# CSE 548 Spring 2026 Tor lecture

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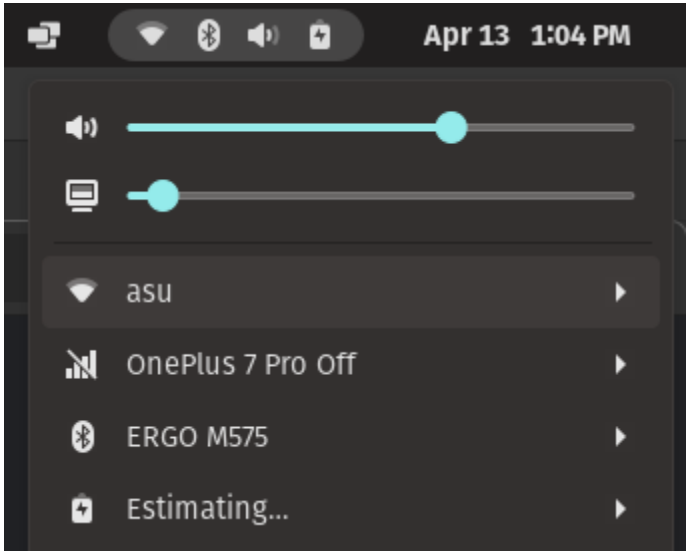
- Some of these slides are from https://community.torproject.org/training/resources/
- See also
  - https://community.torproject.org/onion-services/setup/

# A few of my Tor use cases...



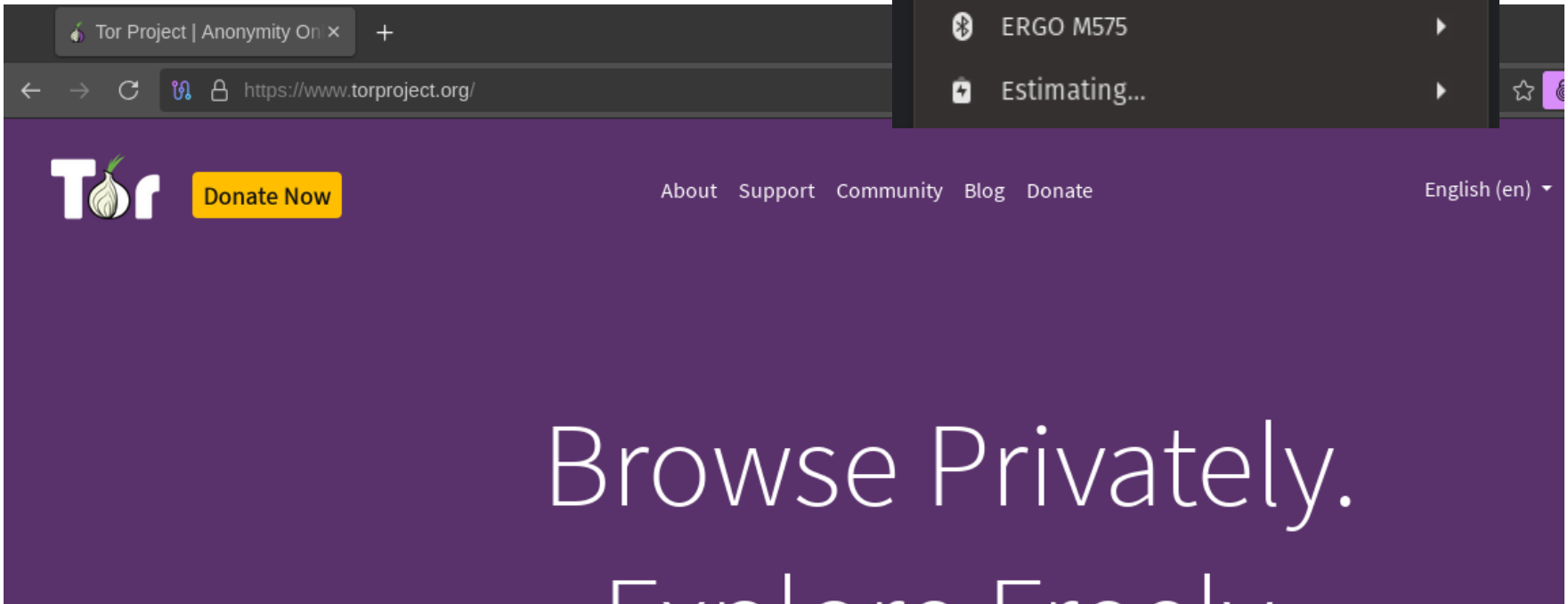

This site can’t be reached

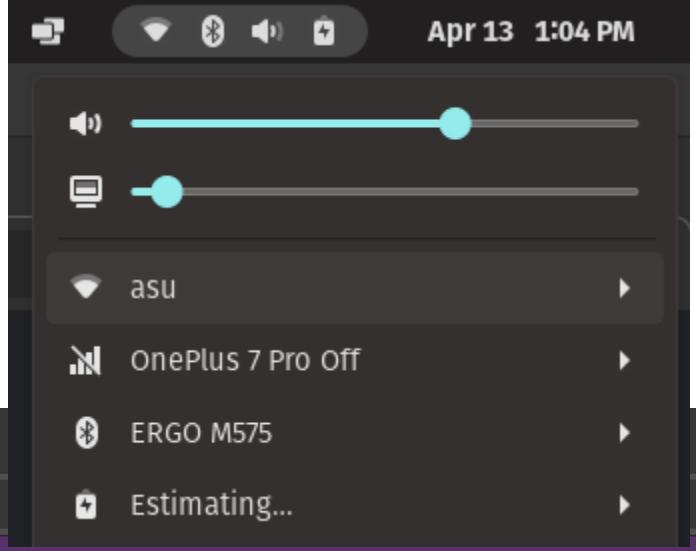
**www.torproject.org** took too long to respond.

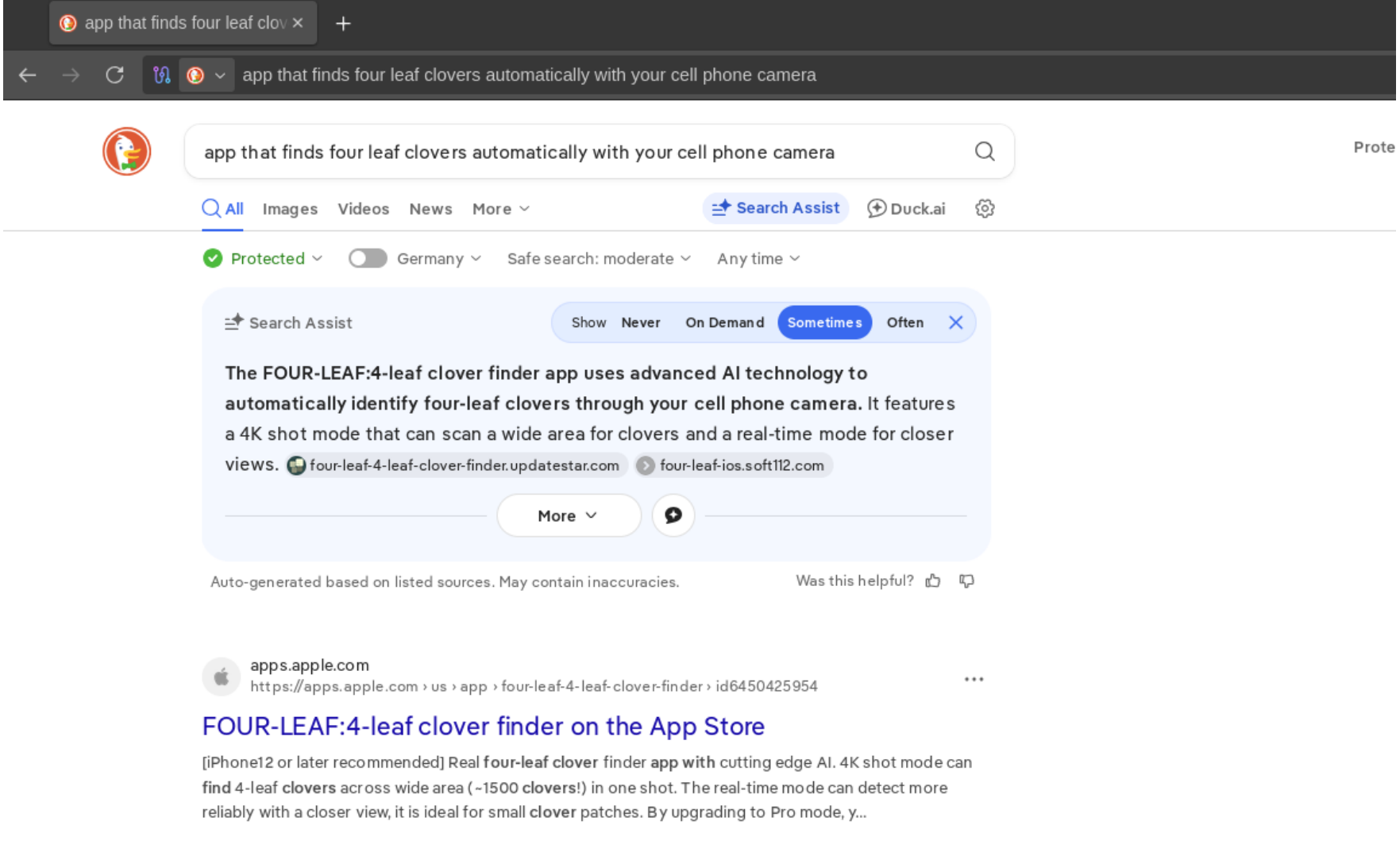
Try:

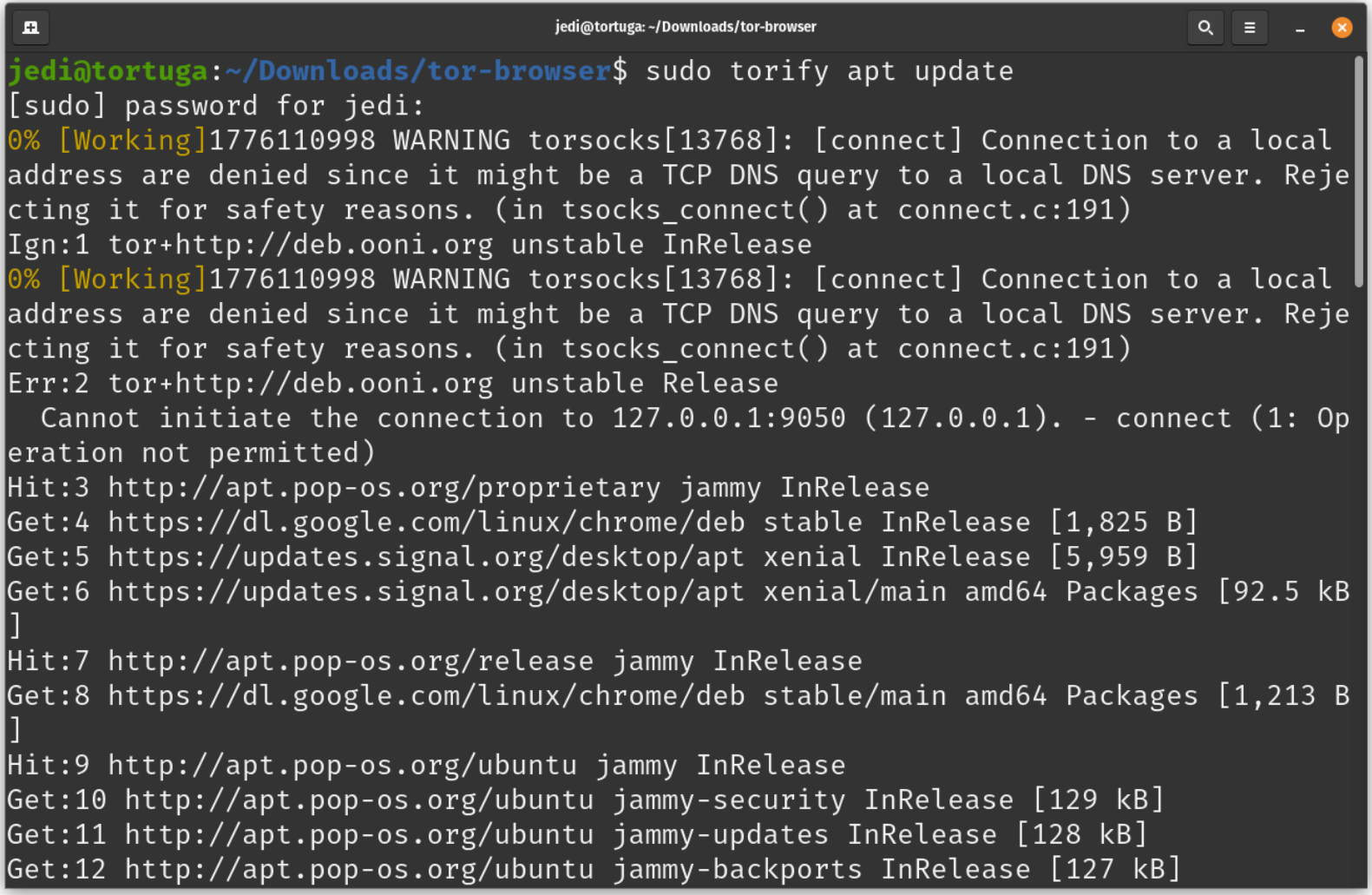
- Checking the connection
- Checking the proxy and the firewall

