Messaging, Malware and Mobile Anti-Abuse Working Group

M³AAWG Companion Document: Recipes for Encrypting DNS Stub Resolver-to-Recursive Resolver Traffic

Version 1.0

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The direct URL to this paper is: www.m3aawg.org/dns-crypto-recipes

This document is intended to accompany and complement the companion document, "M³AAWG Tutorial on Third Party Recursive Resolvers and Encrypting DNS Stub Resolver-to-Recursive Resolver Traffic" (www.m3aawg.org/dns-crypto-tutorial).

This document was produced by the M³AAWG Data and Identity Protection Committee.

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Introduction

Before deciding to use any encrypted recursive-resolver protocol or service, a key point to understand is that encrypting stub-to-recursive traffic is still quite experimental. If you try encrypting your stub-to-recursive traffic, you will be doing so as an early adopter or a pilot project.

This means:

- Standards are still under development and implementations likely will evolve while you are using the technology. There may be bugs or other issues that still need to be fixed.

- Your operating system likely will not have native support for encrypted recursive resolvers, so you will need to add a third party package to try encrypting stub-to-recursive-resolver traffic.

- Your ISP will likely not have encrypted recursive resolvers for you to use, so you will need to trust a third party with your DNS queries.

- Paradoxically, using an encrypted recursive resolver will likely make your traffic stand out because you are doing something that is unusual.

- Since the protection that encrypted recursive resolvers deliver is still imperfect, you increase the chance that your traffic will actually end up being monitored.

If you are interested in encrypted recursive resolvers, try at least one option for you own personal traffic. It is one thing to read about these services and another to actually try using one (or more) of them yourself.

To facilitate this, we have developed detailed "recipes" for various protocols/providers for most common platforms:

- Mac OS X
- MS Windows 10
- iPhone
- Android
- Raspbian on a Raspberry Pi

The recipes in this companion document should be sufficient to allow you to set up the system and be running with at least one encrypted recursive resolver solution for each popular platform.

One remaining question you may have: Should you encrypt device-by-device or at the home gateway only?

If you are like most people, you have multiple devices – maybe a desktop, a laptop, a smart phone, a tablet or e-reader, a smart TV, and more. You probably also use at least some of those devices at multiple locations – home, office, restaurants, your children's schools, the gym, while you are traveling, and so on. Do you plan to encrypt the DNS traffic to/from each of those devices on a device-by-device basis? (It can be difficult to encrypt multiple devices one by one.) Or are you going to encrypt all of your DNS traffic at your home gateway (i.e., your broadband router)? If you decide to go this route, what will you do when you are using a third party network (e.g., at the office, at restaurants, at your children's schools, the gym, while traveling, or somewhere else)?

The best option if you are going to encrypt DNS: Do both –
per-device DNS encryption and at-the-gateway DNS encryption by default

Section 1. Configuring a Mac OS X System to Encrypt Stub-to-Recursive-Resolver Traffic

Example	Encryption Technology	Software	Recursive Resolver Used
A	DNS over HTTPS	Cloudflared-proxy	Cloudflare's 1.1.1.1
B	DNSCrypt	DNSCrypt-proxy 2	Quad9's 9.9.9.9
C	DNS over TLS	Stubby	The Stubby author's test
D	DNS over HTTPS	Firefox TRR	Four different options shown

Example A: Implementing DNS over HTTPS Using the Cloudflared-proxy to Cloudflare's 1.1.1.1

We will install cloudflared-proxy as described at:
https://developers.cloudflare.com/1.1.1.1/dns-over-https/cloudflared-proxy/

The cloudflared-proxy can be installed on the Mac using the third-party Mac package manager "Homebrew" (see https://brew.sh/).

To install cloudflared-proxy for testing:

- As always, before any system maintenance, ensure that you have a recent backup of your system and that your system is fully patched with no pending updates.

- Now open a Terminal window and install Homebrew, if you have not previously done so. (As described above, do this at https://brew.sh/)

- Next, use Homebrew to install cloudflared:
  `$ brew install cloudflare/cloudflare/cloudflared`

```
$ brew install cloudflare/cloudflare/cloudflared
==> Installing cloudflared from cloudflare/cloudflare
==> Downloading https://developers.cloudflare.com/argo-tunnel/dl/cloudflared-201
######################################################################## 100.0%
🍺  /usr/local/Cellar/cloudflared/2018.10.5: 3 files, 29.9MB, built in 13 second
s
$
```

- You may want to check to ensure that cloudflared is now actually installed:
  `$ cloudflared --version`

  You should see something that looks like:

```
$ cloudflared --version
cloudflared version 2018.10.5 (built 2018-10-30-2057 UTC)
$
```

- Now run cloudflared (you will need your admin password because the application binds to a privileged port number):
  `$ sudo cloudflared proxy-dns`

After you have successfully entered your admin password, you should see something that looks like:

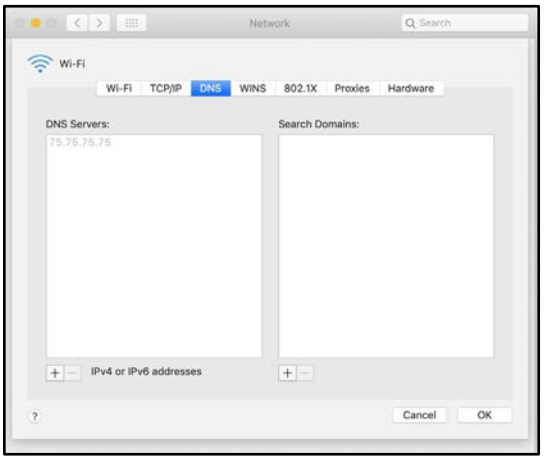
```
$ sudo cloudflared proxy-dns
Password:
INFO[0000] Adding DNS upstream                           url="https://1.1.1.1/dn
s-query"
INFO[0000] Starting metrics server                       addr="127.0.0.1:58674"
INFO[0000] Adding DNS upstream                           url="https://1.0.0.1/dn
s-query"
INFO[0000] Starting DNS over HTTPS proxy server          addr="dns://localhost:5
3"
```

- In **another** terminal window, confirm that you have a recursive resolver answering at 127.0.0.1:

```
$ dig +short @127.0.0.1 cloudflare.com
198.41.214.162
198.41.215.162
$
```

- Now go to Mac OS System Preferences → System Preferences → Network

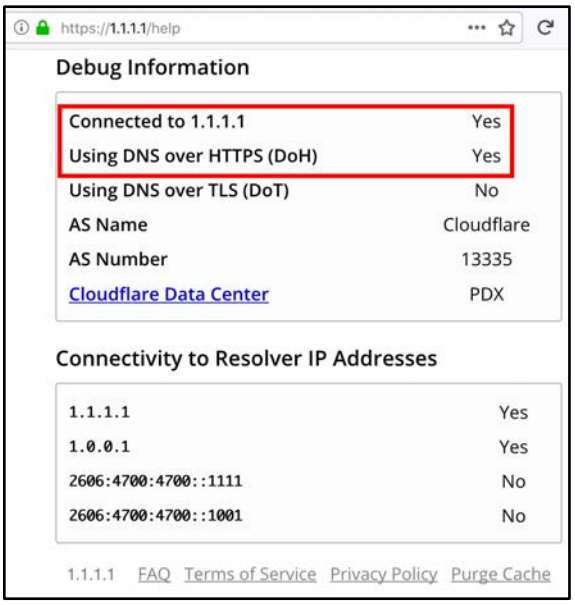
- Select the relevant network interface (probably "WiFi"). Click on the *Advanced* button. Then click on the *DNS* tab.



Important: Carefully write down the current domain name server IP(s) you see!

- Once you have written down the current name server IP(s), change the DNS server to point at 127.0.0.1 instead. Normally you can do this by clicking the "+" sign underneath the left column and entering 127.0.0.1 as the new nameserver to use. Click *OK* to close the *Advanced* window and *Apply* to save the *Network* setting. Close the *Network* settings window.

- Do whatever other testing you would like to do. For example, use a browser to visit https://1.1.1.1/help:



If you want to **uninstall cloudflared** after you are done testing it:

- Click on the Terminal window running cloudflared proxy-dns, then hit *control-C* to kill that process.

- Go to *Mac OS System Preferences* → *Network* → *Advanced* → *DNS* and change 127.0.0.1 back to the IP address(es) you were originally using.

- Click OK to close the *Advanced* window and click *Apply* to save the Network setting.

- Use Homebrew to remove the cloudflared software:
  ```
  $ brew remove cloudflare/cloudflare/cloudflared
  ```

Or, if you want to **make cloudflared persistent; e.g., keep and use cloudflared from this point forward:**

- Complete steps 5 and 6 as described at https://developers.cloudflare.com/1.1.1.1/dns-over-https/cloudflared-proxy/

Example B: Implementing DNSCrypt Using DNSCrypt-proxy 2 with Quad9's DNSSEC-enabled and Filtered Service

We will install DNSCrypt-proxy approximately as described at
https://github.com/jedisct1/DNSCrypt-proxy/wiki/Installation-macOS

To install DNSCrypt-proxy 2 for testing:

- As always, before any system maintenance, ensure that you have a recent backup of your system, and that your system is fully patched with no pending updates.

- Now open a Terminal window and install Homebrew if you have not previously done so. Do this as described at https://brew.sh/

- Use Homebrew to install `wget` if you do not already have it:
  `$` **`brew install wget`**

- Also use Homebrew to install `minisign` if you do not already also have that package:
  `$` **`brew install minisign`**

- Get the DNSCrypt-proxy 2 code (**Note:** the version of this may change over time):
  `$` **`wget https://github.com/jedisct1/DNSCrypt-proxy/releases/download/2.0.17/DNSCrypt-proxy-macos-2.0.17.tar.gz`**

- Also get the corresponding signature for verification:
  `$` **`wget https://github.com/jedisct1/DNSCrypt-proxy/releases/download/2.0.17/DNSCrypt-proxy-macos-2.0.17.tar.gz.minisig`**

- Use minisign to confirm the downloaded code is intact and authentic:
  `$` **`minisign -Vm DNSCrypt-proxy-*.tar.gz -P RWTk1xXqcTODeYttYMCMLo0YJHaFEHn7a3akqHlb/7QvIQXHVPxKbjB5`**

  You should see something like: "Signature and comment signature verified"

- Assuming the signature verifies correctly, untar/ungzip that file by entering:
  `$` **`tar xfv DNSCrypt-proxy-macos-2.0.17.tar.gz`**

  As that archive is processed, you will see a number of file names displayed.

- Change down into the directory just created by tar:
  `$` **`cd macos`**

- Copy the template config file to DNSCrypt-proxy.toml:
  `$` **`cp example-DNSCrypt-proxy.toml DNSCrypt-proxy.toml`**

- Tweak the options in that config file appropriately:
  - For example, tell DNSCrypt-proxy to **only** use DNSCrypt. To help ensure this, edit the **`DNSCrypt-proxy.toml`** file with your favorite text editor and make sure **`DNSCrypt_servers = true`** and **`doh_servers = false`**
  - If your connectivity is IPv6 enabled, try setting **`ipv6_servers = true`** and set **`server_names = ['quad9-DNSCrypt-ip4-filter-pri', 'quad9-DNSCrypt-ip4-filter-alt', 'quad9-DNSCrypt-ip6-filter-pri', 'quad9-DNSCrypt-ip6-filter-alt']`**
  - If you do **not** have IPv6, leave **`ipv6_servers = false`** and set **`server_names = ['quad9-DNSCrypt-ip4-filter-pri', 'quad9-DNSCrypt-ip4-filter-alt']`**
  - Save these changes and exit.

