Privacy in the Domain Name System (DNS):

DNS Privacy in Practice

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Overview

• First - lets look at your DNS queries!
• Desktop DoT stub resolvers (client) (Stubby)
• Set up your own DoT recursive (Unbound) - decrypt DoT
• DoH - Clients & Browsers (Firefox) - decrypt DoH
• Mobile Apps
• DNS Libraries (getdns)
• Routers

Firefox DoH Decryption is easier....
dnsprivacy.org

- DNS Privacy Clients
- DNS Privacy Servers setup guides
- DNS Privacy Test and Public resolvers
- DNS Privacy Monitoring
- DNS Privacy Current work

Reference material here for most setups and recursive resolvers
DNS Basics
DNS Basics - A UDP query

'sig' is available on most *nix systems (or 'drill')

```
sara@virgo:~> dig @8.8.8.8 www.example.com A

; <<>> DiG 9.12.0 <<>> @8.8.8.8 www.example.com A
; (1 server found)
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 60505
;; flags: qr rd ra ad; QUERY: 1, ANSWER: 1, AUTHORITY: 0, ADDITIONAL: 1

;; OPT PSEUDOSECTION:
;; EDNS: version: 0, flags:; udp: 512
;; QUESTION SECTION:
;www.example.com. IN A

;; ANSWER SECTION:
www.example.com. 3429 IN A 93.184.216.34

;; Query time: 6 msec
;; SERVER: 8.8.8.8#53(8.8.8.8)
;; WHEN: Tue Jun 11 14:21:59 BST 2019
;; MSG SIZE  rcvd: 60
```
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DNS Basics - A UDP query

'nslookup' is available on Windows

C:\Users\sara>nslookup -type=A www.example.com 8.8.8.8
Server: google-public-dns-a.google.com
Address: 8.8.8.8

Non-authoritative answer:
Name: www.example.com
Address: 93.184.216.34

order is important!
DNS Basics - A UDP query

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Server: google-public-dns-a.google.com
Address: 8.8.8.8

Name: www.example.com
Address: 93.184.216.34
```

```
C:\Users\sara>nslookup -debug -type=A www.example.com 8.8.8.8
----------
Got answer:
HEADER:
  opcode = QUERY, id = 1, rcode = NOERROR
  header flags: response, want recursion, recursion avail.
  questions = 1, answers = 1, authority records = 0, additional = 0

QUESTIONS:
  8.8.8.8.in-addr.arpa, type = PTR, class = IN
ANSWERS:
  -> 8.8.8.8.in-addr.arpa
     name = google-public-dns-a.google.com
     ttl = 1957 (32 mins 37 secs)