ERR_TIMED_OUT

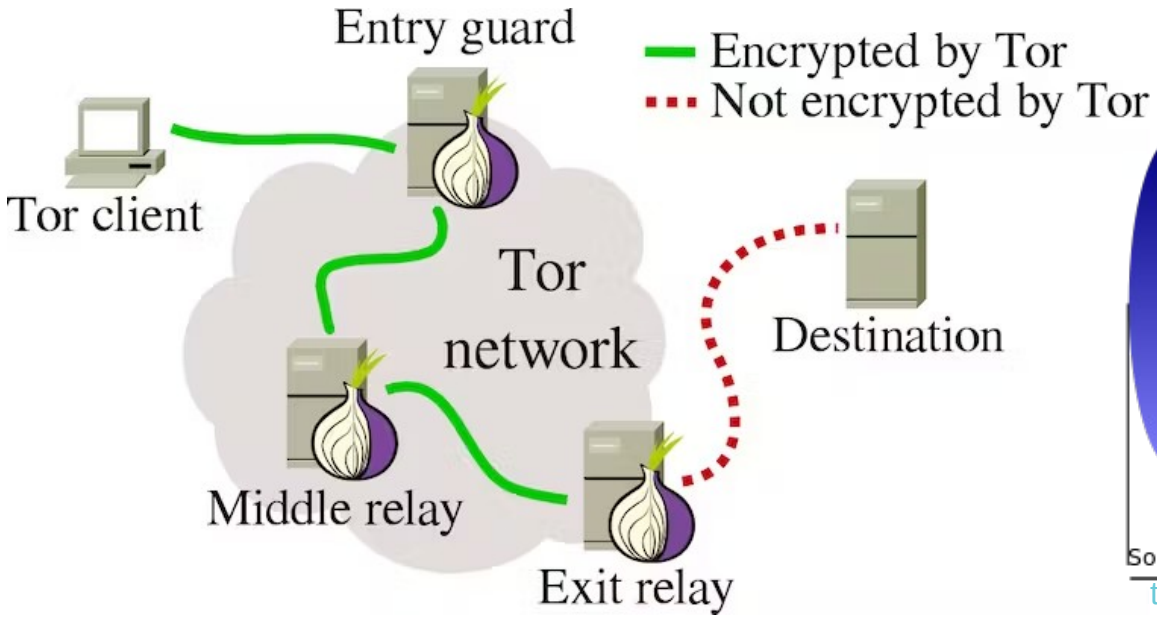

Tor Project | Anonymity On
https://www.torproject.org/
Donate Now
About
Support
Community
Blog
Donate
English (en)
Browse Privately.

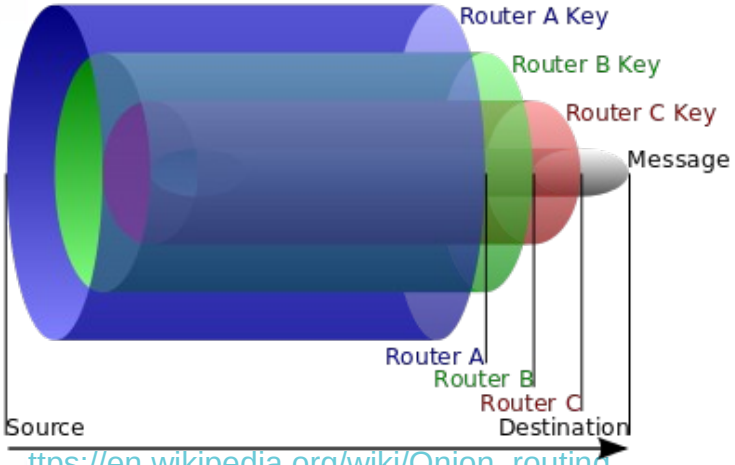

Apr 13 1:04 PM
asu
OnePlus 7 Pro Off
ERGO M575
Estimating...


app that finds four leaf clov ×
app that finds four leaf clovers automatically with your cell phone camera
app that finds four leaf clovers automatically with your cell phone camera
Prote
All
Images
Videos
News
More
Search Assist
Duck.ai
Protected
Germany
Safe search: moderate
Any time
Search Assist
Show
Never
On Demand
Sometimes
Often
The FOUR-LEAF:4-leaf clover finder app uses advanced AI technology to automatically identify four-leaf clovers through your cell phone camera. It features a 4K shot mode that can scan a wide area for clovers and a real-time mode for closer views.
four-leaf-4-leaf-clover-finder.updatestar.com
four-leaf-ios.soft112.com
More
Auto-generated based on listed sources. May contain inaccuracies.
Was this helpful?
apps.apple.com
https://apps.apple.com › us › app › four-leaf-4-leaf-clover-finder › id6450425954
FOUR-LEAF:4-leaf clover finder on the App Store
[iPhone12 or later recommended] Real four-leaf clover finder app with cutting edge AI. 4K shot mode can find 4-leaf clovers across wide area (~1500 clovers!) in one shot. The real-time mode can detect more reliably with a closer view, it is ideal for small clover patches. By upgrading to Pro mode, y...


jedi@tortuga: ~/Downloads/tor-browser
jedi@tortuga:~/Downloads/tor-browser$ sudo torify apt update
[sudo] password for jedi:
0% [Working]1776110998 WARNING torsocks[13768]: [connect] Connection to a local address are denied since it might be a TCP DNS query to a local DNS server. Rejecting it for safety reasons. (in tsocks_connect() at connect.c:191)
Ign:1 tor+http://deb.ooni.org unstable InRelease
0% [Working]1776110998 WARNING torsocks[13768]: [connect] Connection to a local address are denied since it might be a TCP DNS query to a local DNS server. Rejecting it for safety reasons. (in tsocks_connect() at connect.c:191)
Err:2 tor+http://deb.ooni.org unstable Release
Cannot initiate the connection to 127.0.0.1:9050 (127.0.0.1). - connect (1: Operation not permitted)
Hit:3 http://apt.pop-os.org/proprietary jammy InRelease
Get:4 https://dl.google.com/linux/chrome/deb stable InRelease [1,825 B]
Get:5 https://updates.signal.org/desktop/apt xenial InRelease [5,959 B]
Get:6 https://updates.signal.org/desktop/apt xenial/main amd64 Packages [92.5 kB]
Hit:7 http://apt.pop-os.org/release jammy InRelease
Get:8 https://dl.google.com/linux/chrome/deb stable/main amd64 Packages [1,213 B]
Hit:9 http://apt.pop-os.org/ubuntu jammy InRelease
Get:10 http://apt.pop-os.org/ubuntu jammy-security InRelease [129 kB]
Get:11 http://apt.pop-os.org/ubuntu jammy-updates InRelease [128 kB]
Get:12 http://apt.pop-os.org/ubuntu jammy-backports InRelease [127 kB]

# Tor in a nutshell




ttps://en.wikipedia.org/wiki/Onion_routing

https://theconversation.com/tor-upgrades-to-make-anonymous-publishing-safer-73641

# Why are we learning about Tor?

- Brings together many concepts from the course
  - Encryption, anti-censorship and NIDS evasion, privacy, anonymity, *etc.*
- A basic network security tool that many people use for many different things
  - *i.e.*, a “critical infrastructure”