- Now run DNSCrypt-proxy as administrator:
  `$ sudo ./DNSCrypt-proxy`

  After supplying your administrator password, you should see multiple lines of output, ending with something like:
  ```
  [2018-11-05 15:25:28] [NOTICE] Server with the lowest initial latency: quad9-DNSCrypt-ip4-filter-alt (rtt: 20ms)
  [2018-11-05 15:25:28] [NOTICE] DNSCrypt-proxy is ready - live servers: 4
  ```

  Note: To learn more about the configuration of any particular server, see https://DNSCrypt.info/public-servers

- Now go to *Mac OS System Preferences* → *Network*
  - Select the relevant network interface (likely "WiFi"). Click on the *Advanced* button. Then click on the *DNS* tab.
  - **Important**: Carefully write down the current domain name server IP(s) you see!
  - Once you have written down the current name server IP(s), change the DNS server to point at 127.0.0.1 instead.
  - Click *OK* to close the *Advanced* window, then click *Apply* to save the Network setting.

- Check to make sure the proxy works. Open a new terminal window and enter:
  `$ dig +short @127.0.0.1 example.com`

  You should get one or more IP addresses returned. If the program is not working correctly, you will get no response.

- Perform whatever other testing you would like to do.

If you want to **uninstall DNSCrypt-proxy** after you are done testing it:

- Click on the Terminal window running DNSCrypt-proxy, then hit *control-C* to kill that process.
- Go to *Mac OS System Preferences* → *Network* → *Advanced* → *DNS* and change 127.0.0.1 back to the IP address(es) you were originally using.
- Click *OK* to close the *Advanced* window, then click *Apply* to save the Network setting.
- Delete the DNSCrypt-proxy software by dragging it to the Trash icon in Finder and then emptying the Trash.

Or, if you want to make **DNSCrypt-proxy persistent** (e.g., keep and use DNSCrypt-proxy from this point forward):

- Complete step 5 as shown at https://github.com/jedisct1/DNSCrypt-proxy/wiki/Installation-macOS

Example C: Implementing DNS over TLS Using Stubby with the Stubby Author's DNS over TLS Test Servers

We will install Stubby approximately as described at
https://dnsprivacy.org/wiki/pages/viewpage.action?pageId=3145812

By default, this installation uses the Stubby DNS over TLS Test Servers, as described at
https://dnsprivacy.org/wiki/display/DP/DNS+Privacy+Test+Servers#DNSPrivacyTestServers-DoTservers

To install Stubby for testing:

- As always, before any system maintenance, ensure that you have a recent backup of your system and that your system is fully patched with no updates pending.
- Now open a Terminal window and install Homebrew if you have not previously done so. Do this as described at https://brew.sh/
- Next, use Homebrew to install Stubby:
  `$ brew install stubby` (**Note:** this will also install Unbound and getdns if they are not already installed)
- If you do not have IPv6 enabled, edit `/usr/local/etc/stubby/stubby.yml` with your favorite editor and comment out the IPv6 upstream servers. (You can also look at some of the other commented-out public servers listed there.)
- Start Stubby for testing:
  `$ sudo /usr/local/bin/stubby -C /usr/local/etc/stubby/stubby.yml`

After entering your admin password, you should see something like:

```
[23:52:48.163152] STUBBY: Read config from file
/usr/local/etc/stubby/stubby.yml
[23:52:48.164771] STUBBY: DNSSEC Validation is ON
[23:52:48.164788] STUBBY: Transport list is:
[23:52:48.164793] STUBBY:   - TLS
[23:52:48.164798] STUBBY: Privacy Usage Profile is Strict
(Authentication required)
[23:52:48.164801] STUBBY: (NOTE a Strict Profile only applies when
TLS is the ONLY transport!!)
[23:52:48.164805] STUBBY: Starting DAEMON....
```

- Now go to *Mac OS System Preferences* → *Network*
  - Select the relevant network interface (likely "WiFi"). Click on the *Advanced* button. Now click on the *DNS* tab.
  - **Important:** Carefully write down the current domain name server IP(s) you see!
  - Once you have written down your current name server IP(s), change the DNS server to point at 127.0.0.1 instead.
  - Click *OK* to close the *Advanced* window and *Apply* to save the Network setting.

- Check to make sure Stubby works. Open a new Terminal window and type:
  `$ dig +short @127.0.0.1 example.com`

  You should get one or more IP addresses returned. If the program is not working correctly, you will get no response.

- Do whatever other testing you would like to do.

If you want to **uninstall Stubby** after you are done testing it:

- Click on the terminal window running Stubby, then hit *control-C* to kill that process.

- Go to *Mac OS System Preferences* → *Network* → *Advanced* → *DNS* and change 127.0.0.1 back to the IP address(es) you were originally using. Click *OK* to close the *Advanced* window, then click *Apply* to save the Network setting.

- Delete Stubby by typing:
  `$ brew remove stubby`

- If you do not have a reason to keep it, delete getdns by typing:
  `$ brew remove getdns`

- If you do not have a reason to keep it, you can also delete Unbound by entering:
  `$ brew remove unbound`

Or, if you want **to make Stubby persistent** (e.g., keep and use Stubby from this point forward):

`$ sudo brew services start stubby`

Example D: Implementing DNS over HTTPS for the Firefox Web Browser *Only*

Examples A through C above illustrated installation of a DNS proxy enabling:

- DNS over HTTPS (Example A)
- DNSCrypt (Example B)
- DNS over TLS (Example C)

Use of a DNS proxy enables those protective protocols for all the applications that may be using DNS.

In this example, we will show enabling DNS over HTTPS **just** within current versions of the Firefox Web Browser. That is, by setting up TRR within Firefox, you will circumvent or override the current system recursive resolver setting.

Important: This only implements DNS over HTTPS for Firefox. All other applications on the Mac will still use your regular (non-encrypted) recursive resolvers.

To <u>persistently</u> enable DNS over HTTPS just for the Firefox Web browser:

- As always, before any system maintenance, ensure that you have a recent backup of your system and that your system is fully patched with no pending updates.

- Ensure that you have a current version of Firefox (63.0.1 or later should be fine. You can check the version of Firefox you have by going to *Firefox* → *About Firefox*).

- In the Firefox address bar, enter **`about:config`** (if asked, confirm that you do not mind voiding your warranty).

- In the search bar, enter **`trr`** to search for **`network.trr.mode`**

- Double-click on the resulting search item and set it to 2

  The allowed values include:

0	Off (default). Use standard native resolver only (do not use TRR at all)
1	Race native against TRR. Use them both in parallel and go with the one that returns a result first.
2	TRR first. Use TRR first, and only if the name resolver fails, use the native resolver as a fallback.
3	TRR only. Only use TRR. Never use the native resolver (after the initial setup).
4	Shadow mode. Runs the TRR resolver in parallel with the native for timing and measurements but uses only the native resolver results.
5	Explicitly off. Also off, but selected off by choice and not default.

- By default you will be using the Cloudflare Firefox DNS over HTTPS server at https://mozilla.cloudflare-dns.com/dns-query

- If you would like to use a different DNS over HTTPS server, go to `about:config` and search for **`network.trr.uri`**

    - For Google's servers, set **`network.trr.uri`** to **`https://dns.google.com/resolve`** (see https://developers.google.com/speed/public-dns/docs/DNS over HTTPS)

    - For Quad9's servers, set **`network.trr.uri`** to **`https://dns.quad9.net/dns-query`** (see https://www.quad9.net/doh-quad9-dns-servers)

    - For CleanBrowsing's security-filter server set, set **`network.trr.uri`** to **`https://doh.cleanbrowsing.org/doh/security-filter`** (see https://cleanbrowsing.org/dnsoverhttps)

Disabling DNS over HTTPS in Firefox TRR:

- In the Firefox address bar, enter **`about:config`** (If asked, confirm that you do not mind voiding your warranty.)

- In the search bar, enter `trr` to search for **`network.trr.mode`** , double-click on that item, and set it to 5

Section 2. Configuring Windows 10 to Encrypt Stub-to-Recursive-Resolver Traffic

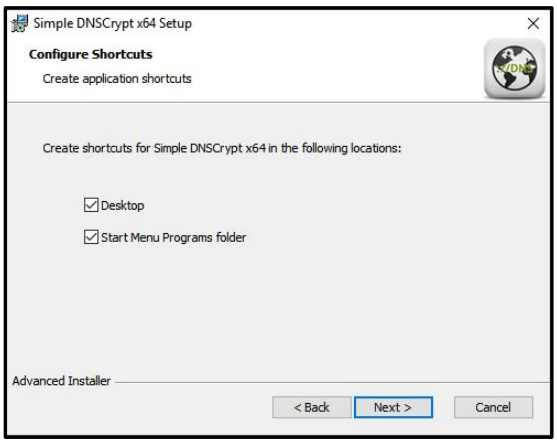
While it is possible to install a traditional encrypted DNS proxies command line in Microsoft Windows, most Windows users will probably prefer a point-and-click graphical interface. Fortunately, **Simple DNSCrypt**[1] is an excellent option for that scenario:

- Most Windows 10 users will want to click the "Download .msi (X64 Installer)" from the bottom of the Simple DNSCrypt page.

- After the file downloads, click on the downloaded file to begin installation, confirming that you want to open the executable and (if asked) confirm that you are okay with the installer modifying your system. You should see:

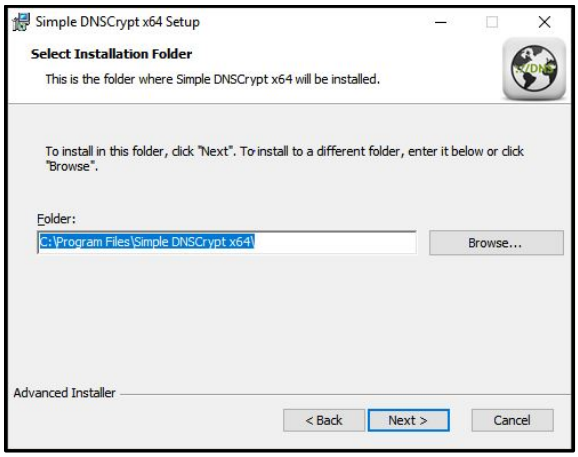
[1] https://simplednscrypt.org/

- Click *Next* to proceed. You should see:



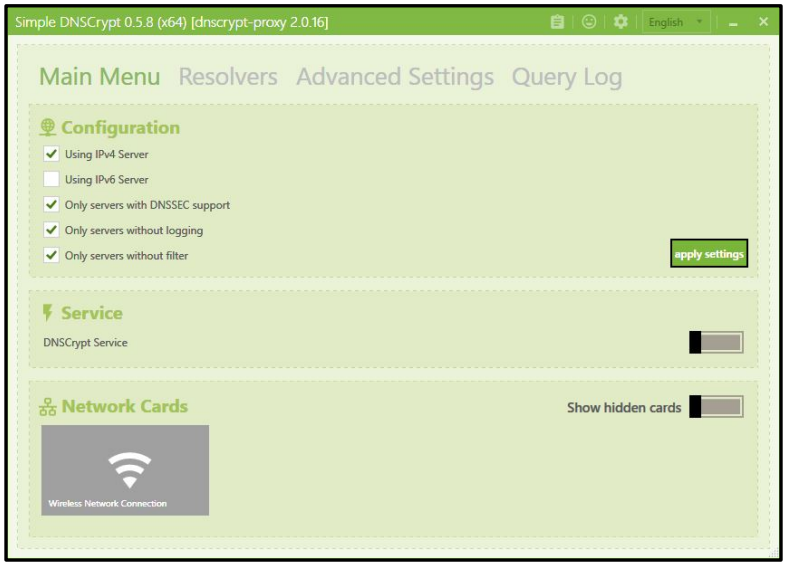
- Click *Next*.

