve the requested resource

Main query types:

Non-recursive: query a single server and receive a response

May be a partial response

Recursive: query a single server, which may then query (as a client itself) other DNS servers on behalf of the requester

Has to reply with the requested response or “doesn’t exist” (cannot refer the client to a different DNS server)

Iterative: query a chain of one or more DNS servers

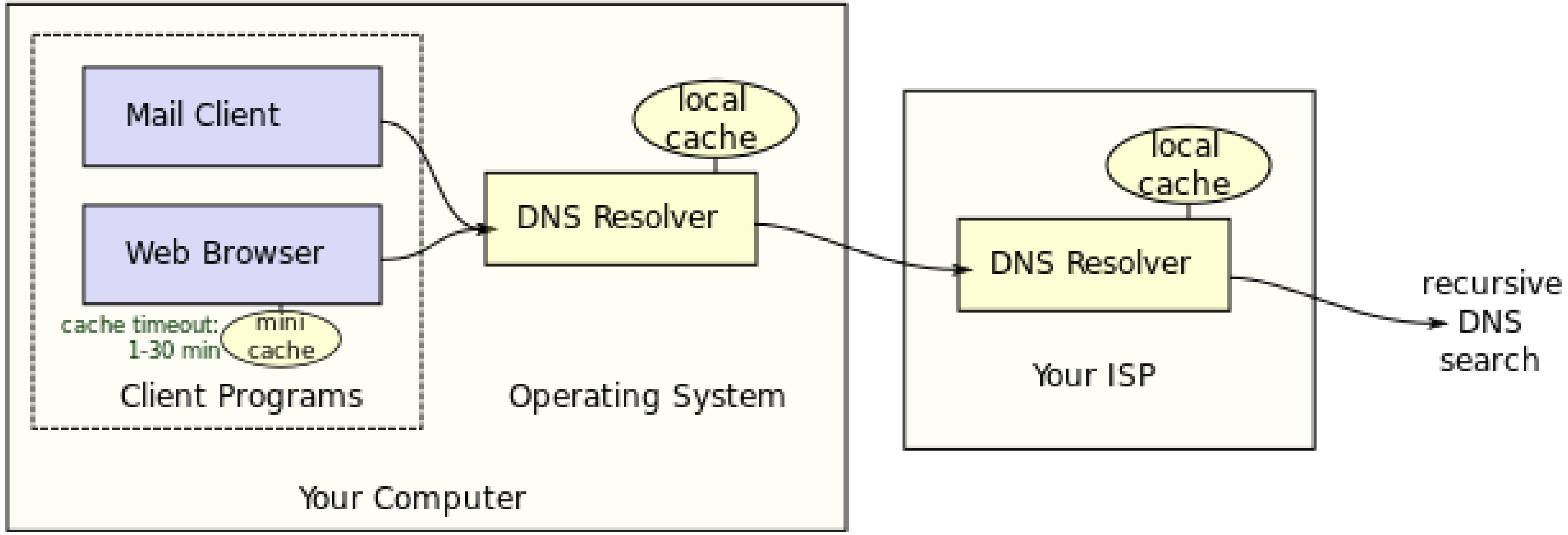
Each server returns the best answer it has

If the server cannot find an exact match, it returns a *referral:* a pointer to a server authoritative for a lower level of the domain namespace