----------
Server: google-public-dns-a.google.com
Address: 8.8.8.8
----------
Got answer:
HEADER:
```
DNS Packet structure
DNS Packet structure

- ID
- QDCOUNT
- NSCOUNT
- Questions...
- Answer RRs...
- Authority RRs...
- Additional RRs...
- Opcode
- AA
- TC
- RD
- RA
- Z
- AD
- CD
- RCODE
DNS Packet structure
Exercise - use dig

- Do a dig for a domain name and also try these options

  dig @8.8.8.8 www.example.com A
  - +short (just IP)
  - +qr (also print query)
  - +trace (trace delegations from the root - shows auth servers)
  - +tcp (but alas, ‘dig’ doesn’t do TLS, more on that later)
Exercise -
look at your DNS Settings

• Do ‘dig’ again, without the @8.8.8.8 - what IP was used?

• Look at system settings via a GUI or command line
  • Note there are usually multiple settings from command line

• See next slides for OS specifics
  • *nix systems
  • Windows
Finding your DNS settings - *nix

- **macOS GUI:**
  - Settings->Network->Advanced->DNS

- **Command line:** (Most *nix distros don’t directly use /etc/resolv.conf now)
  - systemd-resolved.service: `resolvectl status` (Global)
  - for macOS run `scutil --dns` and look at ‘lan’

- **Flush the cache:**
  - macOS 10.14: `sudo killall -HUP mDNSResponder`
  - systemd: `sudo systemctl-resolve --flush-caches`
Finding your DNS settings  
- Windows

- Open the Control Panel
- Choose 'Network and Internet'
- Choose 'View network status and tasks' under 'Network and Sharing Center'
- Choose 'Change adapter settings' from the left hand menu
- Then choose your interface - most likely either 'Wi-fi'
- In the dialog that appears, click on the 'Properties' button at the bottom
- Double click on 'Internet Protocol Version 4 (TCP/IPv4)' at the bottom
- Repeat for 'Internet Protocol Version 6 (TCP/IPv6)'
- Flush DNS cache: from a terminal run 'ipconfig /flushdns'
Exercise - DNS traffic inspection

- Install Wireshark (GUI) or tcpdump (command line)
- Close all your apps
- Flush the local DNS cache (see previous slides)

- Start a capture with WS:
  - Choose the Wifi (or Ethernet) interface
  - Add a capture filter of ‘port 53’
  - Hit the Blue fin
  - Add a filter of ‘ip.addr == 8.8.8.8’
  - `tcpdump -i eth0 host 8.8.8.8 and port 5 -n --v --X`  

- Do a few ‘dig’s to 8.8.8.8 and look at the packets
  (capture bytes for later on!)
Exercise - DNS traffic inspection

• Close all your apps

• Flush the local DNS cache (see previous slides)

• Then open one by one to see the DNS queries….

• Change your DNS setting and send all your queries to Google/Cloudflare/Quad9 (if you dare!)
What DNS reveals

- Mail clients - email hosting (server name!), which client
- Chat services - jabber server and Slack channels
- Calendars - where hosted
- Apps - often check for updates when opened
- Browsers - which client, which plugins. Open tabs, most visited, favourites, .... Then your browsing...
DoT on the Desktop
kdig & getdns_query

- ‘kdig’ comes as part of the ‘knot’ package (no Windows package)
  - syntax is exactly like ‘dig’ but…
  - +tls

- getdns_query - comes as part of the Stubby packages,
  - syntax is similar to dig, but different and output format is very different!
Lets do DoT on the desktop!
# DNS Privacy

Let's do DoT on the desktop!

<table>
<thead>
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<th>Software</th>
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| **Stubby**     | • Specifically designed as a privacy stub  
                 • Best for upstream performance (pipelines queries) + privacy features (but no cache yet) |
| **Unbound**    | • Can use as a caching forwarder  
                 • But uses a new connection for each query (poor performance)  
                 • Can also configure stub zones |
| **BIND**       | • Does not do DoT natively, but can be set up with a TLS proxy to forward queries over TLS |
| **Knot resolver** | • Similar to Unbound but less well known |
| **systemd**    | • Native support but very ‘systemd’-like…. (only Opportunistic) |
**Lets do DoT on the desktop!**

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How does Stubby work?

- **DHCP provided resolver**
- **System stub resolver**
- **DNS**
- **App**
- **Desktop**

- DNS system library call `getaddrinfo()`
How does Stubby work?

App

DNS system library call
getaddrinfo()

Desktop

system stub resolver
How does Stubby work?

In the diagram:
- **App** interacts with a **DNS system library call** `getaddrinfo()` to retrieve DNS addresses.
- A **system stub resolver** is used to resolve DNS requests.
- A **Stubby** component is involved in DNS resolution.

Desktop
How does Stubby work?

- System stub resolver
- Stubby

Desktop

DNS system library call `getaddrinfo()`

Stubby Configured resolver

DoT
Stubby - Installing

• Stubby [Homepage] - built on the [getdns] library
• Stubby [Installation Guide]

  • Linux distros
    • Packages (NOTE: debian package version is wrong!)
    • Build from source

  • macOS
    • Homebrew
    • Prototype StubbyManager GUI for macOS

• Windows
  • Windows installer (MSI, zip)
  • Chocolatey package
Install Stubby!
Stubby GUI

Service Status: **Running**

- **Start**
- **Stop**
- **Test**
- **Restart**

**DNS Servers:**
- **Use Stubby DNS**

Start the service then check this box and apply settings to start using Stubby DNS.

Hit the Stop button to return to default DNS settings.

**Advanced...**  **View the log...**

**Revert to default**  **Revert**  **Apply**
Stubby GUI

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Stubby GUI

- Update system resolver
- Edit the config file

![Screenshot of Stubby GUI]

**Service Status:** Running

**DNS Servers:**
- Use Stubby DNS

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*Hit the stop button to return to default DNS settings.*
Stubby GUI

Update system resolver

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Start the service then check this box and Apply settings to start using Stubby DNS.
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Advanced...
View the log...

Revert to default
Apply
Stubby - Configuring

- Stubby has a stubby.yml config file - defaults:

```yaml
resolution_type: GETDNS_RESOLUTION_STUB
listen_addresses:
  - 127.0.0.1
  - 0::1
dns_transport_list:
  - GETDNS_TRANSPORT_TLS
tls_authentication: GETDNS_AUTHENTICATION_REQUIRED
tls_query_padding_blocksize: 128
edns_client_subnet_private: 1
round_robin_upstreams: 1
idle_timeout: 10000
upstream_recursive_servers:
  - address_data: 145.100.185.15
tls_auth_name: "dnsovertls.sinodun.com"
tls_pubkey_pinset:
  - digest: "sha256"
    value: 62lKu9HsDVbyiPenApnc4sfmSYTHOVfFgL3pyB+cBL4=
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Listen for queries coming from the local machine.
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Use ONLY TLS to the recursive, require auth
```
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Details of what/how to send queries to recursive
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Which recursive + auth details (default is Stubby servers)
```
Stubby - Run it

- Run from the command line to start e.g.
  