- The next screen of the installer will ask you to select where you would like to install Simple DNSCrypt:



- Click *Next* to proceed when you have selected the location where you would like to install the programs. You should see:

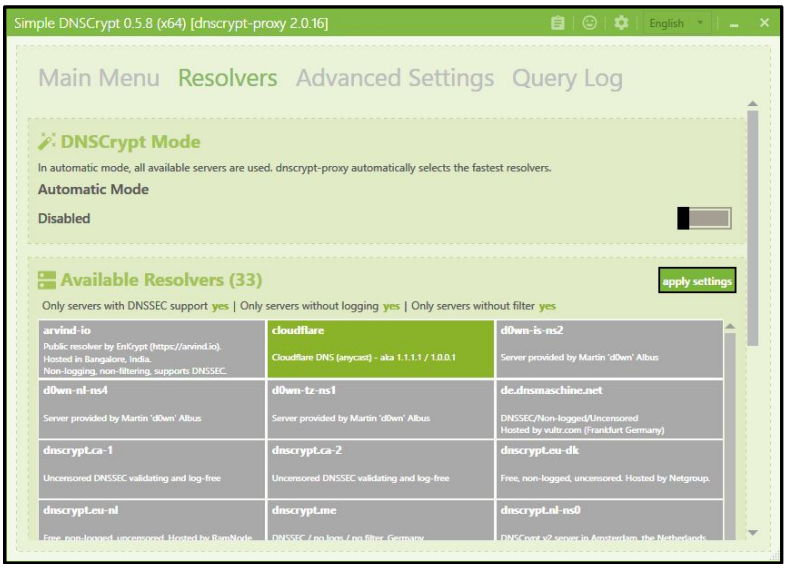
- Click *Finish* to close the installer and launch Simple DNSCrypt. You will then be able to configure Simple DNSCrypt:



- There are two primary approaches you can take to configuring Simple DNSCrypt:

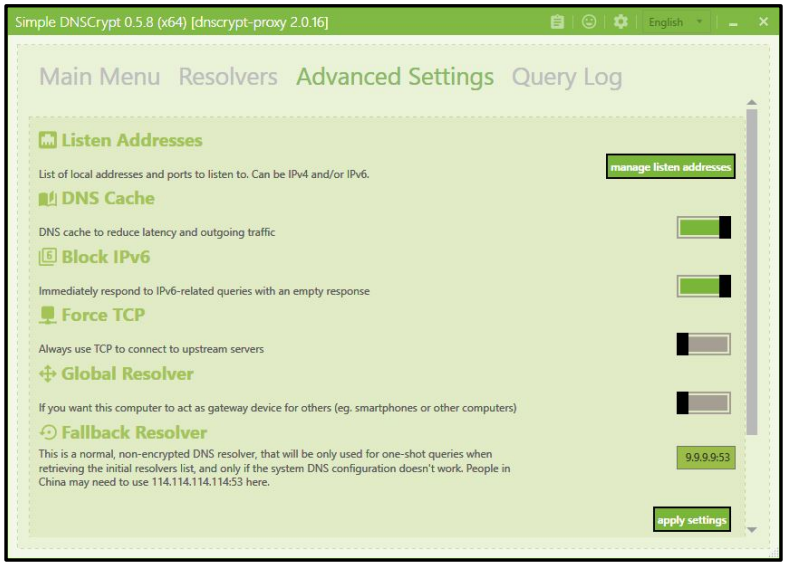
  - You can select the type of server you want and let Simple DNSCrypt pick the servers that meet those specifications. (In this case, the sample screen capture above shows selecting IPv4-accessible servers that support DNSSEC but that do not filter or log.)

  - Alternatively, you can go to the *Resolvers* panel and select a specific resolver you like, then click on *Apply Settings*.



  In the *Resolver* panel shown above, we have selected Cloudflare's 1.1.1.1/1.0.0.1 anycast resolver and then disabled "automatic" mode.

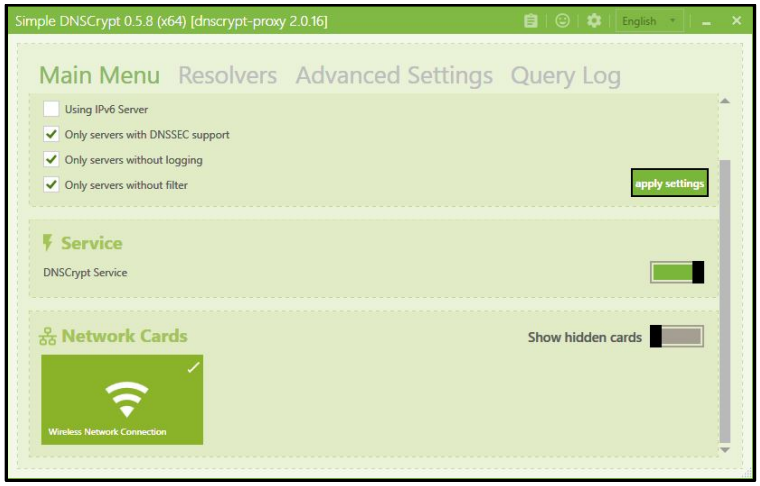
- The next screen shows the *Advanced* panel and the settings available from it:



- In this case, we have enabled the *DNS Cache* and blocked IPv6 requests for improved performance. If we were using a VPN, we might want to tunnel all DNS traffic over TCP, but since we are not in this example, we left it unchecked. We are not planning to have this system act as a resolver for other devices either, so we left *Global Resolver* disabled. We accepted the default Quad9 *Fallback Resolver* to handle bootstrapping and captive portal situations.

- Click *Apply Settings* and close that interface.

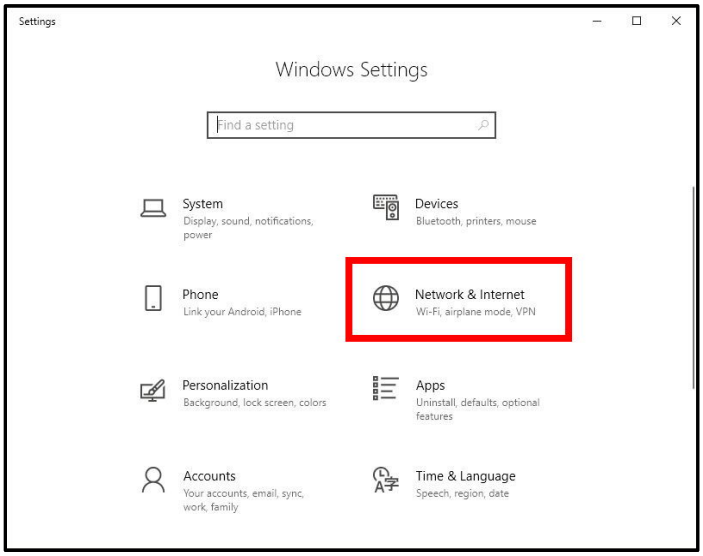
- **Important**: Now go back to the *Main Menu*, instruct DNSCrypt (the service) to start and select your interface card:



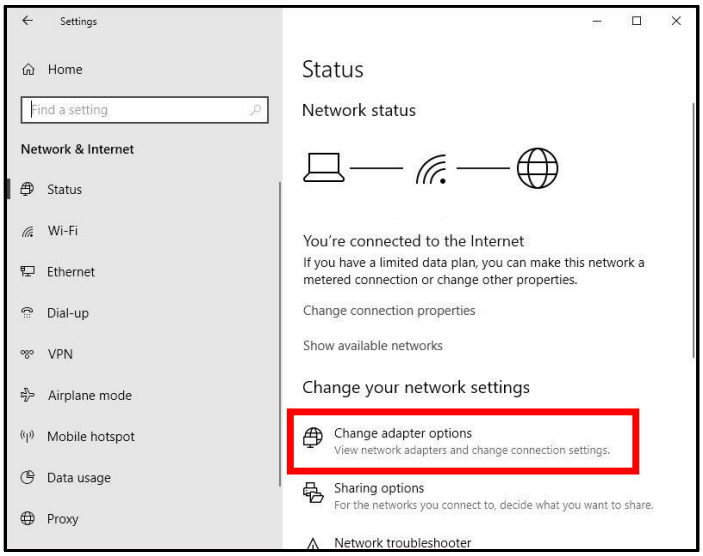
We will instruct the Windows WiFi connection to route DNS requests via Simple DNSCrypt on the next page.

We are going to access Cloudflare's 1.1.1.1 via the forwarder that is running locally at 127.0.0.1 port 53.

- Begin by opening *Windows Settings* (the gear icon):

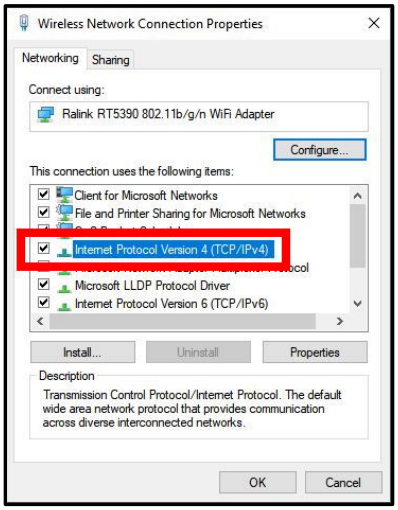


- Select *Network & Internet* from that panel. You should see the *Status* page. Select *Change adapter options:*

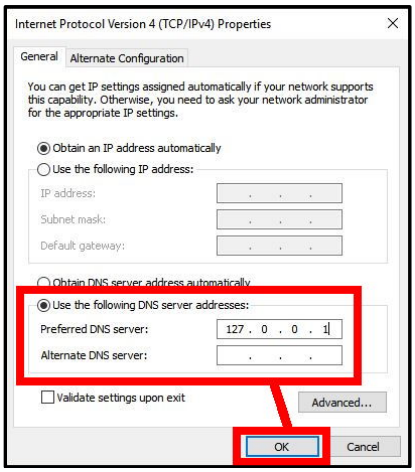


- Select your network interface (usually *Wireless Network Connection*), then click *Change settings of this connection*

- Double-click on *Internet Protocol Version 4 (TCP/IPv4)*:

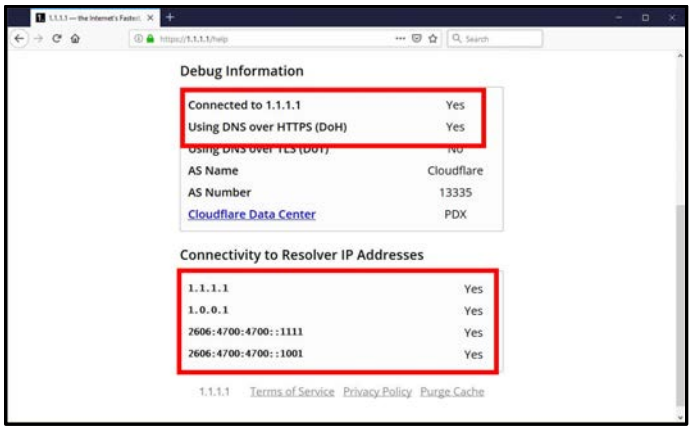


- Now set the DNS server to manual and enter 127.0.0.1 as shown. Click *OK*.



- All that is left to do now is to confirm the settings are working as they should be. Open your Web browser and try going to https://1.1.1.1/help .

- If it is operating correctly, you should see something like the following:



- Note that in this case, while we configured Simple DNSCrypt to **not** use IPv6, it actually **is** on the sample system if we were to want to take advantage of it.