Walking the Tree: End User

Applications place resolution requests to the *stub resolver* of the OS

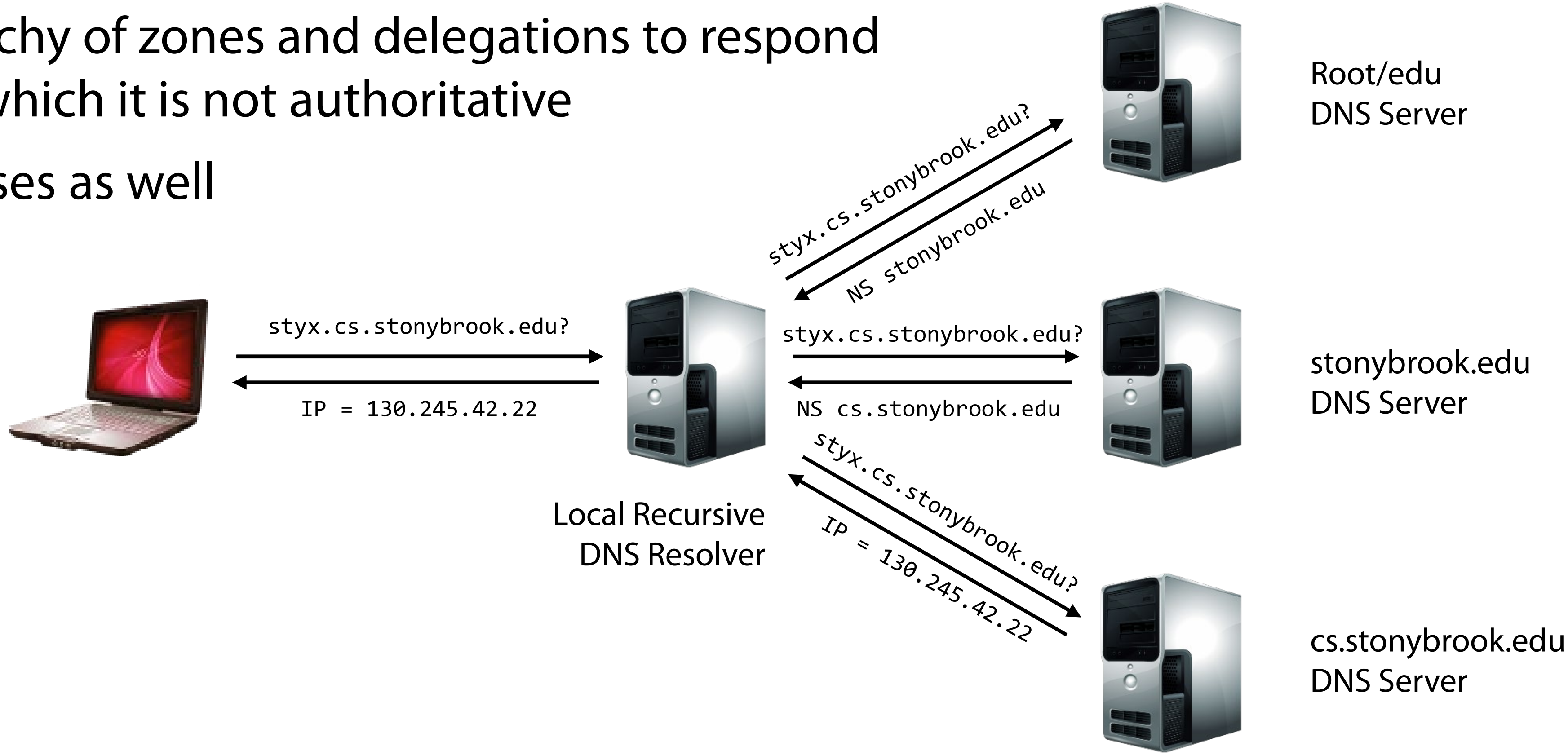
- The stub resolver then typically sends DNS queries to a *recursive resolver*
- Caches responses for future queries (TTL specified by owner)
- Negative responses are cached as well ➔ save time (misspelling, expired domains, …)



Walking the Tree: Recursive Resolver

Hosts know at least one local DNS *recursive resolver*

- Usually specified by the ISP or organization through DHCP – users can manually override it
- Uses the hierarchy of zones and delegations to respond to queries for which it is not authoritative
- Caches responses as well



DNS message

```
+---------------------+
|        Header       |
+---------------------+
|       Question      | the question for the name server
+---------------------+
|        Answer       | RRs answering the question
+---------------------+
|      Authority      | RRs pointing toward an authority
+---------------------+
|      Additional     | RRs holding additional information
+---------------------+
```