# Introduction to Tor

# Connecting through **HTTP**

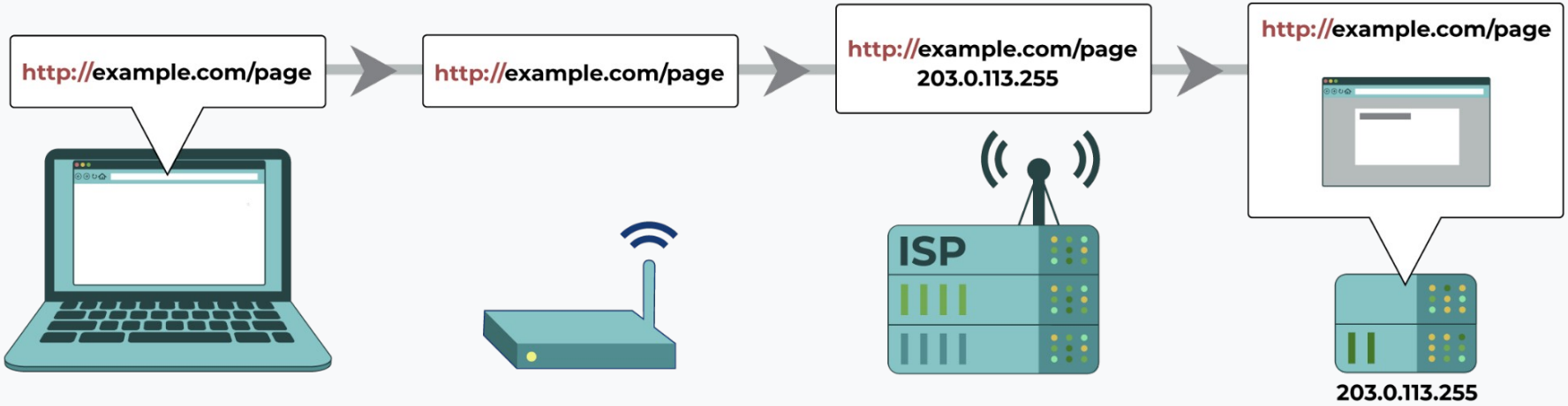



*Image source: eff.org*

# Connecting through HTTPS

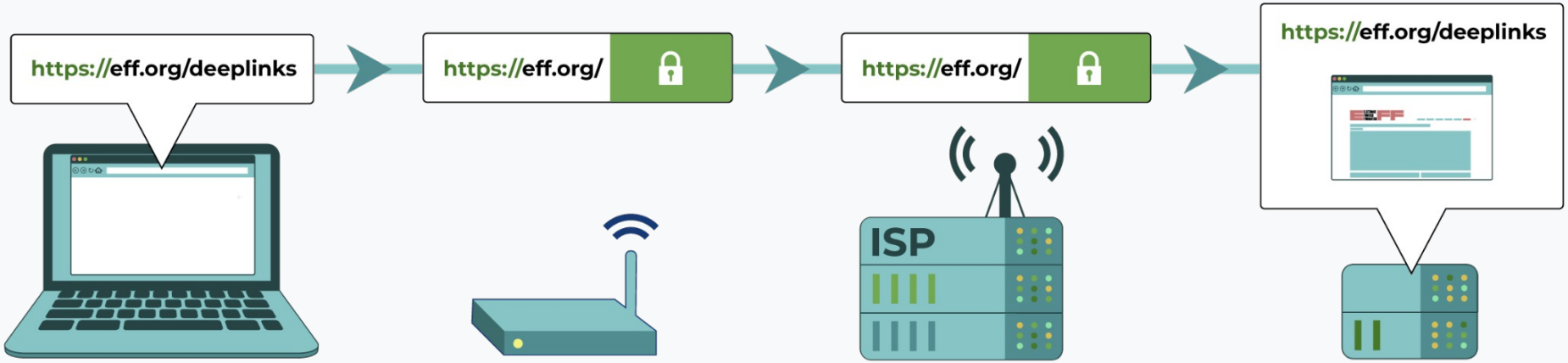



*Image source: eff.org*

# Connecting through VPN

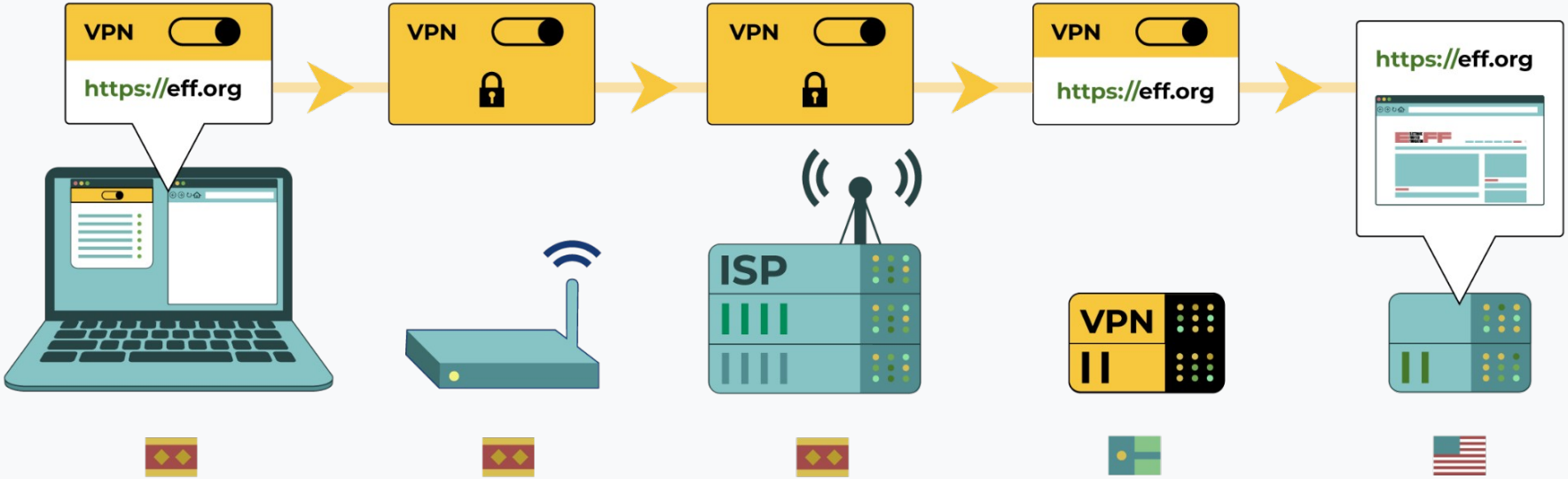



*Image source: eff.org*

# Connecting through Tor

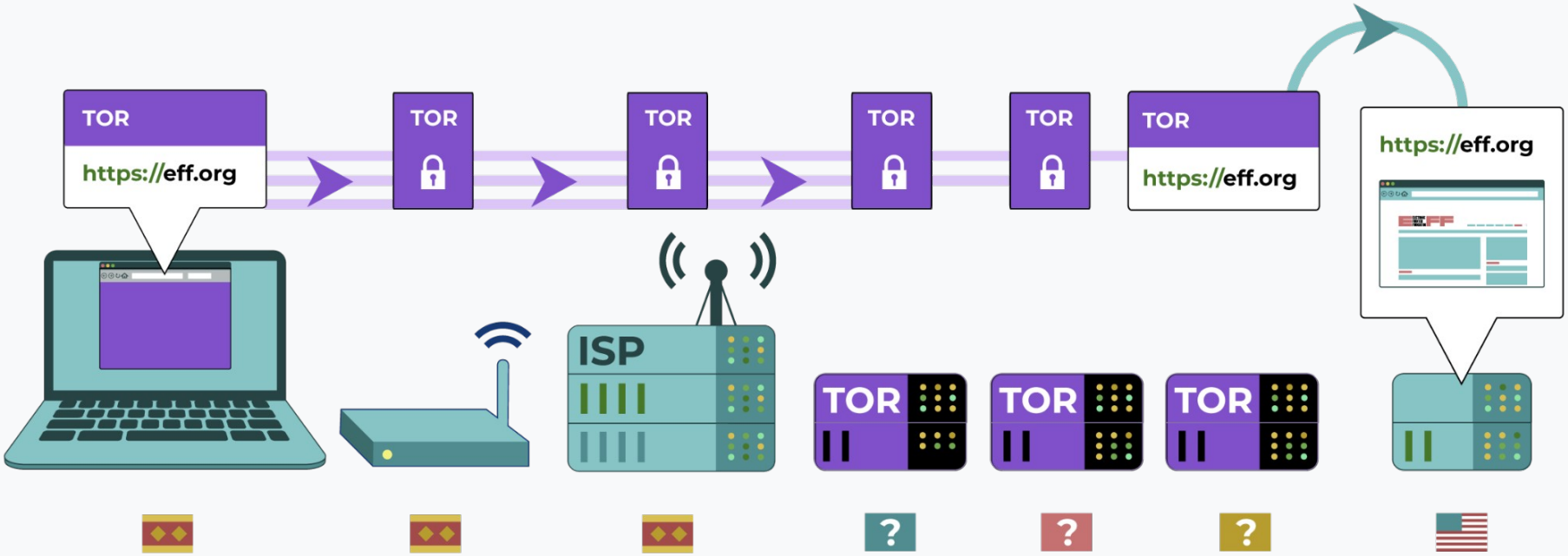



*Image source: eff.org*

**Who** can see your activity through **HTTPS** and **what** can they see?

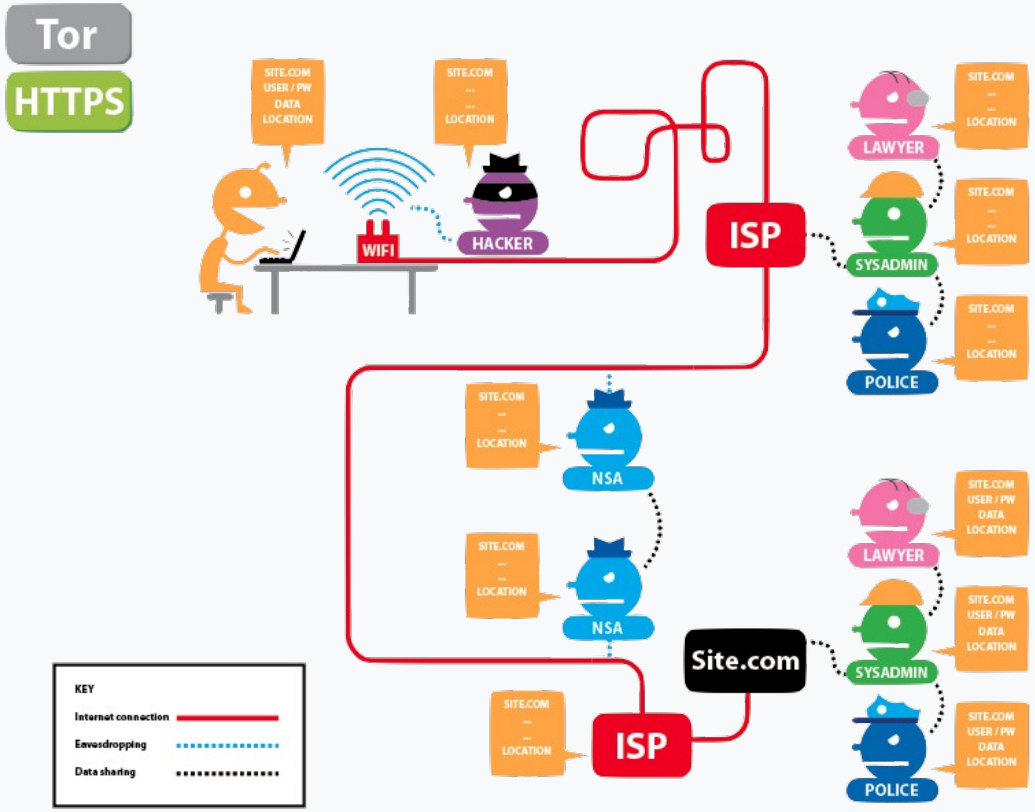



*Image source: eff.org*

**Who** can see your activity through **Tor** and **HTTPS** and **what** can they see?

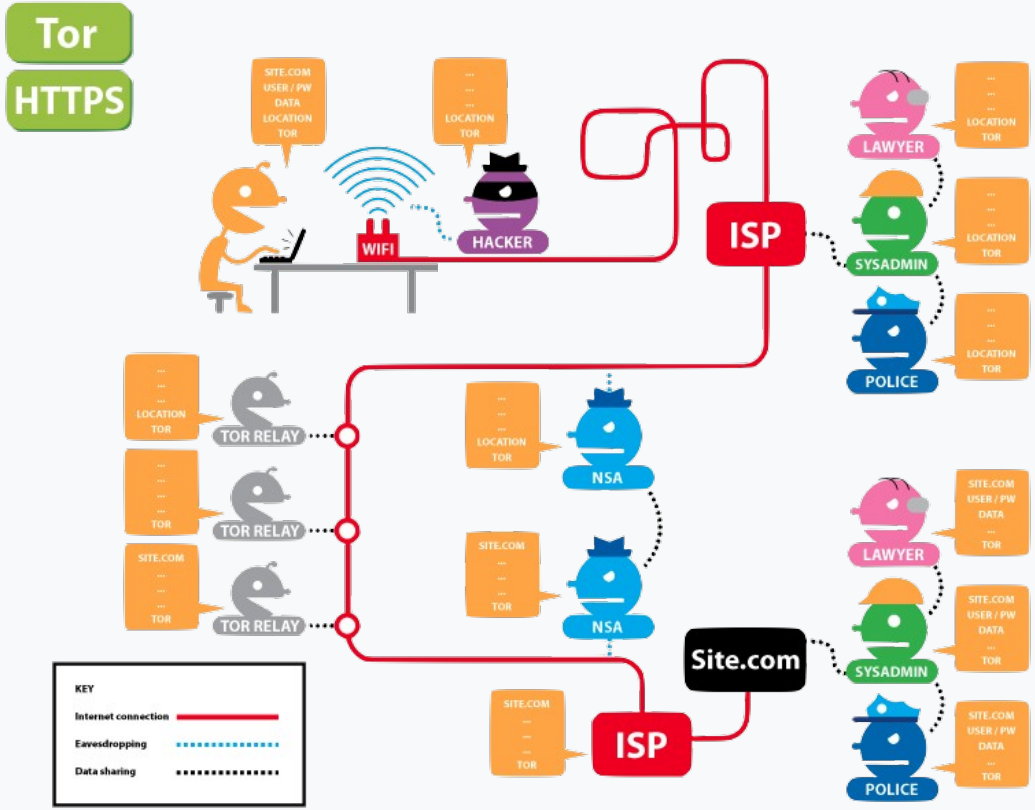
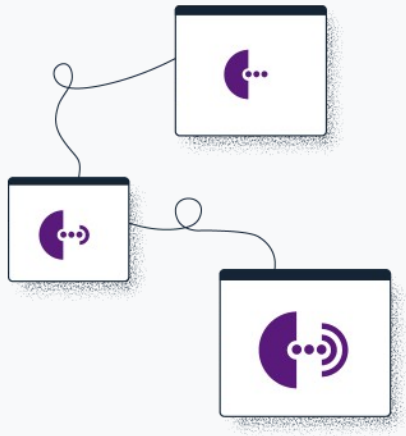



*Image source: eff.org*

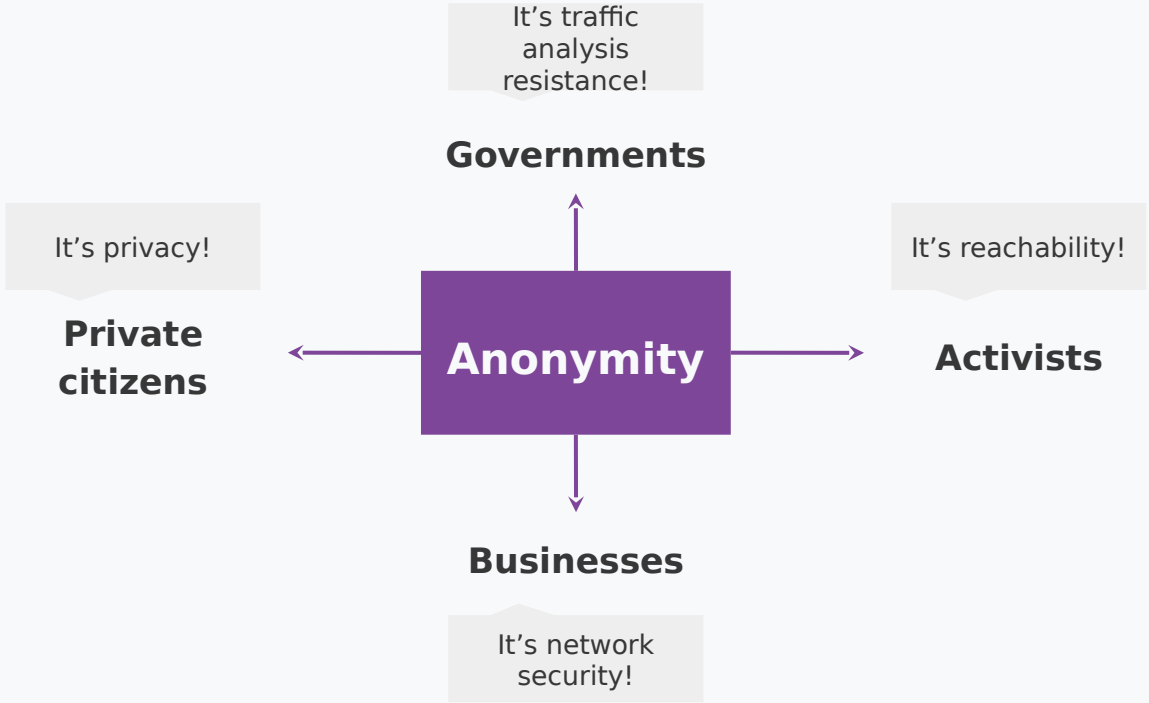
# Different ways of defining Tor

- Tor ⇒ free software created at NRL starting 2001/2.
- Tor ⇒ an open network of ~9,500 nodes – anyone can join!
- Tor ⇒ a browser that connects you to the Tor network.
- Tor ⇒ a US non-profit formed in 2006.
- Tor ⇒ a community of volunteers, researchers, developers, trainers, advocates from all over the world.



# Fighting the Internet’s original sins

- It’s Tor (not capitalized).
- The goal is to have a way to use the internet with as much privacy as possible:
  a. by routing traffic through multiple nodes; and
  b. by encrypting traffic multiple times – hence the term “onion routing”.
- Tor provides **anonymity**, which mitigates against both surveillance and censorship.


It’s traffic analysis resistance!
Governments
It’s privacy!
It’s reachability!
Private citizens
Anonymity
Activists
Businesses
It’s network security!