- As one last test, restart your system. After restarting, revisit https://1.1.1.1/help and confirm that you are **still** seeing DNS via the configured service (as shown above).

- If so, you should be all set!

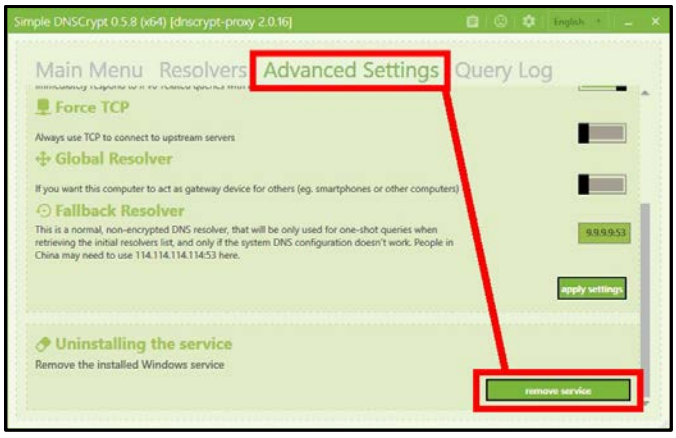
Uninstalling Simple DNSCrypt

Uninstalling Simple DNSCrypt requires three steps:

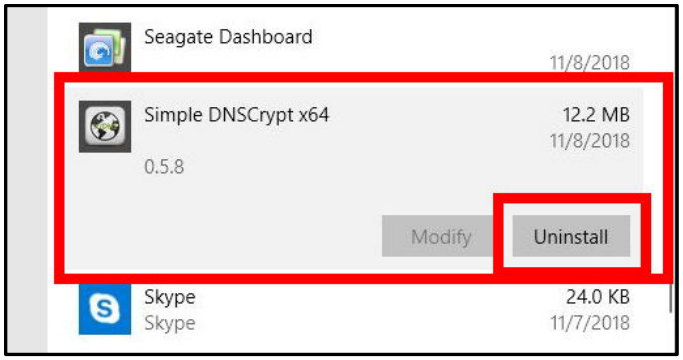
1. Our first step is to return to using the automatically recommended DNS servers from our ISP.

   To do this:
   a. Go to *Windows Settings* (the gear icon) → *Network & Internet* → *Change Adaptor Options*
   b. Pick your interface (normally the Wireless Network), then click *Changes Settings of This Connection*
   c. Double-click on *Internet Protocol Version 4 (TCP/IPv4)*.
   d. Ensure that *Obtain DNS Server Address Automatically* is checked. If it is not, select it. Save the settings and exit.

2. Now remove the DNSCrypt system service. You can do this from the *Advanced Settings* menu tab on the Simple DNSCrypt interface.:



3. Finally, uninstall the Simple DNSCrypt software from *Windows Settings* → *Apps and Features*:

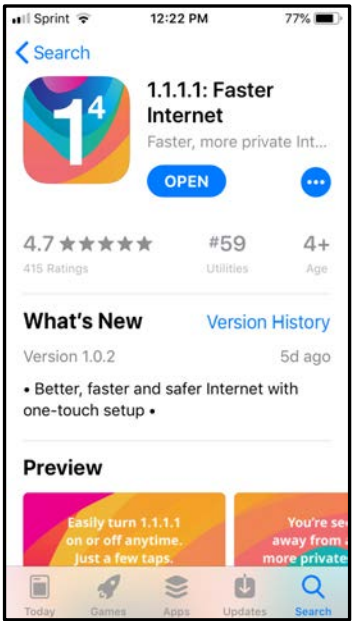


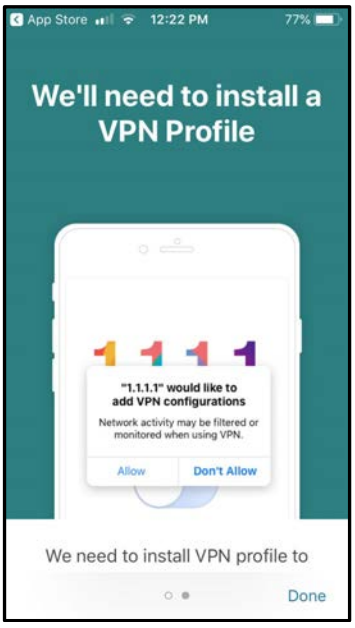
Section 3. Configuring an iPhone to Encrypt Stub-to-Recursive-Resolver Traffic

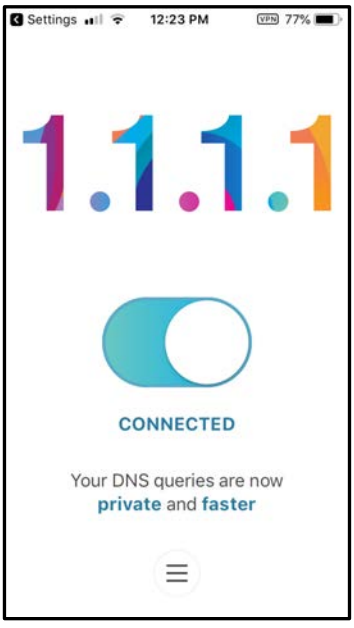
Example A: Using the Cloudflare 1.1.1.1 Native Application

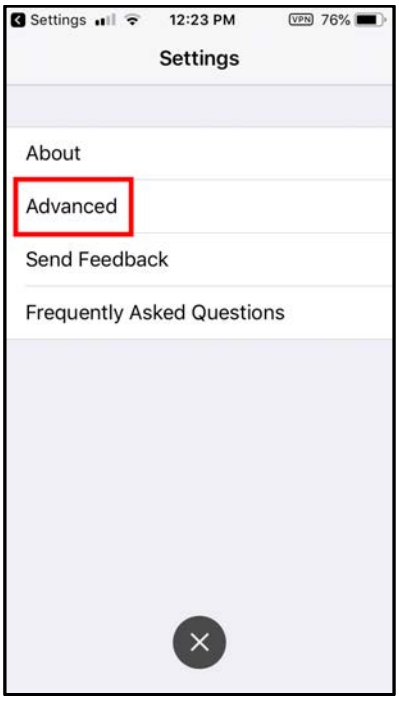
Cloudflare recently released their "1.1.1.1" app via the Apple App Store. (It is somewhat confusingly named because the app has the same name as the IP address of their recursive resolver service.) We tested it on an iPhone A1453 (iPhone 5S CDMA connecting via Sprint) and it worked well. The remainder of this section will show the process of setting up the 1.1.1.1 app.

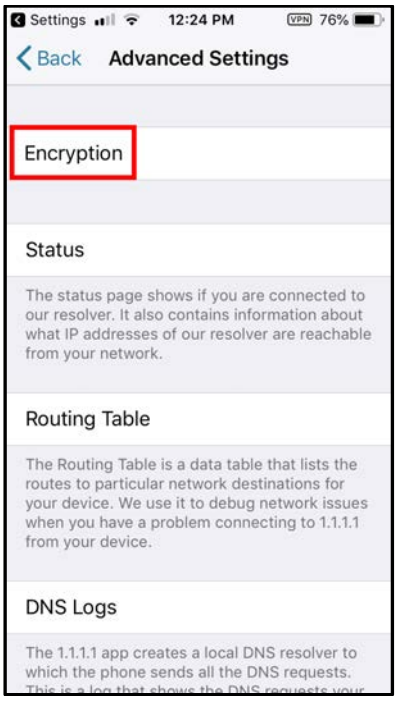
Find the 1.1.1.1 app in the Apple App Store, download it and install it – it is free.

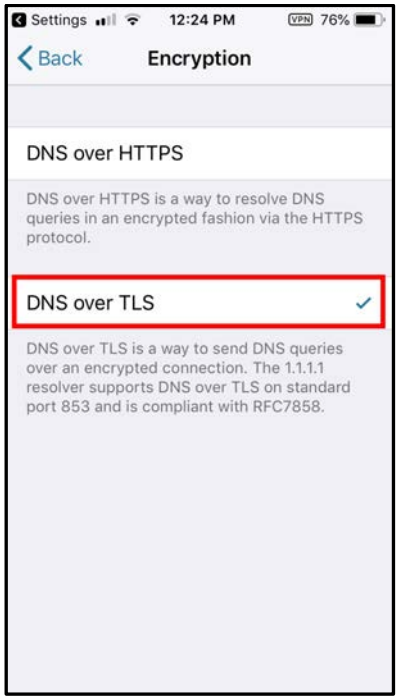







Settings 12:23 PM VPN 76%
Settings
About
Advanced
Send Feedback
Frequently Asked Questions


Settings 12:24 PM VPN 76%
Back
Advanced Settings
Encryption
Status
The status page shows if you are connected to our resolver. It also contains information about what IP addresses of our resolver are reachable from your network.
Routing Table
The Routing Table is a data table that lists the routes to particular network destinations for your device. We use it to debug network issues when you have a problem connecting to 1.1.1.1 from your device.
DNS Logs
The 1.1.1.1 app creates a local DNS resolver to which the phone sends all the DNS requests.

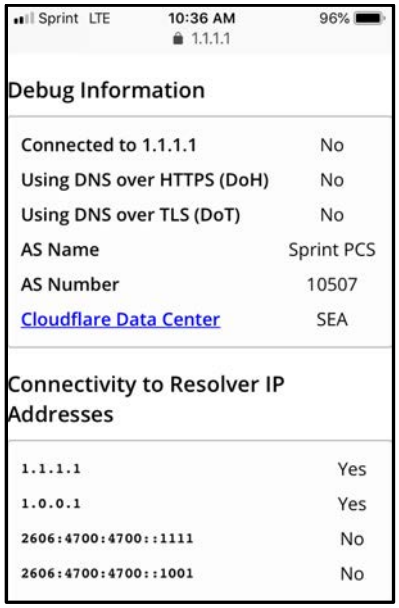

Settings 12:24 PM VPN 76%
Back
Encryption
DNS over HTTPS
DNS over HTTPS is a way to resolve DNS queries in an encrypted fashion via the HTTPS protocol.
DNS over TLS
DNS over TLS is a way to send DNS queries over an encrypted connection. The 1.1.1.1 resolver supports DNS over TLS on standard port 853 and is compliant with RFC7858.


Settings 12:24 PM VPN 76%
Back
Status
DEBUG INFORMATION
Connected to 1.1.1.1 Yes
Using DNS over HTTPS No
Using DNS over TLS Yes
CONNECTIVITY TEST
1.1.1.1 Yes
1.0.0.1 Yes
2606:4700:4700::1111 Yes
2606:4700:4700::1001 Yes
YOUR DEVICE
Connection type Cellular

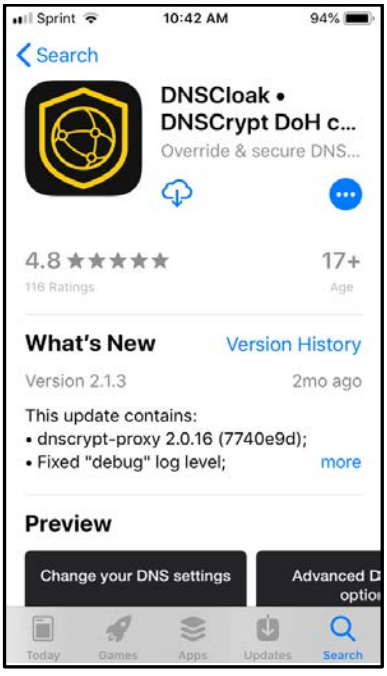
Example B: Using DNSCloak

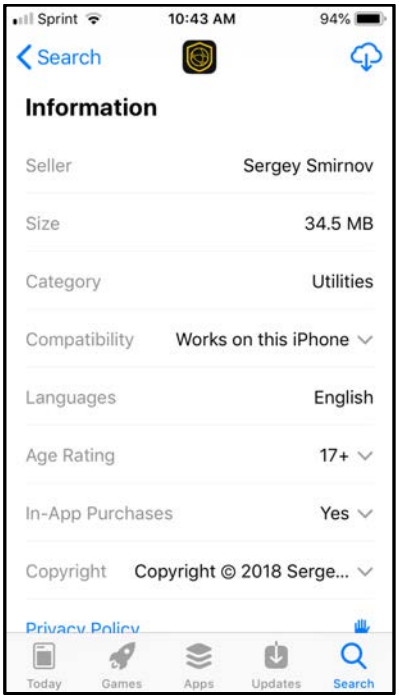
If you are looking for an alternative to the native Cloudflare 1.1.1.1 app, you can also try using DNSCloak.