DNS header

```
                                1  1  1  1  1  1
  0  1  2  3  4  5  6  7  8  9  0  1  2  3  4  5
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                      ID                       |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|QR|   Opcode  |AA|TC|RD|RA|   Z    |   RCODE   |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                    QDCOUNT                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                    ANCOUNT                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                    NSCOUNT                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|                    ARCOUNT                    |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

Mostly uses UDP (port 53); TCP sometimes is used for long responses and zone transfers

Recent developments: DNS over TLS (port 853) and DNS over HTTPS (port 443)

DNS resource record

```
                                    1  1  1  1  1  1
      0  1  2  3  4  5  6  7  8  9  0  1  2  3  4  5
    +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
    |                                               |
    /                                               /
    /                      NAME                     /
    |                                               |
    +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
    |                      TYPE                     |
    +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
    |                     CLASS                     |
    +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
    |                      TTL                      |
    |                                               |
    +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
    |                   RDLENGTH                    |
    +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--|
    /                     RDATA                     /
    /                                               /
    +--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
```

NAME: Name of the node to which this record pertains

TYPE: RR type in numeric form (e.g., 15 for MX RRs)

CLASS: Class code

TTL: Count of seconds the RR stays valid

RDLENGTH: Length of RDATA field

RDATA: Additional RR-specific data

Types of Resource Records

Besides translating host addresses, DNS is in essence a generic "directory" service for other host-related information

`A:` host address

`NS:` authoritative name server

`MX:` mail server of domain

`CNAME:` aliases for other names (not IP addresses)

`PTR:` map IP addresses to names (reverse lookup)

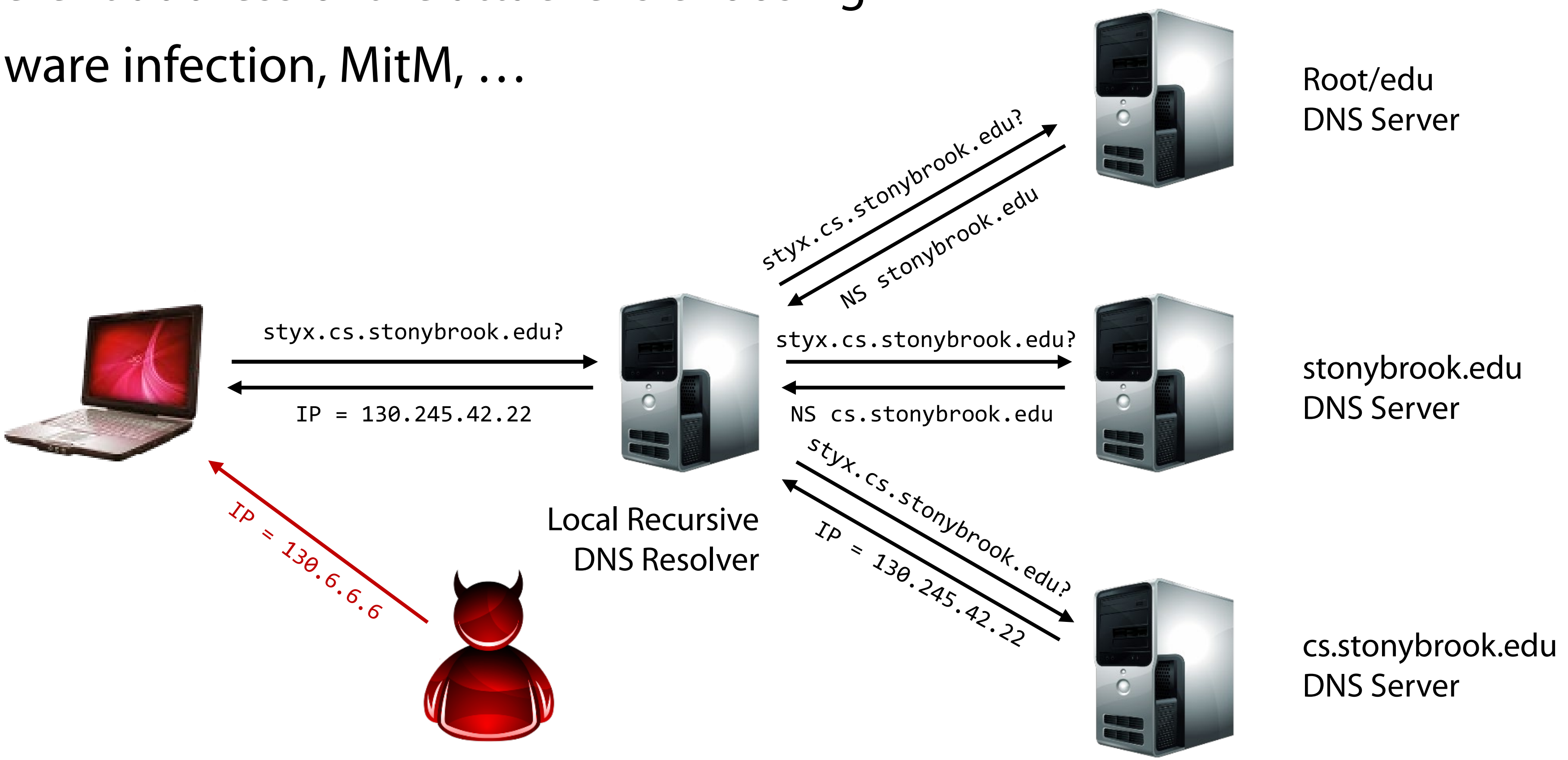
`TXT:` arbitrary data associated with the domain

`HINFO:` host information

DNS Spoofing/Cache Poisoning

No authentication: responses can be spoofed!

- Point to a different address of the attacker's choosing
- Phishing, malware infection, MitM, …



Subverting Name-based Authentication [Bellovin 1990]