# We kill people based on metadata

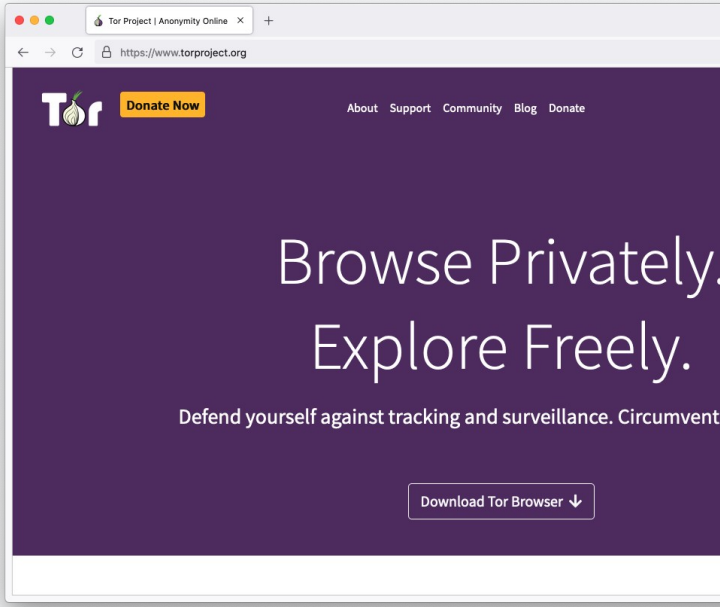
**Director of the NSA and CIA**
General Michael Hayden

# Two sides of the same coin

- Censorship and surveillance go hand-in-hand.
- In order to **block** access to an online service, censors need to **spot** when users want to access said service.
- Anonymity grants protection from surveillance and censorship.

# What is Tor Browser?

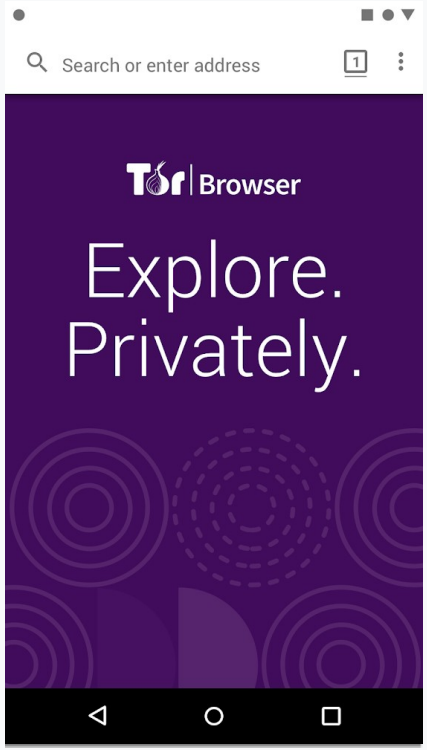
- Just like any other browser (Chrome, Firefox, Safari, Yandex) except it does not expose traffic.
- Traffic is encrypted and bounces through three random volunteer-run nodes called **relays**.
- When using Tor Browser, we don’t know who you are or what you’re visiting.



## Tor Browser on Android

Developed by the Tor Project

https://www.torproject.org/download/



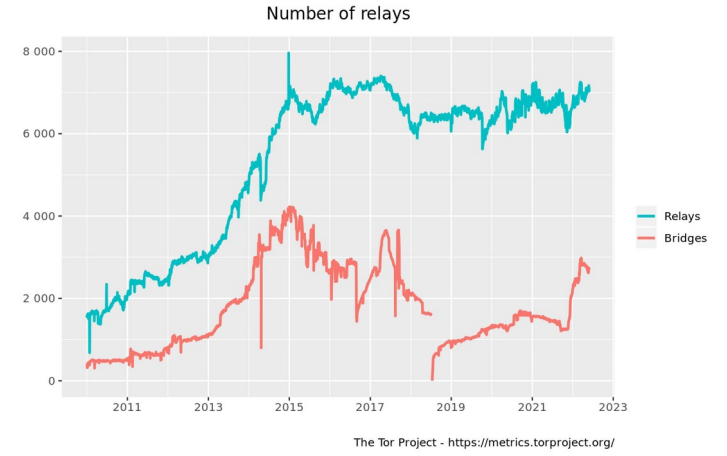

## Onion Browser on iOS

Developed by the Guardian Project

https://onionbrowser.com/

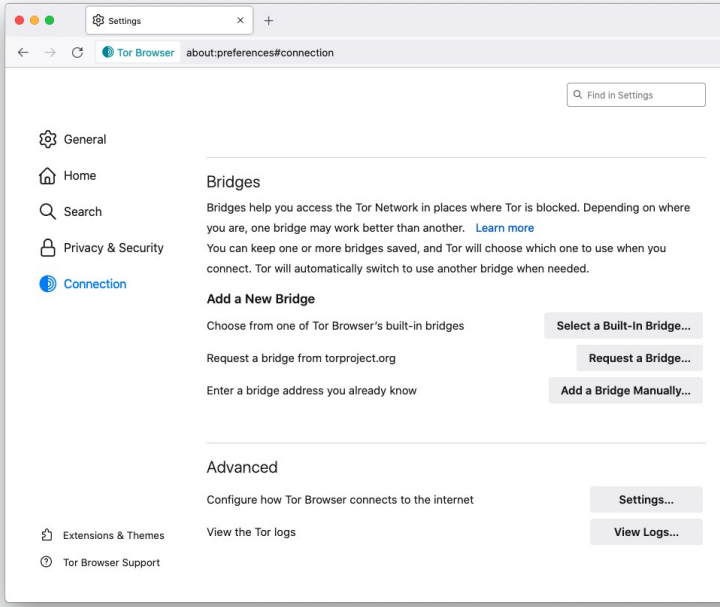
# A growing network of relays

- Tor relays and bridges are run by volunteers from around the world, including individuals, NGOs, and companies.
- They form the backbone of the Tor network.
- Today we count: 7000+ relays and 2660+ bridges.



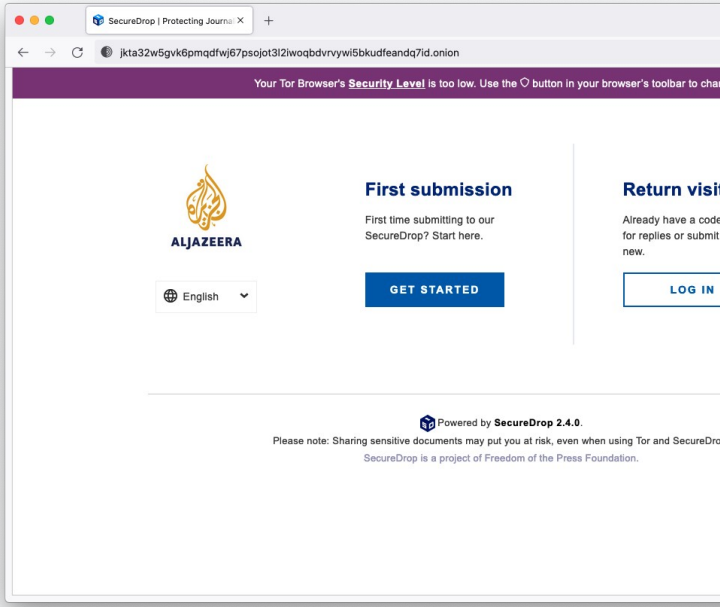
# Bypassing censorship of the Tor network

- Direct access to Tor may be blocked by some Internet Service Providers and governments.
- Tor Browser includes circumvention tools for getting around these blocks called bridges.
- Bridges are relays that are private and harder to block: [https://bridges.torproject.org/](https://bridges.torproject.org/)



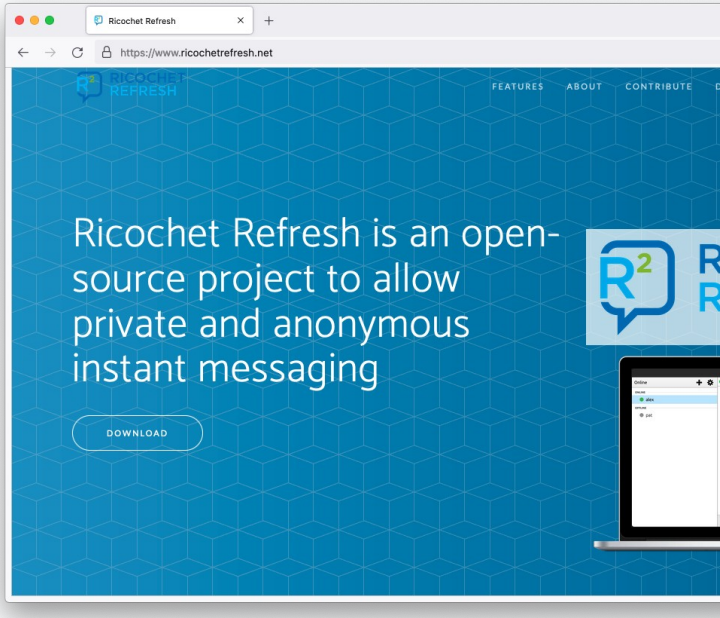
# Secure whistleblowing

- SecureDrop and GlobaLeaks are tools for whistleblowers to communicate securely with journalists.
- Newsrooms around the world have set up their own whistleblowing platforms to receive leaks securely.



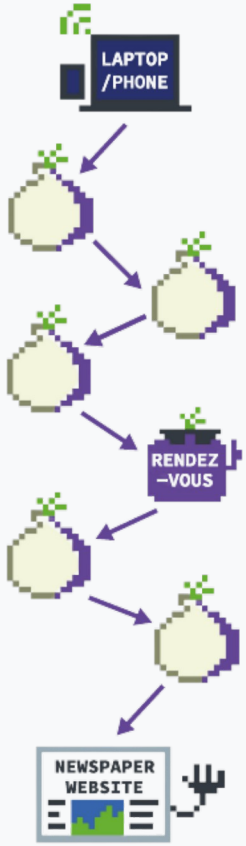
# Anonymous peer-to-peer messaging

- Ricochet Refresh is an instant messenger that routes all messages through Tor.
- Nobody knows who you're talking to, or what you're talking about.
- Supported by Blueprint for Free Speech: https://www.blueprintforfreespeech.net/

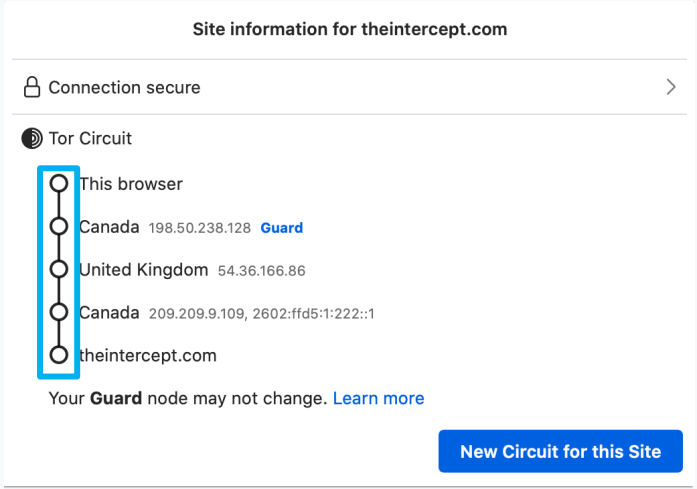


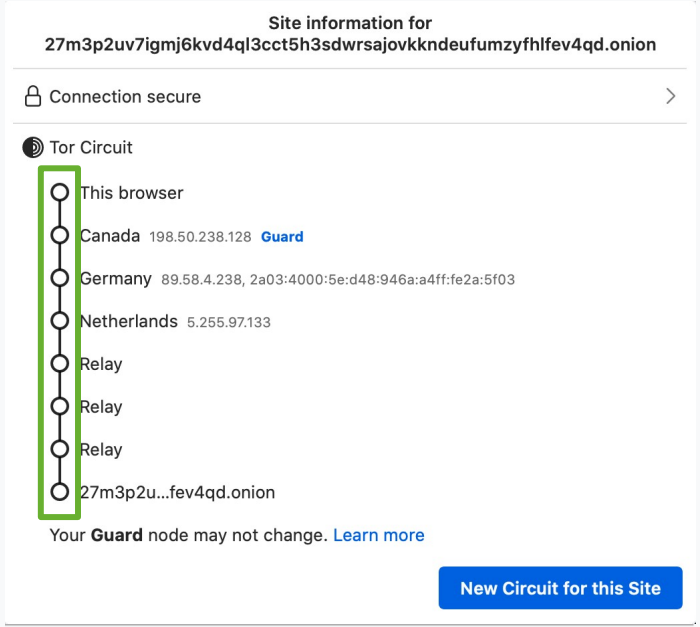
# Introduction to Onion Services (.onion)

- Onion Services are online services that are only available through the Tor network.
- An Onion Service connects to a rendez-vous node/relay inside the Tor network; and the user wanting to connect to it does the same.
- As a user, you never leave the Tor network when visiting an Onion Service.
- Onion Services provide end-to-end encryption: both visitor and website use Tor (without HTTPS).



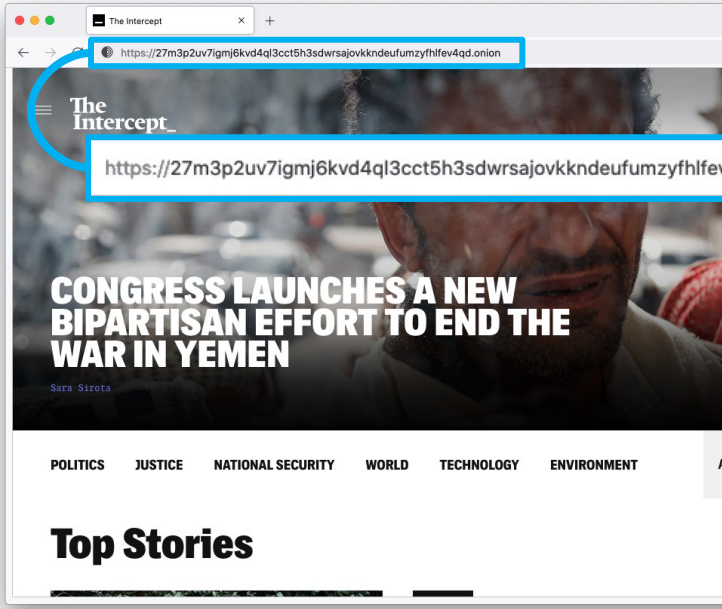
# Visiting the Intercept's site on Tor Browser vs. visiting the Intercept's onion service



# .onion addresses

- Just like any other website, you need to know the address of an onion service in order to reach it.
- The .onion address is automatically generated, so there is no need to purchase a domain.
- An onion address is a string of 56 random letters and numbers followed by ".onion".