The phone configured for this demonstration normally uses Sprint's own DNS servers, as can be seen by visiting https://1.1.1.1/help from Chrome:

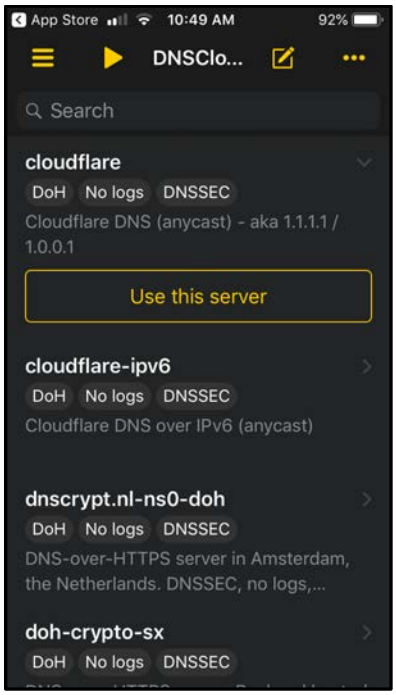


For the purposes of this document, we will install and configure DNSCloak available via the App Store:

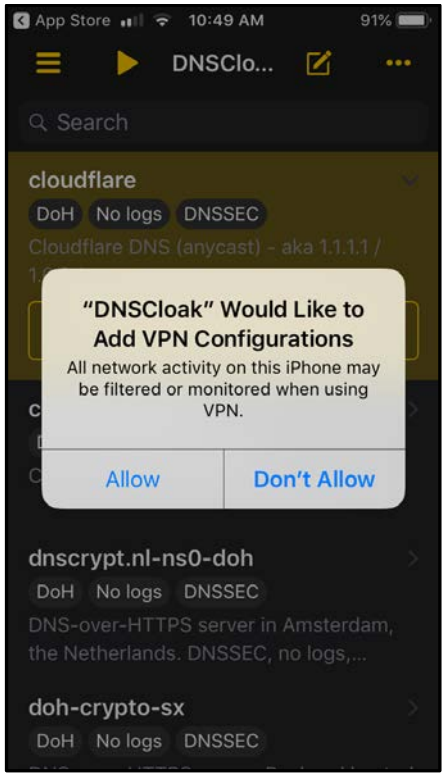


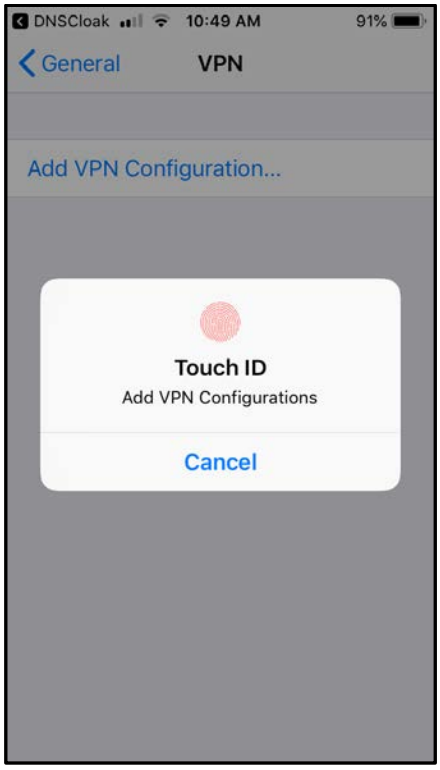


Open the application once it has downloaded and scroll down to select the provider you want to use – we will select Cloudflare's 1.1.1.1:

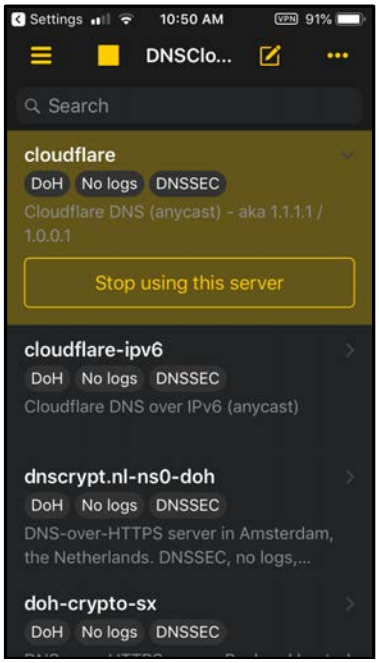


We will need to authorize installation of a VPN profile for the application to work:

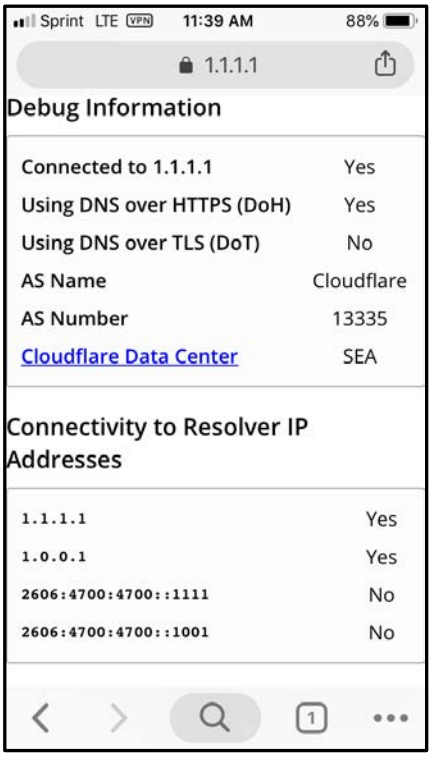




Once a profile has been selected and installed, you will see a screen that looks like the screenshot below. (Note the orange square, which is the sign that DNSCloak is running. It will change to a triangle if it is off; if you see a triangle, click it to start the app.)



We can confirm use of the server by revisiting https://1.1.1.1/help and noting the new configuration that is reported.

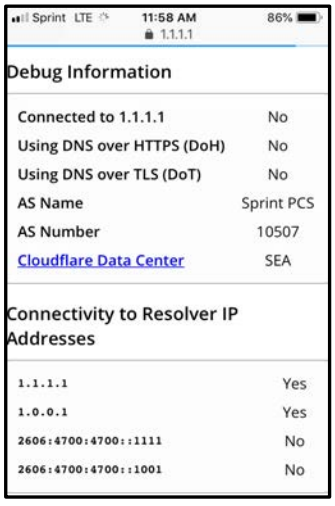


Uninstalling DNSCloak from your iPhone:

To remove DNSCloak from your iPhone, simply delete the application as you normally would any other app:

- Go to the app on your home screen and hold your finger down on the DNSCloak app icon.
- When the app begins to shake, click the X to delete it.
- Confirm that you want to delete the app.

Your DNS will revert to using the automatically assigned DNS servers, which you can confirm by visiting https://1.1.1.1/help in your browser:



Section 4. Configuring an Android Phone to Encrypt Stub-to-Recursive-Resolver Traffic

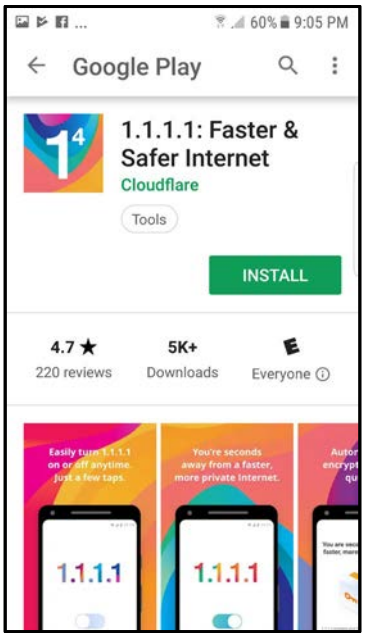
- The latest version of the Android operating system, Android 9 Pie, has out-of-the box support for DNS over TLS.[2] However, only very limited devices ship with Android 9 Pie (or are even updateable to Android 9 Pie).[3]

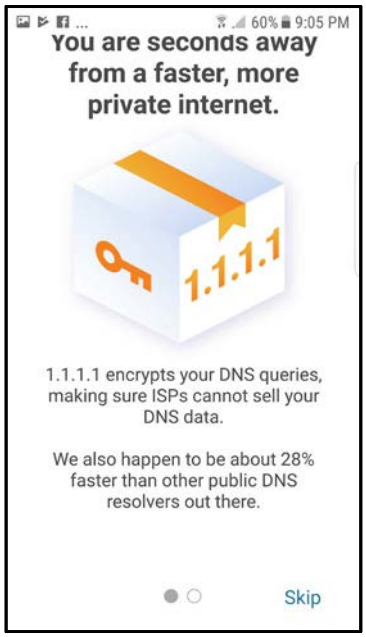
- Android will **not** normally allow you to change the recursive resolvers when you are connecting via **mobile service providers.** You **can** set **unencrypted** third party recursive resolvers when you are connecting over a WiFi connection.[4]

- Until recently, the situation was less favorable if you wanted ***encrypted*** recursive resolver service on your Android phone. Until mid-November 2018, Android applications that claimed the ability to encrypt your DNS traffic actually required you to root your device.[5] But attempting to root your device, would normally void your phone's warranty (and can also potentially "brick"[6] your handset if the rooting process goes badly). **M³AAWG does NOT recommend that users attempt to root their handsets.**

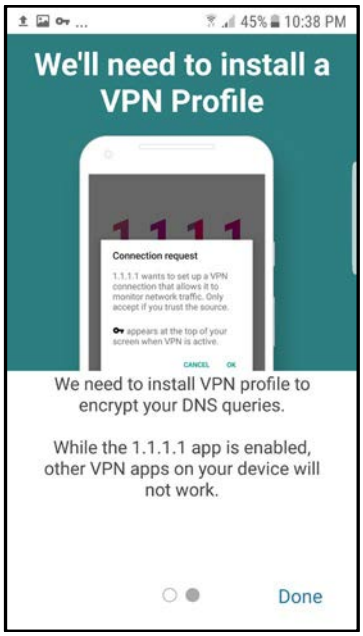
- Fortunately, Cloudflare recently released their 1.1.1.1 app via the Playstore (it is somewhat confusingly named—the app has the same name as the IP address of their recursive resolver service). We tested it on a Samsung S6 Edge running Android 7.0 Nougat connected over WiFi, and it worked well. The remainder of this section will show the process of installing the 1.1.1.1 app on Android.