Trusted access based on host names *(not a good idea)*

- Server performs reverse DNS lookup to check if a client's host name is contained in a list of authorized host names
- Example: "r-utilities" perform name-based authentication (e.g., permit all hosts in `.rhosts` to `rsh`/`rlogin` on the server)

Attack: fake a PTR record for an attacker-controlled IP address to return a trusted hostname

- When `rsh`/`rlogin` receives the connection, the reverse lookup using the attacker's originating IP will return a trusted name…

Fix: cross-check the returned name by performing a name lookup

- The returned IP address will not match the attacker's IP address (IP ➔ name ➔ IP)

DNS Poisoning: Different Vantage Points

Off-path: attackers cannot observe any DNS messages *(blind)*

- Blind packet injection: must *guess* the proper values in the forged response fields according to the query
- Race condition: forged response must arrive before the real one

On-path: attackers can passively observe the traffic (queries) and inject properly forged responses *(MotS)*

- Easy to mount in WiFi networks, by ISPs, …
- Race condition: forged response must arrive before the real one

In-path: attackers can block responses from reaching the victim, and inject forged ones instead *(MitM)*

- But then the attacker can do so much more…

DNS TXID

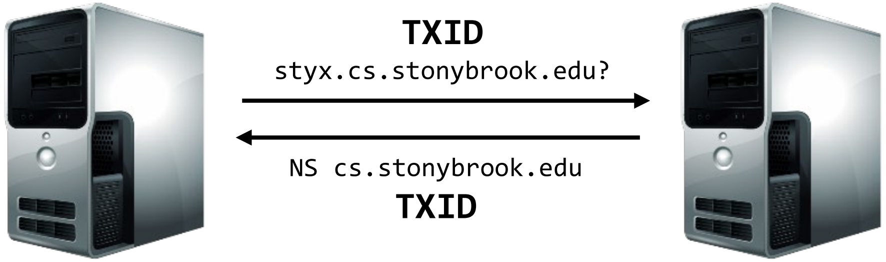
Synchronization mechanism between clients and servers

16-bit transaction identifier

- Randomly chosen for each query
- Response accepted only if TXIDs match
- Response cached according to TTL (e.g., one day)

Attacker has to win a race

- Guess the correct TXID
- Response *src IP* and *dst port* should match query *dst IP* and *src port*



It's possible! Kaminsky attack

Kaminsky Attack (Dan Kaminsky, 2008)

Goal: poison a server's DNS cache entry for `example.com`

- Cannot just send random DNS packets to the recursive
- The server will only accept responses to *pending* queries

Requirements for a successful forged response:

- Matching source and destination IP address ➔ trivial
- Matching source and destination UDP port ➔ old DNS servers would use 53 for source port too (even if different, can be easily inferred if it changes predictably)
- Matching TXID ➔ 16 bits of randomness
- Matching question section ➔ the attacker targets a particular recursive server, and thus can trigger a query at will

Additional issue: `www.example.com` may already be in the recursive's cache

- In that case the recursive will not ask the authoritative

Kaminsky Attack (Dan Kaminsky, 2008)

Query the recursive with any subdomain not in the cache

- Non-existent subdomains are fine: `foo1.example.com`
- Not affected by TTL (e.g., as would be the case for `www.example.com`)
- Causes the targeted resolver to query the authoritative server(s) for the requested subdomain

The attacker then floods the resolver with many forged responses

- Each containing a different guess of the query's TXID

Fake referral →