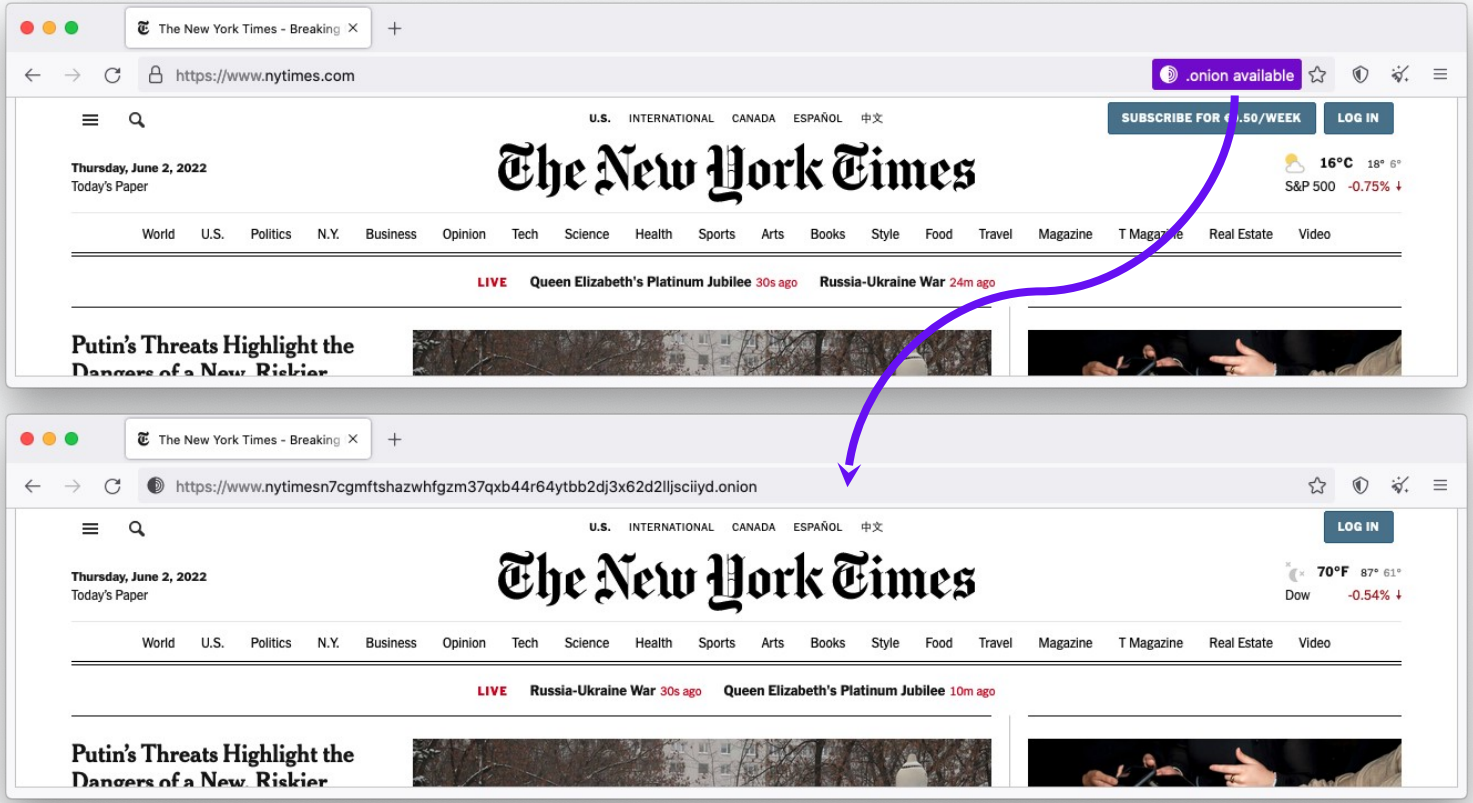


# Censorship resistance

- Both location and IP address of an Onion Service are hidden, making it difficult to censor or identify who runs the service. Used to be called “hidden services”.
- Tor exit nodes can block websites (rare), Onion Services never exit the Tor network.
- It’s the **most censorship-resistant technology** available out there as long as the Tor network is reachable.

# Metadata obfuscation and elimination

- When you use the Tor network to browse the web you are not sending any information by default of who you are or where you are connecting from.
- The Onion Services use the Tor network to eliminate information about where they are situated.
- Using them **eliminates all metadata** that may be associated with the service otherwise.


The New York Times - Breaking
https://www.nytimes.com
.onion available
U.S. INTERNATIONAL CANADA ESPAÑOL 中文
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Thursday, June 2, 2022
Today's Paper
The New York Times
16°C 18° 6°
S&P 500 -0.75%
World U.S. Politics N.Y. Business Opinion Tech Science Health Sports Arts Books Style Food Travel Magazine T Magazine Real Estate Video
LIVE Queen Elizabeth's Platinum Jubilee 30s ago Russia-Ukraine War 24m ago
Putin's Threats Highlight the
The New York Times - Breaking
https://www.nytimesn7cgmftshazwhfgzm37qxb44r64ytbb2dj3x62d2lljsciiyd.onion
U.S. INTERNATIONAL CANADA ESPAÑOL 中文
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Thursday, June 2, 2022
Today's Paper
The New York Times
70°F 87° 61°
Dow -0.54%
World U.S. Politics N.Y. Business Opinion Tech Science Health Sports Arts Books Style Food Travel Magazine T Magazine Real Estate Video
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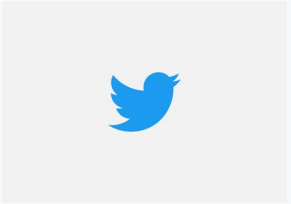
Putin's Threats Highlight the

# Popular Onion Services

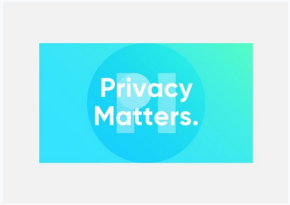











# Benefits of Onion Services

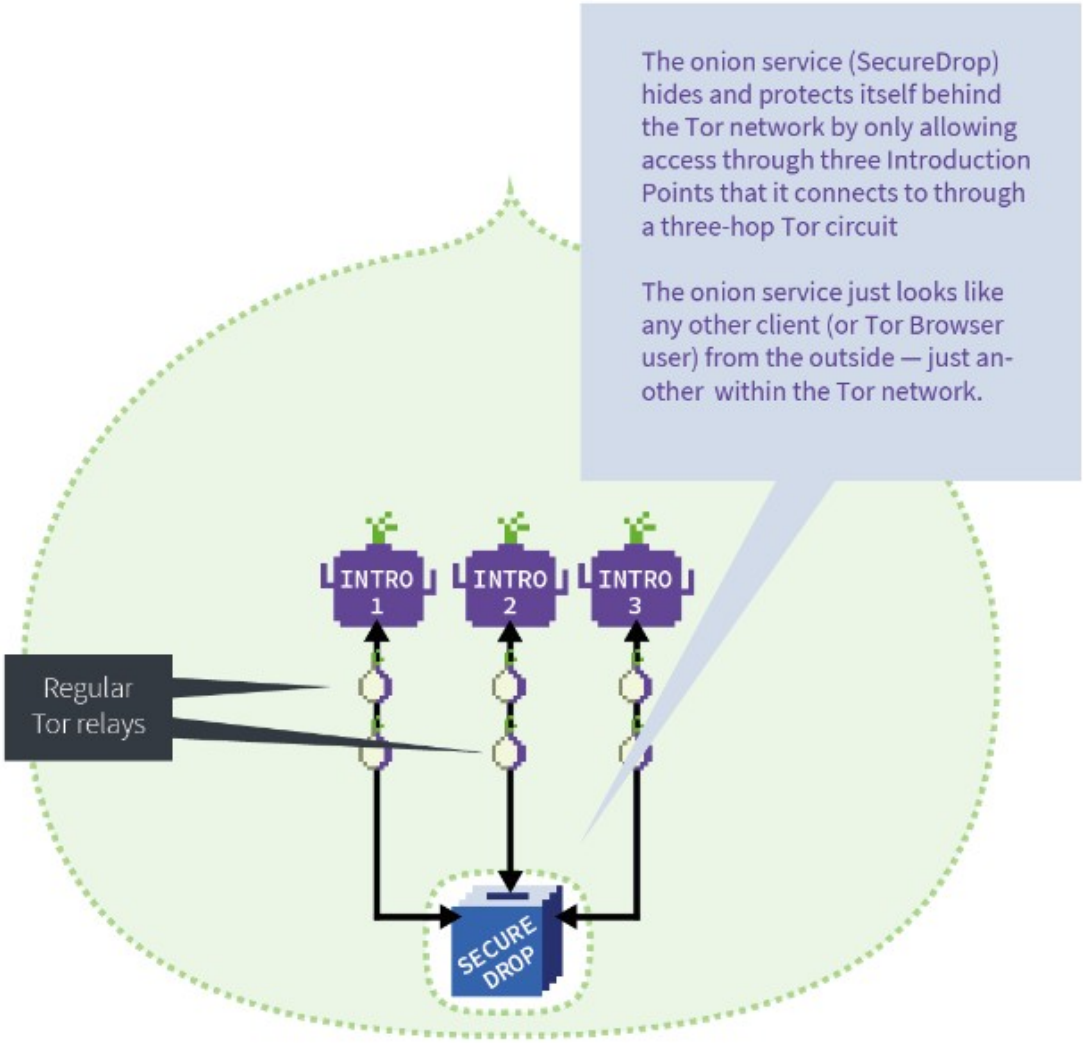
1. Censorship resistance as long as the user has access to Tor.
2. End-to-end encryption between user and website.
3. Contributing to the decentralization of the web.
4. Tor network sustainability.
5. Protection of sources, whistleblowers, and journalists.
6. Opportunity to educate users about privacy by design.
7. Metadata obfuscation and elimination.