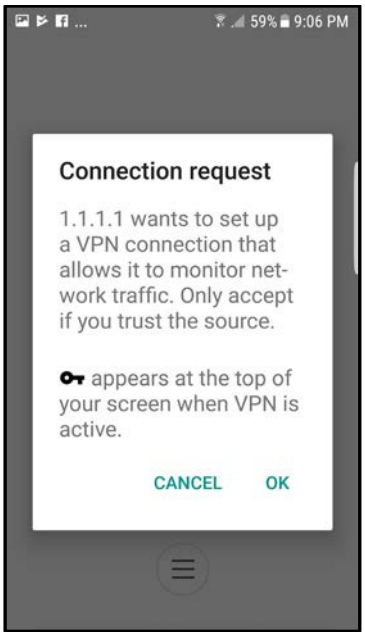
Find the 1.1.1.1 app in the Google Play Store, download it, and install it – it is free.

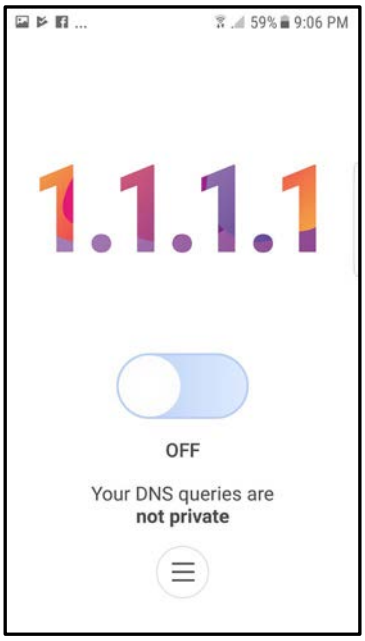


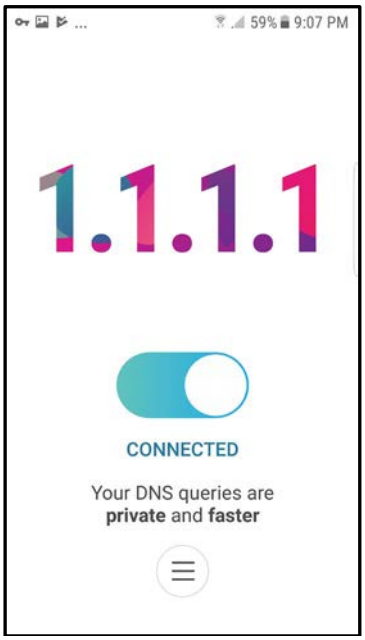


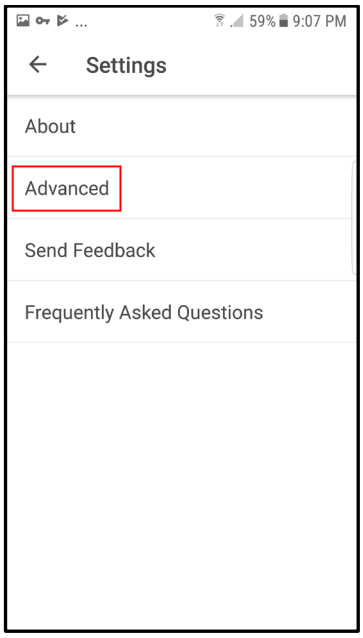
[2] https://developers.cloudflare.com/1.1.1.1/setting-up-1.1.1.1/android/
[3] See one such list at https://android.gadgethacks.com/news/always-updated-list-phones-will-get-android-pie-0186401/
[4] https://support.opendns.com/hc/en-us/articles/228009007-Android-Configuration-instructions-for-OpenDNS
[5] https://en.wikipedia.org/wiki/Rooting_(Android)
[6] https://en.wikipedia.org/wiki/Brick_(electronics)

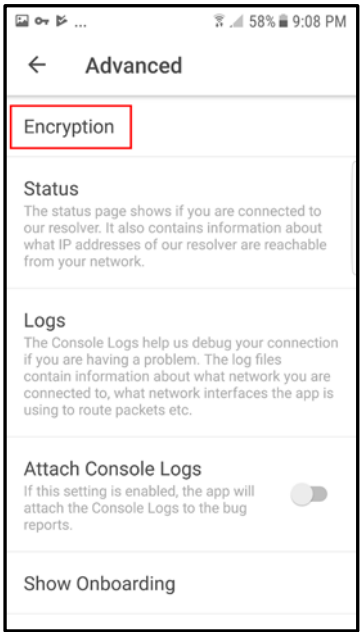

45% 10:38 PM
We'll need to install a VPN Profile
We need to install VPN profile to encrypt your DNS queries.
While the 1.1.1.1 app is enabled, other VPN apps on your device will not work.
Done

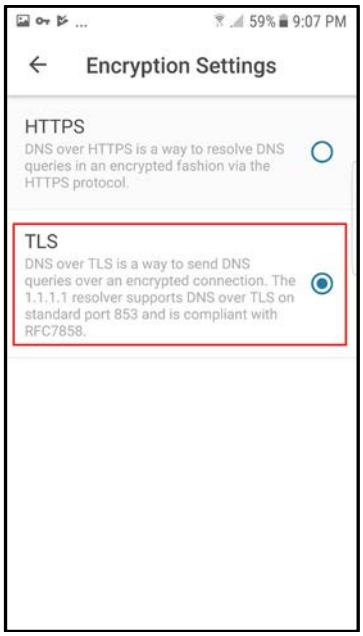

59% 9:06 PM
Connection request
1.1.1.1 wants to set up a VPN connection that allows it to monitor network traffic. Only accept if you trust the source.
appears at the top of your screen when VPN is active.
CANCEL
OK


59% 9:06 PM
1.1.1.1
OFF
Your DNS queries are not private


59% 9:07 PM
1.1.1.1
CONNECTED
Your DNS queries are private and faster


59% 9:07 PM
Settings
About
Advanced
Send Feedback
Frequently Asked Questions


58% 9:08 PM
Advanced
Encryption
Status
The status page shows if you are connected to our resolver. It also contains information about what IP addresses of our resolver are reachable from your network.
Logs
The Console Logs help us debug your connection if you are having a problem. The log files contain information about what network you are connected to, what network interfaces the app is using to route packets etc.
Attach Console Logs
If this setting is enabled, the app will attach the Console Logs to the bug reports.
Show Onboarding


59% 9:07 PM
Encryption Settings
HTTPS
DNS over HTTPS is a way to resolve DNS queries in an encrypted fashion via the HTTPS protocol.
TLS
DNS over TLS is a way to send DNS queries over an encrypted connection. The 1.1.1.1 resolver supports DNS over TLS on standard port 853 and is compliant with RFC7858.


57% 9:12 PM
Status
DEBUG INFORMATION
Connected to 1.1.1.1 YES
Using DNS over HTTPS (DOH) NO
Using DNS over TLS (DOT) YES
CONNECTIVITY TEST
1.1.1.1 YES
1.0.0.1 YES
2606:4700:4700::1111 YES
2606:4700:4700::1001 YES

Section 5. Configuring a Raspberry Pi Running Raspbian Stretch to Run Unbound and DNS over TLS

Design Goal: Deploy a dedicated local recursive resolver forwarding DNS queries using DNS over TLS

Hardware	**Dedicated Raspberry Pi B+** (a ≈US$35, single-board computer popular with hobbyists and professionals)
Physical Connectivity	**Gigabit Ethernet** between the new Raspberry Pi and the user's existing broadband router
IP Addressing	**Static RFC 1918** (192.168.1.250), sitting alongside other downstream clients behind an existing broadband router
Operating System	**Raspbian Stretch**
DNS Recursive Software	**Unbound**, performing caching, DNSSEC validation, and forwarding over an encrypted channel
Third Party Upstream Recursive Software (e.g., the forwarding target)	**Cloudflare's 1.1.1.1.** and related IPs
Encryption of Wide-area DNS traffic	**DNS over TLS**
Encryption of Local Traffic	Because the only queries going to the box will be from local clients connecting directly via the RFC 1918 switch fabric, local DNS traffic to/from the recursive resolver will not use encryption (no WiFi directly to the Pi).
Administrative Traffic	**SSH v2** from a private address space-connected device, or https Web portal from private address space

What We Bought: The build described in this section was done using a new CanaKit Raspberry Pi 3 B+ Starter Kit (≈US$80). That kit included:

- Raspberry Pi 3 B+
- Case
- 32GB microSD card preloaded with NOOBS
- Power supply
- HDMI cable
- Heatsinks, etc.

To obtain a graphical interface for initial setup, the user needs to supply an HDMI-capable monitor plus a USB keyboard and mouse.

Hardware Specifications: The Raspberry Pi 3 B+ is the latest Raspberry Pi model, as of this writing, and has impressive specifications relative to some older commercial broadband routers. The Raspberry Pi 3 B+ might be overkill for most consumer-class recursive resolver requirements, but lesser alternatives are not much cheaper and we cannot complain about a board that only costs ≈US$35. The specifications were:

- ARM Cortex-A53[7] 1.4GHz quad core processor
- 1GB of SDRAM
- A preformatted 32GB microSD card for persistent storage
- NOOBS[8] (New Out Of Box Software, including a full version of Raspbian[9]) preloaded on the microSD card
- 4 USB ports
- 10/100/1000 Ethernet interface (that can reportedly deliver ≈300Mbps throughput).

The parts are shipped unassembled but it only takes a few minutes to put the system together and set it up. Below are some assembly notes.

System Assembly

- **Caution**: **Static-sensitive parts!** Ensure that you take appropriate static-electricity-control protective measures.

- We purchased our Raspberry Pi from Cana Kits and the tiny microSD card was shipped in a small pink plastic envelope – take care not to accidentally discard it!

- **Do not** insert the microSD card in its holder on the board until **after** the case is assembled.

- Did you buy a kit with a preformatted microSD card with NOOBS? You **will not** need to use the microSD card adapter included with the kit – it is only there if you need to reflash the microSD card on your PC or Mac.

- When mounting the Raspberry Pi in the case, separate the case into its three parts (top cover, middle, and bottom cover). **Mount the board onto the bottom cover**, sliding it under the lips as shown at https://www.canakit.com/pi-case, then attach the middle section as shown in the case assembly video. Do **not** attempt to install the board into the middle part of the case and then snap the bottom cover on. That will not work and can damage the case or the board if you try to force it.

- **Apply** the two, small tape-equipped **heat sinks.** The larger one goes on the CPU. The smaller one goes on the Ethernet chip. (The access hole for the Ethernet chip is offset, but if you fiddle with the heat sink a little, you can get it where it needs to go.)

- Our kit included a **separate in-line switch for the power supply.** 1) Plug the in-line switch into the computer; 2) then plug the power supply into the in-line switch; 3) then plug the switch into the wall.

[7] https://en.wikipedia.org/wiki/ARM_Cortex-A53
[8] https://www.raspberrypi.org/documentation/installation/noobs.md
[9] https://www.raspbian.org/

- The top cover for the case **intentionally does not fit flush** (this gap helps provide airflow). You may want to secure it using a couple of rubber bands around the case to ensure that the top cover stays in place. (Just do not block the ventilation.)

- Connect the monitor, keyboard and mouse. Turn on the power switch. The system should then boot. (The red light on the switch means that the device power is on.)

Network Configuration and Safety
There are many different discussions available of what you can and should do to secure your system. We have included some basic recommendations here. Do your **own** due diligence around this important area. (We also assume you can use some type of file editor.)

Prompts and Instructions
In the following instructions, a `$` prompt means "this is an unprivileged task, you can run it as any user," while a command shown after a `#` prompt means "administrative task, either login as root or prefix each such command with `sudo`." (Naturally, do not actually type in the prompt that is shown before commands.)