  ```
  sudo <path_to_exe>stubby -l <-C stubby.conf>
  ```

- Look at log - reports config

- Test Stubby. Open a new terminal and do a query directly to Stubby
  
  ```
  dig @127.0.0.1 www.example.com
  ```
Run Stubby!
Stubby - Use for all DNS

- Need to update your system resolver settings (and hit ‘Apply’):
  [systemd probably edit /etc/systemd/resolved.conf but…]
  - 127.0.0.1
  - 0::1

- Stubby log: lots of TLS connections (or a few long-lived)

- Look in Wireshark
  - No queries on port 53
  - The switch to port 853 - your queries are hidden in TLS sessions (note Wireshark doesn’t recognise DoT)!
How to decrypt TLS traffic?

• Client session keys - need a way to export them from the client (works for all TLS versions/cipher suites)
  • Stubby/Unbound do not support this yet
  • (Later we will see that Firefox does)

• Server private RSA keys - need access to private keys, normally only admins have this
  • Does not work with PFS ciphers (TLS 1.3, some TLS 1.2)
  • We can set up our own server to access the keys but have to restrict server to ‘weak’ ciphers
Stubby - other options

• Depending on your OS, you can configure Stubby to run as a service
  • Note you might have issues as you change network or hit a captive portal….

• Probably have `getdns_query` installed (‘dig’ like but with DoT)
  • `getdns_query @8.8.8.8~dns.google www.example.com -Lm +return_call_reporting`

• If you want to do Opportunistic DoT to the local resolver, reset your system resolvers and update 3 items in your config:

```plaintext
dns_transport_list:
  - GETDNS_TRANSPORT_TLS
  - GETDNS_TRANSPORT_UDP
  - GETDNS_TRANSPORT_TCP
tls_authentication: GETDNS_AUTHENTICATION_NONE
# upstream_recursive_servers:
#  - address_data: 145.100.185.15
#    tls_auth_name: "dnsovertls.sinodun.com"
```
Stubby - as a Sophisticated Service

- Ideally - you could configure which networks you ‘trust’ and which you don’t and use different configurations

- REALLY need a nice GUI with visual indicators to help users understand the state (GUI icon in menu: Bold=Strict)

- BUT - think about the usability here. ‘Usable Security’
  - Green lock in HTTPS is per website (still confusing)
  - DNS is per network… and users don’t understand DNS!
Unbound as a DoT stub
Unbound as a DoT stub

- Actually a recursive resolver but can be configured to cache locally and just forward all queries to another recursive resolver.

- Download from: [https://nlnetlabs.nl/projects/unbound/download/](https://nlnetlabs.nl/projects/unbound/download/)
  - Packages, homebrew, Windows installers

- Example config here: [Unbound config](https://nlnetlabs.nl/projects/unbound/download/) and in git repo
  - Must specify path to CA bundle to do authentication (Windows requires `tls-win-cert` instead). May need to change user...
  - Can set up stub-zones for local queries

- To run in foreground: `sudo unbound -c <conf_file> -d <-vvvv>`
  - Unbound uses a new TCP connection for _every_ query (inefficient)
Bonus points: Unbound+Stubby
Running a DoT recursive resolver
Running a DoT Recursive

- Overview is here: Running a DNS Privacy Resolver
- Several open source DNS implementations do DoT natively (some do DoH too)
- Big differences to ‘normal DNS resolver’
  - Need to have a valid certificate for name (LE is good option)
  - Need a bit more configuration
  - Need to think about data handling (Best practices)
Unbound as a recursive DoT resolver

- Download from: [https://nlnetlabs.nl/projects/unbound/download/](https://nlnetlabs.nl/projects/unbound/download/)
- Packages, homebrew, Windows installers

- Full example config is here: [Unbound server config](https://nlnetlabs.nl/projects/unbound/server-config)
- [Next slide](#) (and git repo) has suggested config for this lab

- Need to create a self-signed certificate using openssl & update paths in config file (need openssl 1.1.1):

```
> openssl req -x509 -newkey rsa:4096 -keyout key.pem -out cert.pem -days 7
> openssl rsa -in key.pem -out key_rsa.pem
```