```
;; ANSWER SECTION:
foo1.example.com.      120   IN A   10.0.0.10
;; AUTHORITY SECTION:
example.com.         86400   IN NS
ns1.example.com.
;; ADDITIONAL SECTION:
ns1.example.com.    604800   IN A   10.6.6.6
```

If the race is lost, just repeat with a different subdomain!

Kaminsky Attack: Key Insights

The recursive will always contact the authoritative of `example.com` for any lookup of a non-existent domain

- E.g., `foooo1.example.com`

The attacker can poison the cache with values in the additional RR field

- It's fine that the query is for a non-existent domain

Today's internet speeds allow flooding the server with thousands of packets before the real response arrives

- Allows for more than enough TXID guesses

Fix: source UDP port randomization

- Orders of magnitude higher TXID + port entropy

Pharming

Traffic redirection at the client side by malware that alters DNS settings

- Change the system's (or the local router's) DNS server
- Add entries in /etc/hosts
- Example: DNSChanger: estimated 4M infected computers, US$14M profit (FBI's "Operation Ghost Click")

Drive-by pharming

- A malicious web page contains JavaScript code that alters the local router's DNS server *from the inside LAN*

Dynamic pharming (aka DNS rebinding)

- Quickly switch mapping of `bank.com` between a malicious and a real IP
- Serve malicious script, then switch to the real site ➔ same origin policy is bypassed

More Ways to Intercept Traffic using DNS

DNS hijacking by going after registrars

- Social engineering, stolen credentials, insider attacks, …

Typosquatting/registering expired domains

- Phishing – www.paypa1.com
- Hijack scripts hosted on expired domains still in use by other web pages
- Hijack third-party libraries/modules of popular programming library repositories (NPM, PyPI, …)

Other DNS Attacks

DoS on root/critical servers

- Or other targets -> DNS amplification attacks

Covert DNS communication

- Data exfiltration, C&C, …

Zone transfers

- Reconnaissance

Server bugs

- System compromise

Censorship

PyPI Python repository h ×

Sophos Ltd. [GB] | https://nakedsecurity.sophos.com/2017/09/19/pypi-python-repository-hit-by-typosquatting-sneak-attack/

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PyPI Python repository hit by typosquatting sneak attack

19 SEP 2017 1

Security threats, Vulnerability

Previous: DOJ lets itself off the privacy hook

Next: Apple's new tracking protection is "sabotage", clai...

by John E Dunn

f 0

Somebody with time on their hands has tested out a devious new form of typosquatting targeting developers installing Python packages from the PyPI (Python Package Index) repository.

According to an advisory posted to the Slovak National Security Office (NBU), ten packages for Python 2.x were removed from the site after their setup.py files were found to contain malicious code. The bad code was hiding in plain site in the repository, using filenames either nearly identical to, or which could be mistaken for, legitimate ones.

M-I-C-K-E-Y-M-C
Guest
equifaxsecurity.com
got caught today, it's all over the papers.
n Computer Crime Scandal",
"Hacker Ar
Damn kids. They're all ALIKE....
piece psychology and 1950's techNObrain, ever take a look behind
what made him tick,
what forces shaped him,
what may have molded him?
volved in numerous secret raids on club penguin, and I have
オシ!
what could be dirt-cheap if it wasn't run by profiteering gluttons, and
We explore...