- If you want to connect remotely via SSH, **you must enable the SSH server**.[10]

- **Reminder:** the root user will normally **not** be allowed to remotely login with a username and password. If you need to do system administration tasks from the command line, create another regular user account using `adduser`, then `ssh` into that user, then use `su` or `sudo`. Alternatively (but a bad idea), set `PermitRootLogin yes` in `/etc/ssh/sshd_config`

- If you are going to be connecting to the device via Ethernet, see `/etc/dhcpcd.conf` to define a static IP, netmask and gateway address for `eth0`. (Note that the service's name is `dhcpcd`, not just `dhcpd`). Be sure to set that IP as static on your home broadband router too.

- If tempted to define an initial default recursive resolver in `/etc/resolv.conf` , note Raspbian's use of `resolvconf (see /etc/resolvconf.conf)`

- You may want to temporarily set `1.1.1.1` or `9.9.9.9` as a recursive resolver in `/etc/resolvconf.conf`. (This will mean temporarily using regular **unencrypted DNS** service from those services; be sure to eventually remove this.)

- Change the password for the `root` account, the default `pi` account, and for any other user accounts you have created.

- Update `/etc/sudoers.d/010_pi-nopasswd` from
  `pi ALL=(ALL) NOPASSWD: ALL`
  to
  `pi ALL=(ALL) PASSWD: ALL`

[10] https://www.raspberrypi.org/documentation/remote-access/ssh/

- `sshd` **may** come with default SSH host keys. Just to ensure that you have your **own** unique SSH server host keys:
  ```
  # rm /etc/ssh/ssh_host_* && dpkg-reconfigure openssh-server
  ```

- Consider using SSH preshared keys for SSH authentication (instead of password authentication).[11]

- Update all the software that is currently installed:
  ```
  # apt-get update && apt-get upgrade
  ```
  (Slow default mirror? Change that in `/etc/apt/sources.list` [There is a list of mirrors at https://www.raspbian.org/RaspbianMirrors])

- Run `ntp` to ensure that system times are synchronized.
  ```
  # apt-get install ntp
  # systemctl enable ntp
  ```

- Install a current SSL/TLS root certificate bundle:
  ```
  # apt-get install ca-certificates
  ```

- We like to use the latest-available ("bleeding-edge") distro (Debian-based operating system). Jessie is installed by default, but that is now old. To upgrade to Raspbian Stretch (which is a little better):
  ```
  # apt-get update && apt-get dist-upgrade
  ```
  Be sure to also **update** your `/etc/apt/sources.list` to reflect the fact that you are using Stretch.
  To also update your firmware to the latest bleeding-edge version:
  ```
  # apt-get update && apt-get install rpi-update
  # rpi-update
  ```
  NOTE: Raspbian Stretch will **not** use predictable interface names `("eth0")` unless you edit `/boot/cmdline.txt` and add `net.ifnames=0` to the end of the string that is currently in that file. However, there are some indications that doing so may make using WiFi interfaces or multiple Ethernet interfaces problematic (see for example https://www.raspberrypi.org/forums/viewtopic.php?t=192729.) Fortunately, we do not need WiFi and do not use multiple Ethernets.

- Remember to **reboot** your system.

- **Recommended:** Install a firewall. We are only connecting this system via RFC1918 address space but we still recommend a firewall.
  ufw[12] ("Uncomplicated Fire Wall") is a comparatively-easy-to-use firewall targeting novice firewall users. Here are some quick notes:

[11] https://www.raspberrypi.org/documentation/configuration/security.md
[12] https://help.ubuntu.com/community/UFW

- `# apt-get install ufw`
- `# ufw enable`
  (If ufw will not enable and you upgraded your distro to Stretch, did you run rpi-update? Did you also remember to reboot after doing so?)
- `# ufw logging low`
  (*ufw sends its log entries to:* `/var/log/syslog`
  to disable logging: `ufw logging off`)
- `# ufw allow from 192.168.1.0/24 to 192.168.1.250 port 22 proto tcp`
  (*allow SSH in from LAN*)
- `# ufw limit ssh/tcp`
  (*maximum of half a dozen SSH login attempts per IP in the last half minute)*
- `# ufw allow from 192.168.1.0/24 to 127.0.0.1 port 53`
  (allow DNS queries from LAN hosts)
- `# ufw allow from 127.0.0.0/8 to 127.0.0.1 port 53`
  (queries from localhost are acceptable, too)
- `# ufw status numbered`
  (see what ufw rules are active)
- *If you added a rule you* ***do not*** *want to use, you can remove it with:*
  `# ufw delete` ***`rule_number_to_del`***

- Optional: Disable unneeded services started by default.[13]

Installing and Configuring Unbound

Installing Unbound: Raspbian Stretch has Unbound version 1.6.0, which was originally released December 15, 2016. The current stable version is 1.8.1 (October 8, 2018).[14]

Actually installing Unbound as a package is simple:
`# apt-get install unbound`

Unbound config file (`/etc/unbound/unbound.conf`): Create the required configuration file using your favorite editor. We assume that the server was given the static IPv4 address `192.168.1.250` and we also assume that you want to use Cloudflare's DNS over TLS accessible servers at 1.1.1.1 and 1.0.0.1. (We have also included commented-out Quad 9's server information and IPv6 equivalent IPs for both.)

[13] https://plone.lucidsolutions.co.nz/hardware/raspberry-pi/3/disable-unwanted-raspbian-services
[14] Want to see a list of the bugs patched for each upgraded version? See https://nlnetlabs.nl/projects/unbound/download/ (hit "Toggle Older Versions" to see the bug fixes since 1.6.0).

```
server:
     interface: 192.168.1.250
     interface: 127.0.0.1
     port: 53
     do-ip4: yes
     do-ip6: no

     access-control: 0.0.0.0/0 deny
     access-control: 127.0.0.0/8 allow
     access-control: 192.168.1.0/24 allow

     log-time-ascii: yes
     qname-minimisation: yes
     rrset-roundrobin: no

     prefetch: yes
     prefetch-key: yes
     so-reuseport: yes

     hide-identity: yes
     hide-version: yes

forward-zone:
     name: "."

     forward-addr: 1.1.1.1@853#cloudflare-dns.com
     forward-addr: 1.0.0.1@853#cloudflare-dns.com
     # forward-addr: 2606:4700:4700::1111@853#cloudflare-dns.com
     # forward-addr: 2606:4700:4700::1001@853#cloudflare-dns.com
     # forward-addr: 9.9.9.9@853#dns.quad9.net
     # forward-addr: 149.112.112.112@853.dns.quad9.net
     # forward-addr: 2620:fe::fe@853#dns.quad9.net
     # forward-addr: 2620:fe::9@853#dns.quad9.net

     forward-ssl-upstream: yes

include: "/etc/unbound/unbound.conf.d/*.conf"
```

Once you have created and saved the above file, check it for errors with `# unbound-checkconf`

Getting DNSSEC Ready for Use:
Get a copy of the trust anchors for doing DNSSEC by running the `# unbound-anchor` command.

As Unbound's authors insist, compare the values in `/var/lib/unbound/root.key` with what you see from https://data.iana.org/root-anchors/root-anchors.xml

Starting and Testing Unbound:
You are now ready to try starting Unbound by entering:
`# unbound`

Test Unbound to see if it is answering queries. You may find `dig` to be a convenient tool for that testing. Install it with:

```
# apt-get update && apt-get install dnsutils
```

You can then try resolving some sites. Be sure to tell `dig` to make these queries against the local server, either at `127.0.0.1` or the static IP address assigned to the Raspberry PI (`192.168.1.250`). For example:

Test #1: Query of a regular site that does not use DNSSEC. (Note: No ad flag is set in the header):

```
# dig www.m3aawg.org @127.0.0.1

; <<>> DiG 9.10.3-P4-Raspbian <<>> www.m3aawg.org @127.0.0.1
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 12633
;; flags: qr rd ra; QUERY: 1, ANSWER: 2, AUTHORITY: 0, ADDITIONAL: 1

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 4096
;; QUESTION SECTION:
;www.m3aawg.org.                IN   A

;; ANSWER SECTION:
www.m3aawg.org.          3587 IN   CNAME     m3aawg.org.
m3aawg.org.         287  IN   A    34.214.179.220

;; Query time: 0 msec
;; SERVER: 127.0.0.1#53(127.0.0.1)
;; WHEN: Thu Nov 15 04:35:36 UTC 2018
;; MSG SIZE  rcvd: 73
```

Test #2: Query for a site that does use DNSSEC. The ad flag should and will be set in the header:

Now to check to see if Unbound is doing DNSSEC. (We are looking for the ad flag to be set in the header):

```
# dig internet2.edu +dnssec +multi @127.0.0.1

; <<>> DiG 9.10.3-P4-Raspbian <<>> internet2.edu +dnssec +multi
@127.0.0.1
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 13430
;; flags: qr rd ra ad; QUERY: 1, ANSWER: 2, AUTHORITY: 0, ADDITIONAL:
1

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags: do; udp: 4096
;; QUESTION SECTION:
;internet2.edu.          IN A
```

```
;; ANSWER SECTION:
internet2.edu.      117 IN A 207.75.164.248
internet2.edu.      117 IN RRSIG A 7 2 120 (
                    20181128182944 20181114182944 46310 internet2.edu.
                    xRHYA8c2SQwAFtkQoYIJ1aNNgbDH/ZKGoBUhFWspzrbI
                    ME952M2dA3OcTMYlRUHnPggF+llXEwxRjHB6FoYmkhZR
                    gEJUT7obM3kSVjLn71Egvsz7zTFf3bIYzq8m18vmFCRU
                    iHqGdZn8re0gB/j37J6jpivZTQa3NlCoC06ockbJazrU
                    a19TVByDNvHhhn7bxfuZrgSIP82jlHPP29ui03pCa+qQ
                    G1F3yIZ8/n1XsaZLdmdSPyIEqWHjO+/MLKL7TElX8KlA
                    PK18+joPIjX6mbEUyG+Iso6MO6+q54I6uZ1CNJatKVQj
                    y7K2Hj8RW6JBDuufhb4Yv92DG+pIEq7K0w== )

;; Query time: 0 msec
;; SERVER: 127.0.0.1#53(127.0.0.1)
;; WHEN: Thu Nov 15 04:46:18 UTC 2018
;; MSG SIZE  rcvd: 359
```

Test #3: Query an intentionally misconfigured site. We should see a SERVFAIL STATUS returned (and we do).

A domain that has an intentionally or accidentally broken DNSSEC cryptographic validation status should return SERVFAIL, e.g.:

```
# dig www.dnssec-failed.org @127.0.0.1

; <<>> DiG 9.10.3-P4-Raspbian <<>> www.dnssec-failed.org @127.0.0.1
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: SERVFAIL, id: 562
;; flags: qr rd ra; QUERY: 1, ANSWER: 0, AUTHORITY: 0, ADDITIONAL: 1

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; udp: 4096
;; QUESTION SECTION:
;www.dnssec-failed.org.       IN   A

;; Query time: 0 msec
;; SERVER: 127.0.0.1#53(127.0.0.1)
;; WHEN: Thu Nov 15 04:47:46 UTC 2018
;; MSG SIZE  rcvd: 50
```

Restarting Unbound: Start and Routinely Run Unbound after reboot; checking on Unbound's status

```
# systemctl restart unbound
# systemctl enable unbound
# systemctl status unbound
```

Telling the local system to use the locally running copy of Unbound for all queries
Edit: `/etc/resolvconf.conf` so that: `name_servers=127.0.0.1` then run: `# resolvconf -u`

Telling your local broadband router (and the clients it services) to use the Raspberry Pi's resolver
Go to your local broadband router's Web configuration screen (this is often at `https://192.168.1.1`) and login. Set the nameservers on that router to point at `192.168.1.250` (or whatever static IP you assigned to the Raspberry Pi). Save the configuration change on the broadband router and reboot it (if it does not reboot automatically). You will only need to do this once.