- Sample cert and key files are in the git repo
unbound_rec.conf

server:
  directory: "/etc/unbound"
username: unbound
chroot: "/etc/unbound"
logfile: "" # logging will be to stdout.
pidfile: "/etc/unbound/unbound.pid"
# verbosity: 1 # uncomment and increase to get more logging.
# listen on localhost on port 853, answer queries from the local subnet.
interface: 127.0.0.1@853
interface: 0::1@853

tls-service-key: "<path>/key_rsa.pem"
tls-service-pem: "<path>/cert.pem"
tls-port: 853
incoming-num-tcp: 100 # Number of simultaneous incoming TCP connections

# Listen on UDP but still issues queries upstream over UDP.
# Only available in 1.6.7 and later
udp-upstream-without-downstream: yes
qname-minimisation: yes # Enable QNAME minimisation

# Force a weak cipher suite to allow decryption
# NEVER USE IN PRODUCTION!!!
tls-ciphers: "RSA"
Unbound as a recursive DoT resolver

- To run in foreground: `sudo unbound -c <conf_file> -d <-v>`

- Now lets point Stubby at this recursive resolver

  ```
  tls_authentication: GETDNS_AUTHENTICATION_NONE
  upstream_recursive_servers:
    - address_data: 127.0.0.1
  ```

- Or use ‘kdig’ or ‘getdns_query’ to do individual queries

- Look in Wireshark again on the ‘loopback’ interface with capture filter ‘port 853’ to see the traffic from Stubby to Unbound

- Look on port 53 to see the traffic from Unbound out the authoritative servers
Decrypt local DoT traffic

- In Wireshark go to Preferences
- Expand ‘Protocols’ and select the word ‘Protocol’
- Start typing ‘TLS’ - this will jump you to the TLS settings
- Click on the Edit button next ‘RSA keys list’
- Add an entry for 127.0.0.1, 853, tls, <path the ‘key_rsa.pem’ file>
- Then hit OK twice to save the settings
Decrypt local DoT traffic

- Now look at the TLS -> Server Hello in Wireshark and you will see a Cipher containing RSA

- Select a packet now marked as ‘Unknown Ignored Packet’ - Wireshark doesn’t support DoT directly

- Click on the ‘Encrypted Application Data’, then at the very bottom select the pane marked ‘Decrypted TLS bytes’ - you should see what looks like a domain name!
DoH on the Desktop
DoH for Desktop

• Clients:
  • Cloudflare have released two tools to provide DoH clients, see Cloudflared
  • Frank Denis has a dnscrypt-proxy (client proxy) that supports DoH.

• ‘dig’ like tool for DoH:
  • Curl also supports DoH https://github.com/curl/doh

./doh www.example.com https://cloudflare-dns.com/dns-query
DoH in Browsers
Browsers

- **Desktop:**
  - Firefox (DoH)
  - [Chrome (DoH)]
  - Yandex (DNSCrypt)

- **Mobile browser:**
  - Bromite - based on Chrome (DoH)
  - Tenta for Android (DoT)
Browsers

- Desktop:
  - Firefox (DoH)
  - [Chrome (DoH)]
  - Yandex (DNSCrypt)

- Mobile browser:
  - Bromite - based on Chrome (DoH)
  - Tenta for Android (DoT)
Firefox

- Download the latest Firefox Nightly (or Firefox)
- Close your other apps.
- See DNS activity via `about:networking` tab
  - Select ‘DNS Lookup’ to do individual queries (use refresh)
  - Select ‘DNS’ to see queries (Note TRR= False)
- 2 levels of config
  - ‘Easy’ via a Preferences GUI option
  - Low-level via `about:config`

Need Latest Firefox Nightly to decrypt DoH
Firefox - DoH in the GUI

- Firefox->Preferences. Scroll to bottom ‘Network Settings’ click on ‘Settings’
- Scroll the bottom to find the DoH checkbox
- Check the box and open a tab, look again at about:networking
- Look in Wireshark again… Nothing on port 53 or 853.
  Look on port 443 - can you tell the DNS from the HTTP?
  Note: all DoH goes to Cloudflare, use a filter expression to see only DoH:

<table>
<thead>
<tr>
<th>host cloudflare-dns.com</th>
</tr>
</thead>
<tbody>
<tr>
<td>ip.addr == 108.61.201.119 or ip.addr == 104.16.248.249 or ipv6.addr == 2606:4700::6810:f9f9 or ipv6 == 2606:4700::6810:f8f9</td>
</tr>
</tbody>
</table>
Firefox - DoH in the GUI