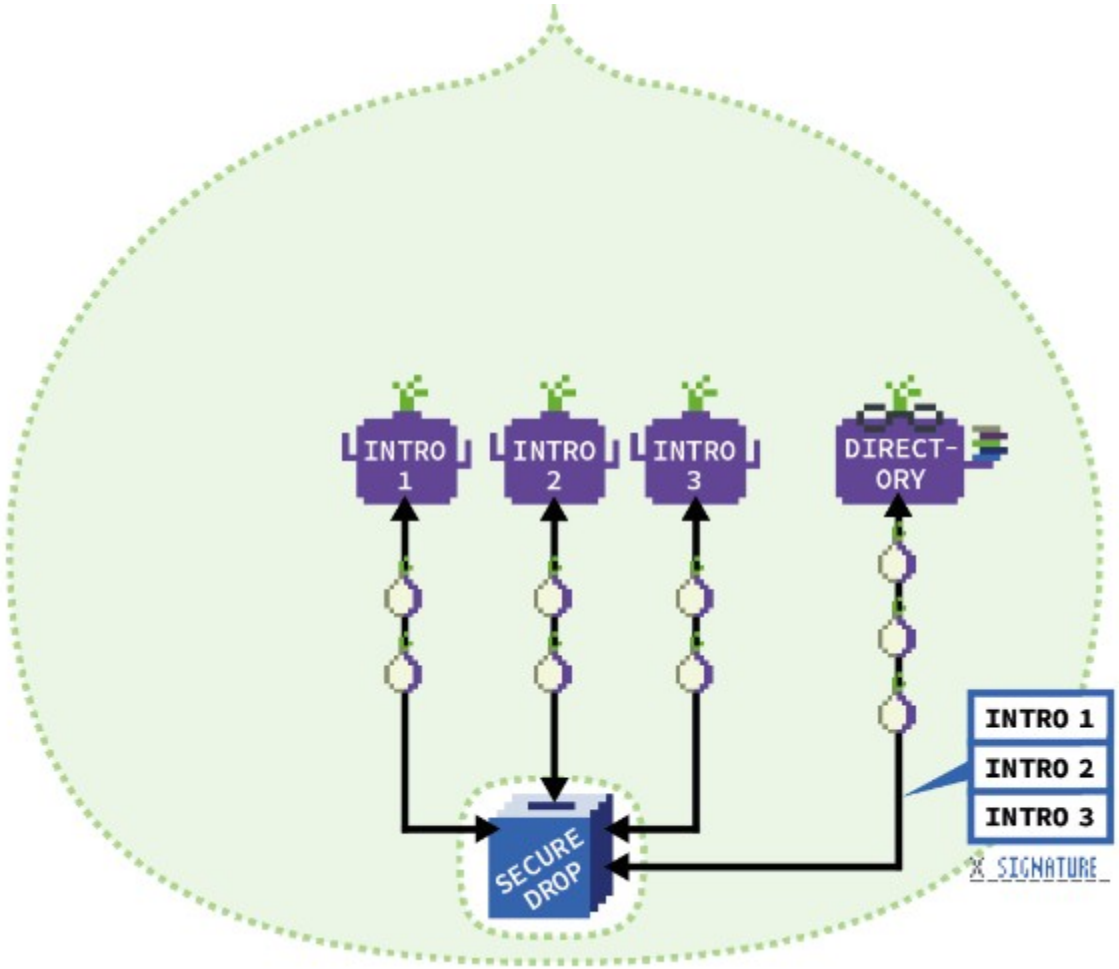
# Comparison

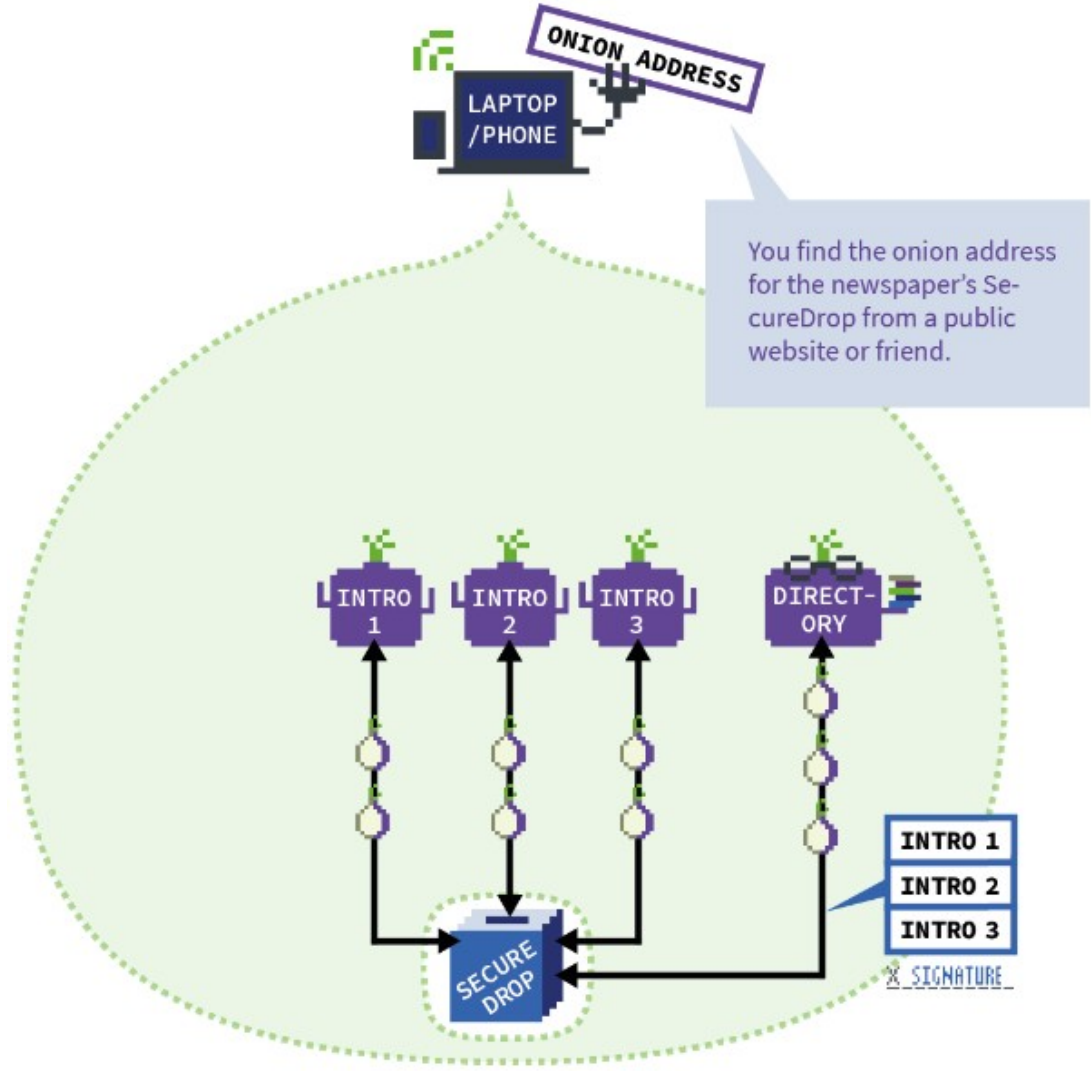
| | Regular Website | Website Over Tor | Onion Service |
|---|---|---|---|
| Censorship Resistance: | **Poor** Website can easily be censored | **Good** Censorship still possible via exit nodes | **Very good** Accessible as long as Tor is reachable, address not censorable |
| Privacy Safeguards: | **Very poor** Minimal safeguards: HTTPS, no tracking, hosting jurisdiction, etc. | **Good** Data correlation is not an eliminated risk | **Very good** End-to-end encryption for user and service, anonymity for both |
| Metadata Elimination: | **Poor** Data about online activity recorded by websites and entities passing traffic | **Good** Data about online activity can be recorded by website if user logs in and identifies themselves | **Very good** Metadata logging eliminated on both ends, but website can record data if user logs in |

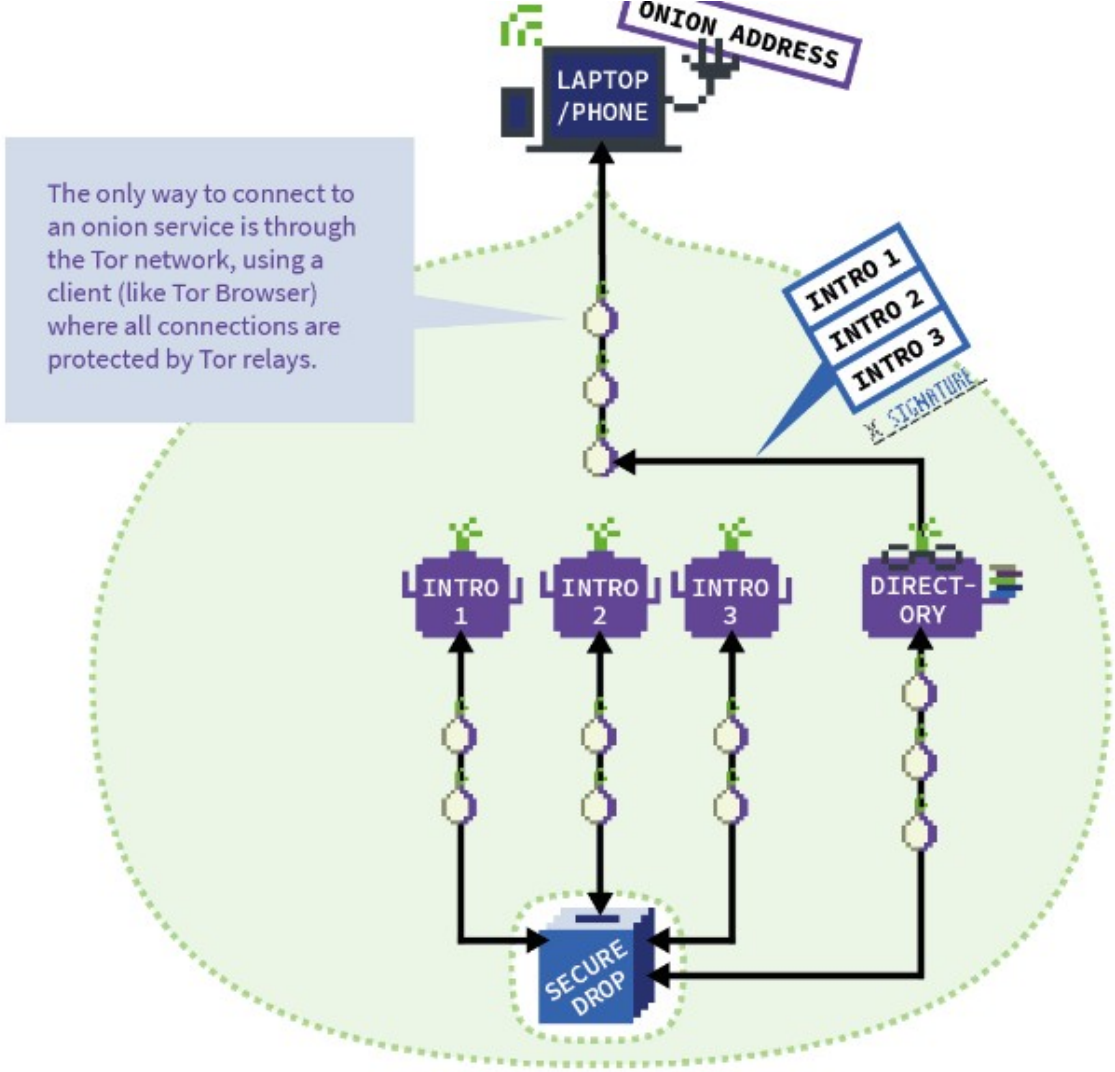
Now some slides from…

https://community.torproject.org/onion-services/overview/

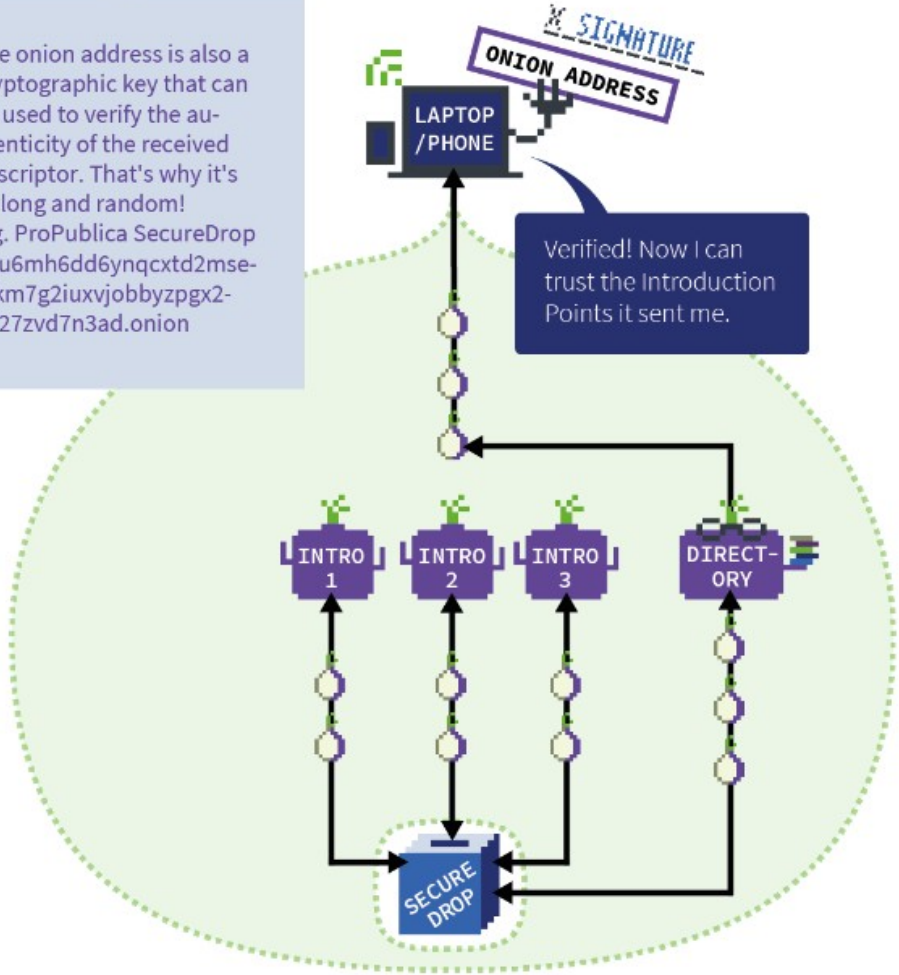

The onion service (SecureDrop) hides and protects itself behind the Tor network by only allowing access through three Introduction Points that it connects to through a three-hop Tor circuit
The onion service just looks like any other client (or Tor Browser user) from the outside — just another within the Tor network.
INTRO 1
INTRO 2
INTRO 3
Regular Tor relays
SECURE DROP