Important Note:
The architecture described in this section is meant for use on a private (RFC1918) network segment. Even there, clients may still encounter other DNS servers that are suggested by the ISP's DHCP server or seen and remembered by the user's existing broadband router. These other DNS servers may be configured **alongside** the encrypted recursive resolver described in this section.

There are four main risks associated with this:

- Clients that were meant to use the new encrypted DNS service may end up configured via DHCP to use unencrypted, ISP-provided recursive resolvers. Users may be able to override this by manually configuring just the encrypted local server (e.g., 192.168.1.250) for DNS.

  If the user fails to do this, DNS traffic that was meant to be forwarded over an encrypted connection may actually end up being forwarded unencrypted.

- If users do manually hard code your local recursive resolver's IP, thereby insisting that 192.168.1.250 be used, the connection will not be encrypted. However, this should not be a problem while they are connected to the home network where that device is installed since the Raspberry Pi and the router are directly connected via a private Ethernet cable. **Offsite**, however, recognize that **your** RFC1918-only encrypted DNS forwarder will **not** be available.

  If users are trying to access the RFC1918-only encrypted DNS forwarder, three negative outcomes may occur:

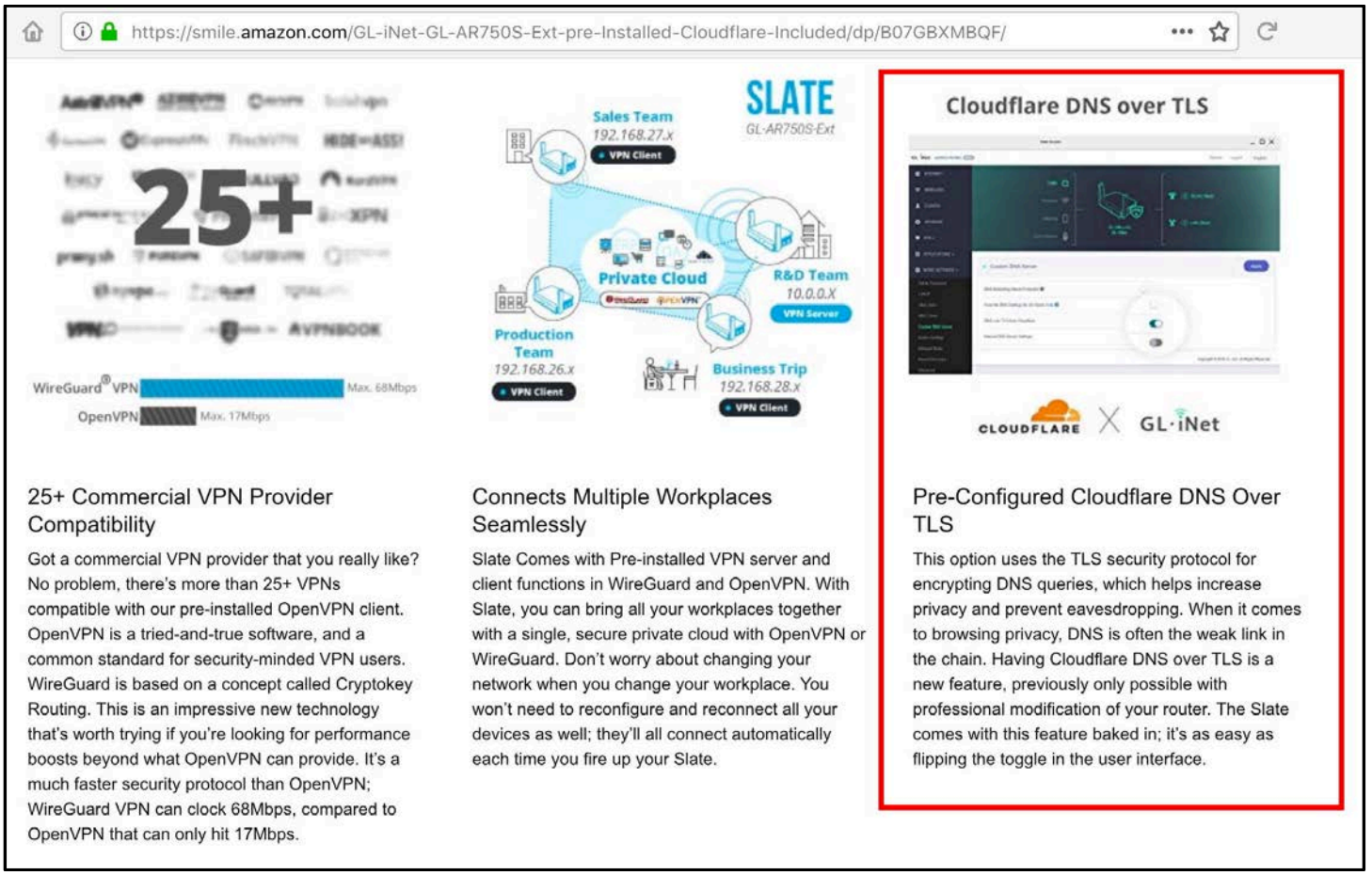
  - Someone else may be running a third party recursive resolver using that same IP address; they may – or may not – be trustworthy.
  - If the user is manually configured to **only** access a resolver on one specific IP address and there is no recursive resolver accessible on the IP, that user may not be able to resolve any domains until they remove the hardcoded IP address or replace it with an address that is accessible.
  - To prevent user support issues associated with incorrect manually-configured DNS, some broadband routers may redirect **all** unencrypted DNS traffic to an alternative DNS server of their choice.

Bottom line? ***Be extremely careful*** about how you configure your computer's recursive resolvers!

Section 6. Commercial Home Routers Supporting Encryption of Stub-to-Recursive-Resolver Traffic

Most commercial home broadband routers **do** allow you to specify **unencrypted** third party recursive resolvers out of the box. Most do **not** support **encrypted** third party recursive resolver services out of the box.

One exception is GL.iNet's AR750S[15] (≈US$70 at the time this was written), which comes pre-configured to do so:



[15] https://smile.amazon.com/GL-iNet-GL-AR750S-Ext-pre-Installed-Cloudflare-Included/dp/B07GBXMBQF/

Section 7. Diagnosing and Testing DNS Stub-to-Recursive Resolver Traffic

Important Note: Do **NOT** run dnstop, tcpdump, Wireshark or any other promiscuous-mode traffic-inspecting tools on M³AAWG-provided connectivity (such as the M³AAWG conference networks). Doing so is explicitly forbidden by the M³AAWG terms of attendance and network acceptable use policies. These tools are **ONLY** mentioned here for your professional use in validating a resolver installed on a private home network or in conjunction with a resolver on an institutional network that you are authorized to operate and monitor.

1) Check top domain names that are being resolved with dnstop[16] by watching live network traffic
Installation of dnstop is often possible via whatever package manager you are normally using on a given platform. For example:

```
# apt-get update && apt-get install dnstop   <-- Raspbian

$ brew install dnstop                        <-- Brew on Mac OS X
```

- Once installed, try:
  `# dnstop -l 4 eth0`

- To see the Source IP for the DNS query plus the domain being resolved (for up to four level names) hit `$`

  `Ctrl-C` interrupts the display. See `$ man dnstop` for more options.

2) Inspect DNS traffic with tcpdump[17]
Ensure that you have tcpdump installed. You should be able to install tcpdump using whatever package manager you normally use:

```
# apt-get update && apt-get install tcpdump          <-- Raspbian

$ brew install tcpdump
```

- To see if there is any traffic on port 53…
  `# tcpdump -nt -i eth0 port 53`

  Decoding those arguments (see $ man tcpdump)

`-n`	"Do not convert addresses (i.e., host addresses, port numbers, etc.) to names."
`-t`	"Do not print a timestamp on each dump line."
`-i`	"Listen on interface…"
`port 53`	"Select just traffic using port 53"

  What if you are testing an installation that is sending **un**encrypted local traffic from local hosts to a local resolver and you see traffic from addresses in 192.168.1.0/24 to addresses 192.168.1.0/24? That is normally acceptable (e.g., assuming the traffic is intra-device, over hard Ethernet links or over encrypted links).

[16] http://dns.measurement-factory.com/tools/dnstop/index.html
[17] http://www.tcpdump.org/

- `# tcpdump -nt -i eth0 port 853`

  If you see traffic from addresses in 192.168.1.0/24 **to** the IP addresses of your upstream resolvers (e.g., 1.1.1.1 or 1.0.0.1) on port 853, or traffic from your specified upstream resolvers (e.g., 1.1.1.1 or 1.0.0.1) **to** 192.168.1.0/24 on port 853, that is also acceptable and as expected.

- Curious what **else** is on the network besides port 53 (normal DNS), port 853 (DNS over TLS), or port 22 (ssh)?

  ```
  # tcpdump -nt -i eth0 port not 53 and port not 853 and port not
  22
  ```

  You will probably see ARP,[18] STP,[19] UPnP/SSDP traffic on port 1900,[20] and ND traffic (IPv6 router advertisements)[21]. (Now you know some of the reasons why the lights blink even when no one is doing anything.)

  Want to focus on what is left? Hide some more of that traffic with:
  ```
  # tcpdump -nt -i eth0 port not 53 and port not 853 and port not
  22 and not arp and not stp and port not 1900
  ```

- Coming back to the DNS traffic, want to see still more detail?
  ```
  # tcpdump -vv -x -X -s 1500 -i eth0 port 53
  ```

  Decoding the new options:

`-vv`	"Even more verbose output."
`-x`	"When parsing and printing, in addition to printing the headers of each packet, print the data of each packet (minus its link level header) in hex. The smaller of the entire packet or snaplen bytes will be printed […]."
`-X`	"When parsing and printing, in addition to printing the headers of each packet, print the data of each packet (minus its link level header) in hex and ASCII."
`-s 1500`	"Snarf snaplen bytes of data from each packet […]"

3) Verifying/troubleshooting SSL/TLS cert issues

Normally, the major alternative recursive resolver providers will have non-problematic SSL/TLS certificate installations that are readily accessible from most end-user networks or systems. However:

- If you are working from an environment that may be blocking, intercepting, or hijacking DNS-related SSL/TLS traffic, you may need to try to figure out what is going on with that.

- It is also possible that a smaller third party alternative encrypted DNS service might have SSL/TLS certificate issues of one sort or another, such as expired certificates.

- You might be curious if your third-party alternative encrypted DNS service provider's SSL/TLS installation is following best practices, or what sort of certificate they are using.

[18] https://en.wikipedia.org/wiki/Address_Resolution_Protocol
[19] https://en.wikipedia.org/wiki/Spanning_Tree_Protocol
[20] https://en.wikipedia.org/wiki/Simple_Service_Discovery_Protocol
[21] https://en.wikipedia.org/wiki/Neighbor_Discovery_Protocol

Nykolas Z has a Medium.com blog post[22] that does a good job of introducing the use of the `openssl_client tool` and the `DNS over TLS-php-client` for troubleshooting in a DNS over TLS context.

Conclusion

As mentioned, this document provides specific instructions for implementing at least one encrypted recursive resolver solution for each popular platform. For basic information to evaluate the benefits and potential issues with encrypting DNS traffic, see the accompanying document, "M³AAWG Tutorial on Third Party Recursive Resolvers and Encrypting DNS Stub Resolver-to-Recursive Resolver Traffic."

As with all documents that we publish, please check the M³AAWG website (www.m3aawg.org) for updates.

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[22] https://medium.com/@nykolas.z/troubleshooting-dns-over-tls-e7ca570b6337