We seek after knowledge...
ut nationality, without religious bias...
and YOU call us criminals.
wage wars, you murder, cheat, and lie to us and try to make us

Cybersecurity Incid
Guest
Secure
https://www.equifaxsecurity2017.com
EQUIFAX
Return to equifax.com
To enroll in complimentary identity theft protection and credit file monitoring, click here.
Cybersecurity Incident & Important Consumer Information
Consumer Notice
FAQs
Potential Impact
Enroll
TrustedID Premier
Contact Us
Equifax Announces Cybersecurity Incident Involving Consumer Information
No Evidence of Unauthorized Access to Core Consumer or Commercial Credit Reporting Databases
Company to Offer Free Identity Theft Protection and Credit File Monitoring to All U.S. Consumers
Rick Smith, Chairman and CEO of E...
September 7, 2017 — Equifax Inc. (NYSE: EFX) today announced a cybersecurity incident potentially impacting approximately 143 million U.S. consumers. Criminals exploited a U.S. website application vulnerability to gain access to certain files. Based on the company's investigation, the unauthorized access occurred from mid-May through July 2017. The company has found no evidence of unauthorized activity on Equifax's core consumer or commercial credit reporting databases.

DNSSEC

Goal: enable authentication and ensure the integrity of DNS requests and responses

Non-goals: availability, confidentiality

Cryptographically signed resource records

Resolvers can verify the signature

Two new resource types:

DNSKEY: creates a hierarchy of trust within each zone

Name = Zone domain name; Value = Public key for the zone

RRSIG: Prevents hijacking and spoofing

Name = (type, name) tuple, i.e. the query itself; Value = Cryptographic signature of the query results

Not a complete solution

Enables DoS amplification/CPU exhaustion attacks

Forgery of delegation records still possible

No "last mile" protection

DoH/DoT (DNS over HTTPS/TLS)

Both protocols use end-to-end encryption between the client and the DoH/DoT-based DNS resolver

- Privacy: DNS requests cannot be monitored (e.g., nosy ISPs, censorship)
- Security: DNS responses cannot be manipulated (e.g., MitM/MotS)

DoH: queries and responses are transferred over HTTPS (RFC8484)

DoT: queries and responses are transferred over TLS (RFC7858)

- Main difference: DoT uses its own standard port (853) → can be trivially blocked
- Better for corporate environments where administrators need to maintain control

Since February 2020, Firefox uses DoH by default for users in the USA

- Cloudflare is the default provider (NextDNS or a custom server can be selected)

DoH/DoT Drawbacks

Privacy: shifts trust to a different entity

- The ISP cannot monitor the traffic, but the DoH server provider now can
- Mozilla's Trusted Recursive Resolver program: Cloudflare has committed to i) throwing away all PII after 24 hours, ii) never provide that data to third parties, iii) regular audits
- Mitigation: spread requests across multiple vendors (K-resolver), introduce intermediate proxies (Oblivious DoH)

Security: reduced visibility and control

- Real-time DNS monitoring is invaluable for threat detection
- Analysis of logged DNS data is invaluable for incident response and forensics
- DNS-level enterprise policies (filtering) becomes challenging
- Mitigation: use endpoint monitoring software (attackers can still tamper with it, not possible for BYOD), intercept HTTPS (some organizations do that anyway)