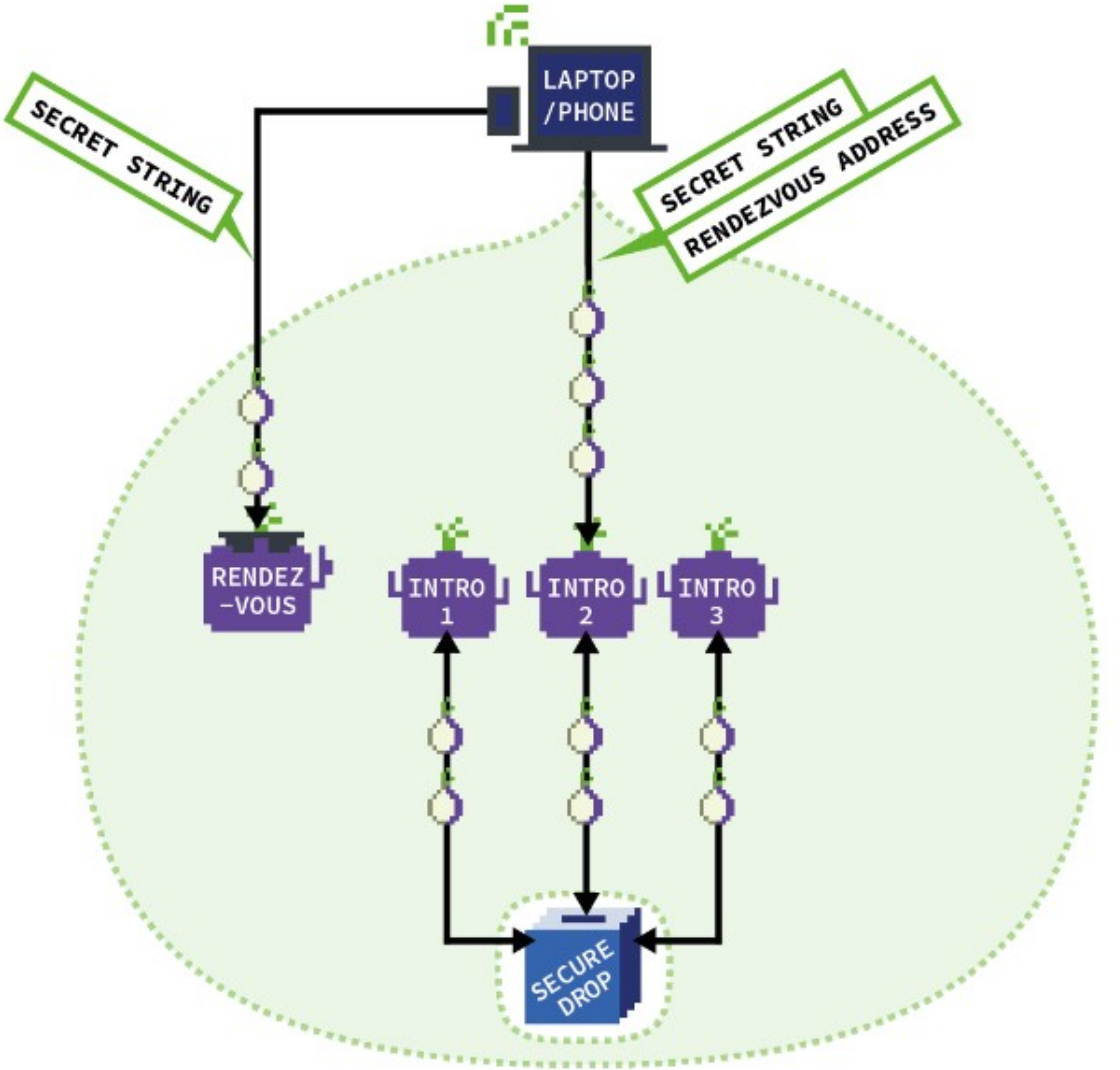

INTRO 1
INTRO 2
INTRO 3
DIRECT-ORY
SECURE DROP
INTRO 1
INTRO 2
INTRO 3
X SIGNATURE


ONION ADDRESS
LAPTOP /PHONE
You find the onion address for the newspaper's SecureDrop from a public website or friend.
INTRO 1
INTRO 2
INTRO 3
DIRECT-ORY
INTRO 1
INTRO 2
INTRO 3
SIGNATURE
SECURE DROP


ONION ADDRESS
LAPTOP /PHONE
The only way to connect to an onion service is through the Tor network, using a client (like Tor Browser) where all connections are protected by Tor relays.
INTRO 1
INTRO 2
INTRO 3
SIGNATURE
INTRO 1
INTRO 2
INTRO 3
DIRECT-ORY
SECURE DROP

The onion address is also a cryptographic key that can be used to verify the authenticity of the received descriptor. That's why it's so long and random!
E.g. ProPublica SecureDrop
lvtu6mh6dd6ynqcxtd2mse-qfkm7g2iuxvjobbyzpgx2-jt427zvd7n3ad.onion

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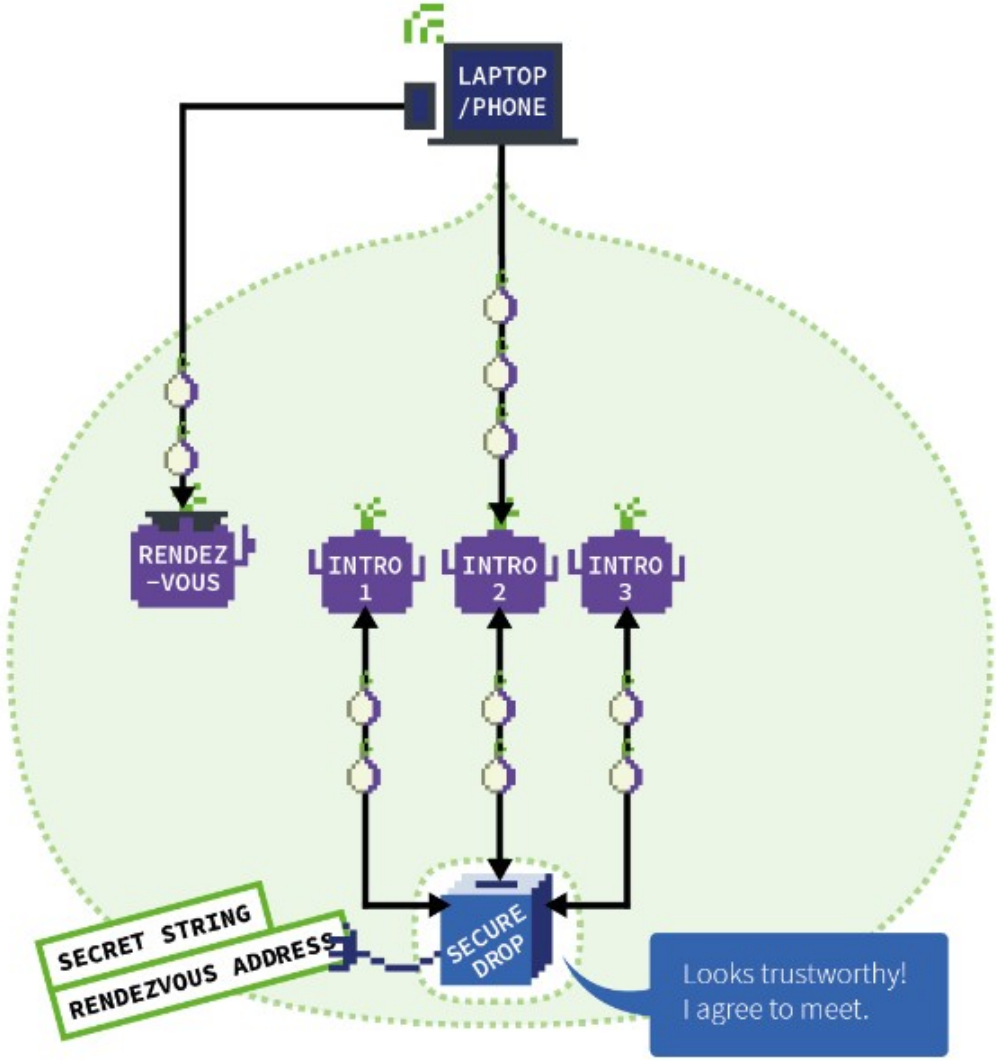
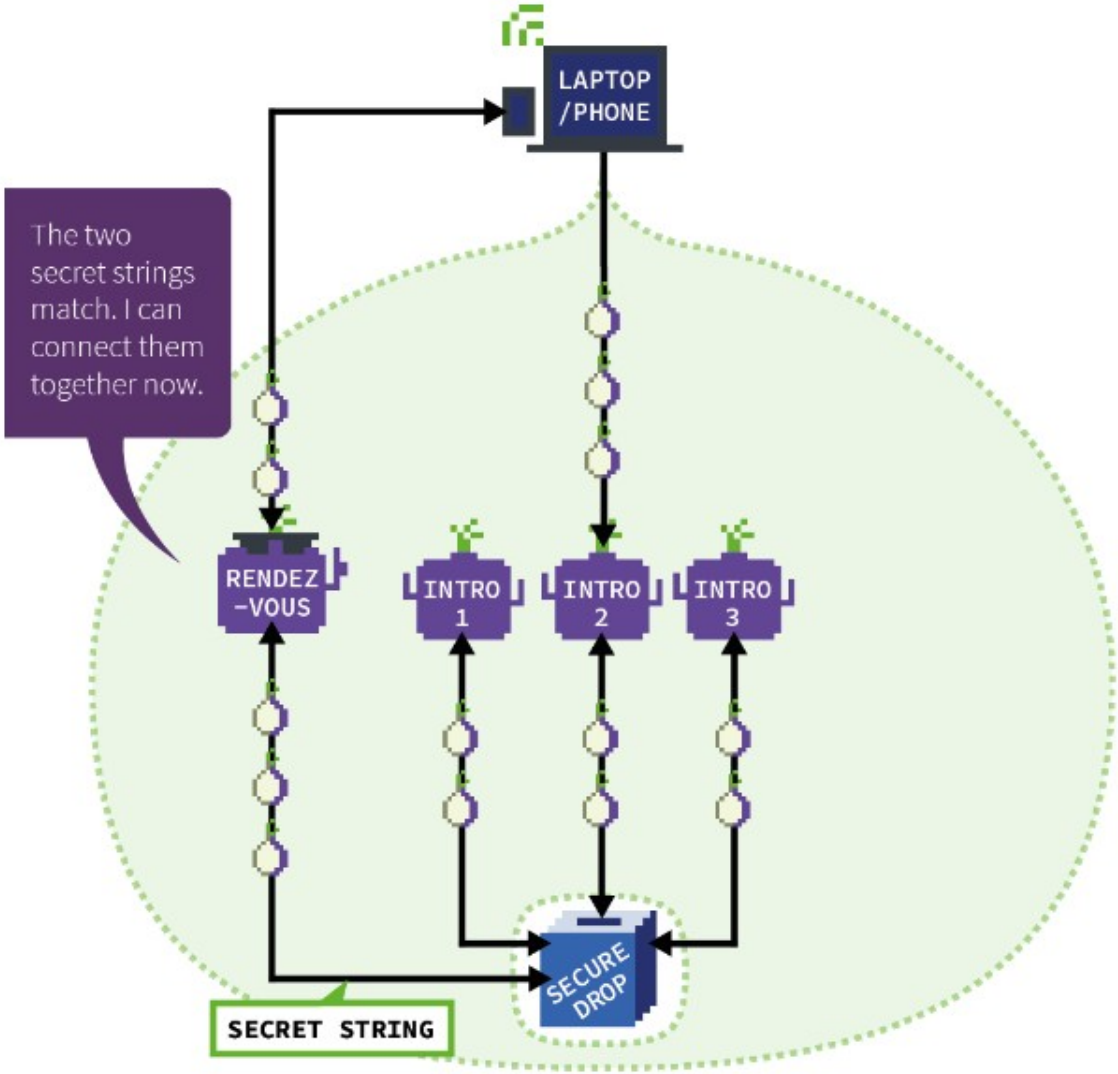
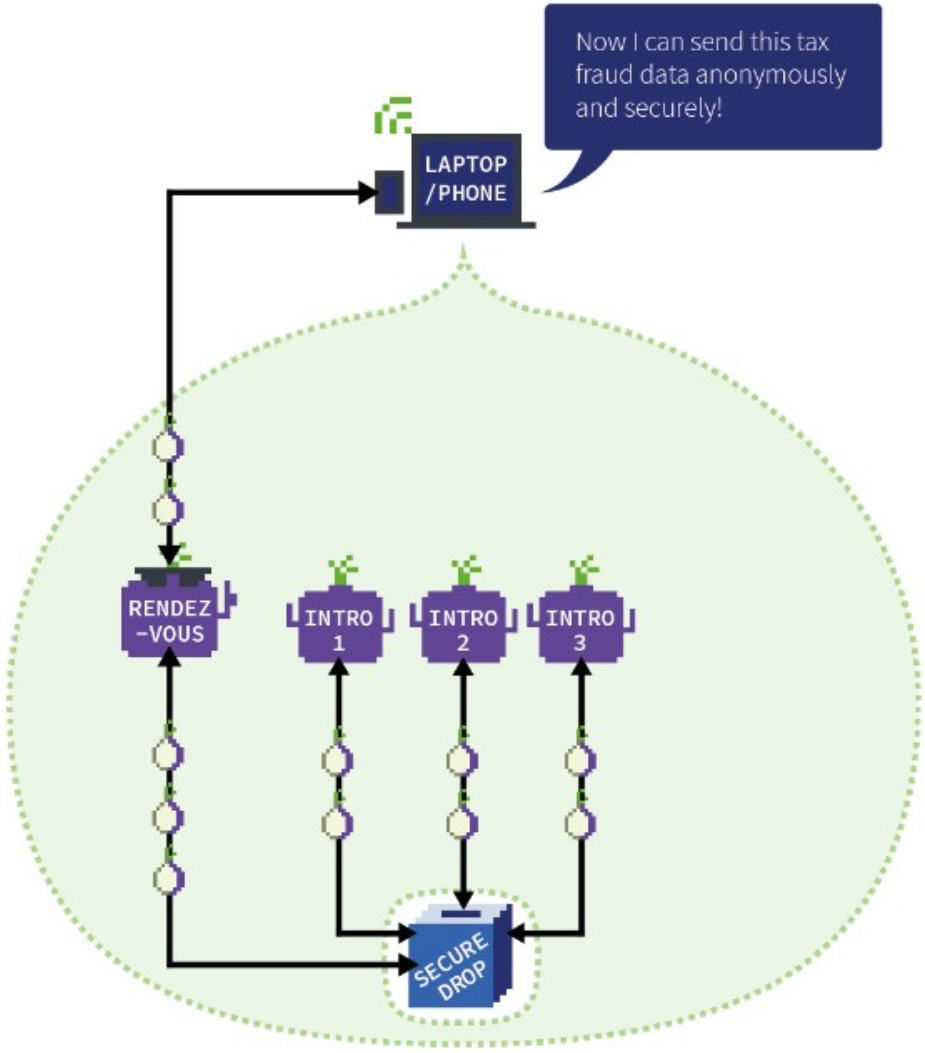
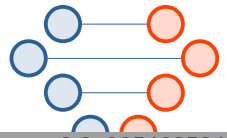
SECURE
DROP


LAPTOP
/PHONE
RENDEZ
-VOUS
INTRO
1
INTRO
2
INTRO
3
SECRET STRING
RENDEZVOUS ADDRESS
SECURE
DROP
Looks trustworthy!
I agree to meet.