• Easy right? And you don’t need to be an Admin on the machine…
  • And remember - in the next release this may be on by default!
  • Too easy? Use it without knowing (back to Informed Consent)

• Extreme scenarios
  • Great to avoid DNS snooping and interference in untrusted network
  • But so easy a child in a house where parental controls are enabled can do it with no-one knowing

• But all your other DNS queries are still clear text…. 
Firefox - DoH via config

- Use the about:config tab and in the search box type ‘trr’

- Will see a variety of settings…
  - ‘trr.mode’ = 2. This will fall back to cleartext DNS via the system resolver if it can’t talk to the DoH resolver (like Op DoT)
  - ‘trr.mode’ = 3 fails instead (like Strict DoT)

- Go back to your DoH setting and ‘mis-type’ the URI and apply
  - Now all the traffic has TRR=false
  - Did you get a warning?

GUIs for DNS settings are hard….
Decrypt DoH traffic

• Great SharkFest presentation on this

• For long captures start Wireshark with capture filter
  `port 443 and host cloudflare-dns.com`

• Close then re-start Firefox Nightly set up to export session keys:

  • Linux/macOS - close Firefox and relaunch from command line:
    SSLKEYLOGFILE="$PWD/keys.txt" <path>/firefox -no-remote -profile /tmp/ff

  • Firefox on Windows, create start-fx.cmd file, without quotes in
    the set line:
    set SSLKEYLOGFILE=C:\Users\User\Desktop\keys.txt
    start firefox
Decrypt DoH traffic

- In Wireshark go to Preferences
- Expand ‘Protocols’ and select the word ‘Protocol’
- Start typing ‘TLS’ - this will jump you to the TLS settings
- (Pre)-Master-Secret log filename - click browse and select the file exported by Firefox. Click OK
- Hey presto! Wireshark decodes packets as DoH.
DoH

- HTTP request to https://dnsserver.example.net/dns-query

- Query can use POST or GET:

  ```
  :method = GET
  :scheme = https
  :authority = dnsserver.example.net
  :path = /dns-query?
  dns=AAABAAABAAAAAAA3d3dwdleGFtcGxlA2NvbQAAAQAB
  accept = application/dns-message

  :status = 200
  content-type = application/dns-message
  content-length = 61
  cache-control = max-age=3709
  <61 bytes represented by the following hex encoding>
  00 00 81 80 00 01 00 01 00 00 00 00 03 77 77 77
  ```

Query

Response
DoT/DoH for your mobile phone
# Mobile DNS encryption

<table>
<thead>
<tr>
<th>Mobile OS</th>
<th>Options</th>
</tr>
</thead>
</table>
| **Android** | **Android supports DNS-over-TLS in Android Pie**<br>Opportunistic by default to system resolver, also user override. Talk by the Android developers: [Video](#), [Slides](#)  
• [App called 'Intra'](#) which can be used to send all queries from the device over DoH to a user configured resolver  
• Cloudflare has an App: [1.1.1.1](#)  
• Quad 9 has an App: [Quad9 Connect](#)  
• Other apps are available…. |
| **iOS** |  
• Cloudflare has an App: [1.1.1.1](#)  
• Other apps are available….  
Work started on a Stubby app but stalled |

Mobile traffic inspection is not straightforward…
## Mobile DNS encryption

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</tr>
<tr>
<td><strong>iOS</strong></td>
<td>• Cloudflare has an App: <a href="#">1.1.1.1</a>&lt;br&gt;• Other apps are available….&lt;br&gt;Work started on a Stubby app but stalled</td>
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Mobile traffic inspection is not straightforward…
DNS Privacy Libraries
## DNS Privacy libraries

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<th>Language</th>
<th>Library</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (Nodejs, python)</td>
<td>getdns</td>
</tr>
<tr>
<td>Go</td>
<td>GoDNS</td>
</tr>
<tr>
<td>Rust</td>
<td>trust-dns</td>
</tr>
</tbody>
</table>
getdns

- **getdns** Modern, asynchronous DNS library with DNSSEC and DoT
- Specifically designed to be used by developers
- Implements new DNS features quickly (experimental)
- Significantly more useful than libc DNS functions

- Written in C but has Python and nodejs bindings
  - [Quick start guide to C library](#)
  - Deeper tutorial: Slides, Video

- Comes with a ‘dig’ like tool: **getdns_query**

```
getdns_query @8.8.8.8~dns.google www.example.com -Lm
+return_call_reporting
```
Routers

• DNS-over-TLS forwarding on a Turris router

• OpenWRT (LEDE)

• Asuswrt-Merlin