LAPTOP
/PHONE
The two secret strings match. I can connect them together now.
RENDEZ
-VOUS
INTRO
1
INTRO
2
INTRO
3
SECURE
DROP
SECRET STRING


Now I can send this tax fraud data anonymously and securely!
LAPTOP /PHONE
RENDEZ -VOUS
INTRO 1
INTRO 2
INTRO 3
SECURE DROP

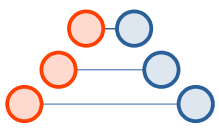
Switching gears… Why do you need something like Tor, a VPN, or ShadowSocks to evade censorship?

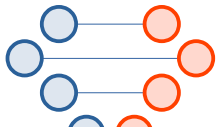


| | | | | | |
|---|---|---|---|---|---|
| 3 | 0.005462504 | 10.155.30.179 | 18.205.53.136 | TCP | 74 40186 → 443 [SYN] Seq=0 Win=64240 Len=0 MSS |
| 8 | 0.067175913 | 18.205.53.136 | 10.155.30.179 | TCP | 74 443 → 40186 [SYN, ACK] Seq=0 Ack=1 Win=2684 |
| 24 | 0.195979757 | 10.155.30.179 | 18.205.53.136 | TLSv1.2 | 104 Application Data |
| 26 | 0.196261196 | 18.205.53.136 | 10.155.30.179 | TLSv1.2 | 104 Application Data |
| 28 | 0.196849481 | 10.155.30.179 | 18.205.53.136 | TLSv1.2 | 108 Application Data |
| 22 | 0.195647004 | 18.205.53.136 | 10.155.30.179 | TLSv1.2 | 144 Application Data |
| 18 | 0.134217638 | 10.155.30.179 | 18.205.53.136 | TLSv1.2 | 192 Client Key Exchange, Change Cipher Spec, En |
| 21 | 0.195646933 | 18.205.53.136 | 10.155.30.179 | TLSv1.2 | 270 New Session Ticket, Change Cipher Spec, Enc |
| 25 | 0.196261086 | 18.205.53.136 | 10.155.30.179 | TLSv1.2 | 352 Application Data |
| 11 | 0.067795926 | 10.155.30.179 | 18.205.53.136 | TLSv1.2 | 624 Client Hello |
| 19 | 0.134536166 | 10.155.30.179 | 18.205.53.136 | TLSv1.2 | 656 Application Data, Application Data |
| 10 | 0.067787461 | 10.155.30.179 | 18.205.53.136 | TCP | 1264 40186 → 443 [ACK] Seq=1 Ack=1 Win=64256 Len |
| 14 | 0.131083829 | 18.205.53.136 | 10.155.30.179 | TLSv1.2 | 1264 Server Hello |
| 16 | 0.131154339 | 18.205.53.136 | 10.155.30.179 | TLSv1.2 | 3202 Certificate, Server Key Exchange, Server He |

```
▾ Extension: server_name (len=19)
    Type: server_name (0)
    Length: 19
  ▾ Server Name Indication extension
      Server Name list length: 17
      Server Name Type: host_name (0)
      Server Name length: 14
      Server Name: boredpanda.com
▾ Extension: Reserved (GREASE) (len=1)
```

```
70  59 7f 51 d5 11 9b ec 81  33 ba 62 5b f0 d5 54 35   Y·Q····· 3·b[··T5
80  80 24 34 4c 3f 3f e7 42  99 35 fd 08 01 f3 77 db   ·$4L??·B ·5····w·
90  3d 46 d2 b5 96 ce cf c5  45 e9 e2 2b 00 1d 00 20   =F····· E··+···
a0  d2 2c b8 f7 90 4f 37 6b  36 5a 09 32 ab 9a d7 52   ·,···O7k 6Z·2···R
b0  f7 30 d3 a5 f7 a0 60 3a  e4 0f a1 e2 3d e6 d5 61   ·0····`: ····=··a
c0  00 00 00 13 00 11 00 00  0e 62 6f 72 65 64 70 61   ········ ·boredpa
d0  6e 64 61 2e 63 6f 6d 1a  1a 00 01 00              nda.com· ····
```





...
zz.....#...3....zz.....A..  t....I...
...\.?n..Sy.nTo.z.2..L..#t...>.P+....d%%..2Ar....q..Q.Tx?...\.....g...$e..A...O.k.RE..%
.....wg..r../1....T.kq.....0x$..x....."e .).s(F.
...dw\.*....hH.+v....FY.I.2.....[..J.2.3.I.|.@s.Ie..8..76]...$".U...?..Cr.H..o..&.(...{.t...
.....  ...c..k1.,qM.....Y.Ch.6...I."....$.q.....M5..ZWM.\.bKEJo.4^.....+..8.....AQ....Av.p..@.....&....d=..Y..E..c.Y...y..y.wNbd:.....:+1.+7a`
{.....+...:..P2.k..LOc...(f.8.QR/X.A.U;c.],'...._..T
.1.Fv.M. ..e...X  .'8X.....y..v9.....zWF.....L..1cy"...%..HY>...#.iC..+$#0.$..+....@.[.....>...4,X.r.....Sq.f....\%"x
....7Z.w;...o..q.....u.z./..,.F..WY8.....+.^"%G#k...{..U".j..M.....49..2x cng1.P..v..".J..V$6.I:Aq...v.x
c.I...&..-..`..t..@A..M..?!m;C..|r.EF....)W.....j..2..V..-....&....M.,.K..F..4R.5..{z....G.tQ..z...M#:%.e...B....K+A"B.....&....W]"...)...ru....A{.1syn..1.
\i..P.`j2T.'..w....8.\.V0..[C...t..I..C}..QF....&..+..Th+.....
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./ ...D.....-..Y..0a.:... ...j...:I.V|.q.Z=.'..|D.U.A$R..yye..!.....c.3[...3.,j...p..v.....H6.Q..(.%..
.....8.1...+@..#.6.x..,x[....z...r...j!.....) ..:`V..Y.Q.....3.b[..T5.$4L??.B.5....w.=F.....E..+... .,...O7k6Z  2...R.
0....`:....=..a.....boredpanda.com.....I...h.....x.h.i@..:5$...VA..}....&..... .....z...q.e..
}9x%....gng...../.. .....h2.#.....0...0.....>.tK...%..e....0
.  *.H..
.....0<1.0  ..U....US1.0
..U.
..Amazon1.0...U....Amazon RSA 2048 M030..
250301000000Z.
260330235959Z0.1.0...U....www.boredpanda.com0.."0
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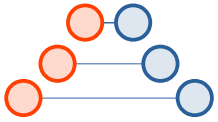


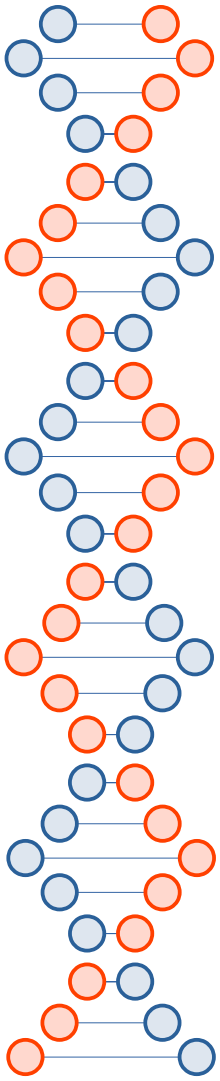
(Encrypted Client Hello, or ECH, is a way to hide the Server Name Indicator, or SNI)

In November 2024, Russia began blocking Cloudflare's implementation of Encrypted Client Hello (ECH), a privacy-focused extension of the TLS protocol. *"This technology is a means of circumventing restrictions on access to information banned in Russia. Its use violates Russian law and is restricted by the Technical Measure to Combat Threats (TSPU),"* the statement by the Russian Internet regulator read.

https://adguard-dns.io/en/blog/encrypted-client-hello-misconceptions-future.html

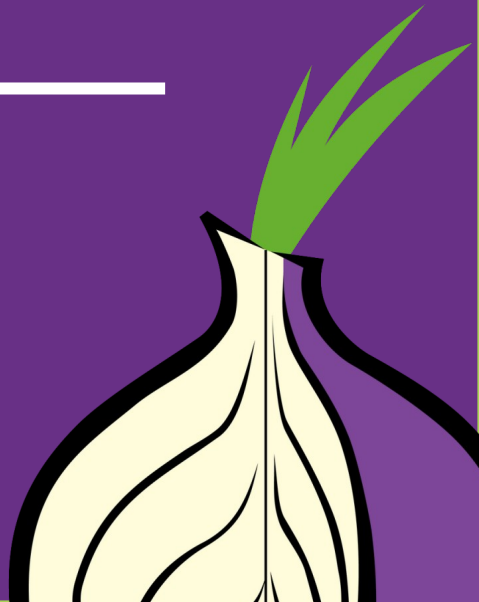
# OONI

- Open Observatory of Network Interference: https://ooni.torproject.org
- Country-level reports of specific censorship tools in use on certain websites
- View their reports: https://explorer.ooni.org/
- Or use your own OONI Probe to test websites: available in App Store and Google Play.

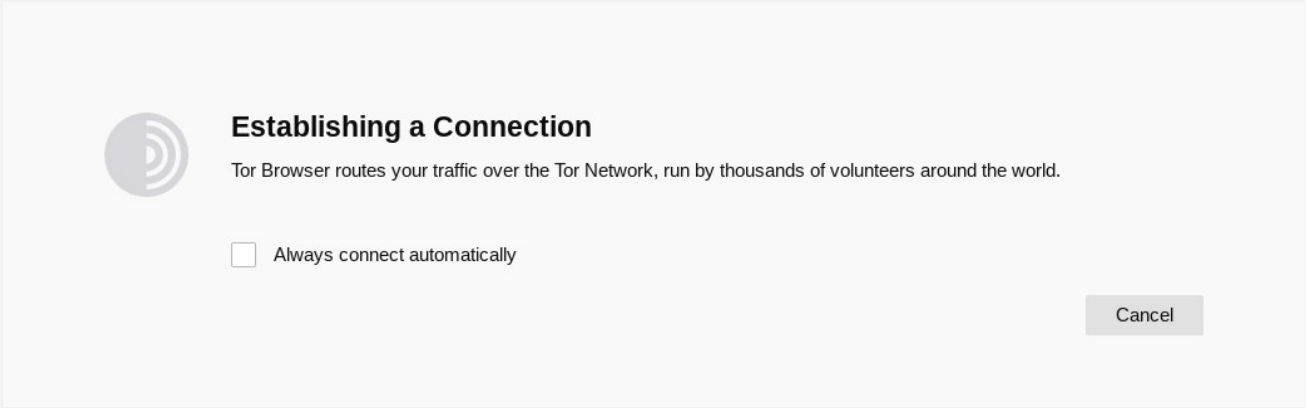


If you get past SNI filtering (*e.g.*, with a VPN or Tor), can encryption hide which apps and platforms you're using, or hide the fact that you're using a VPN or Tor?

# What do you do when Tor is blocked?



# I downloaded Tor Browser, but it won’t connect

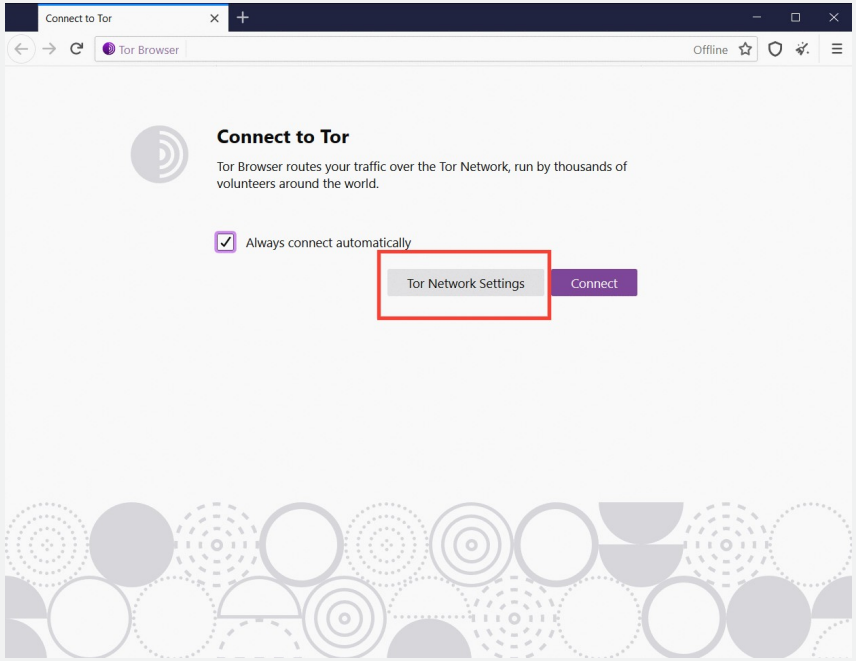


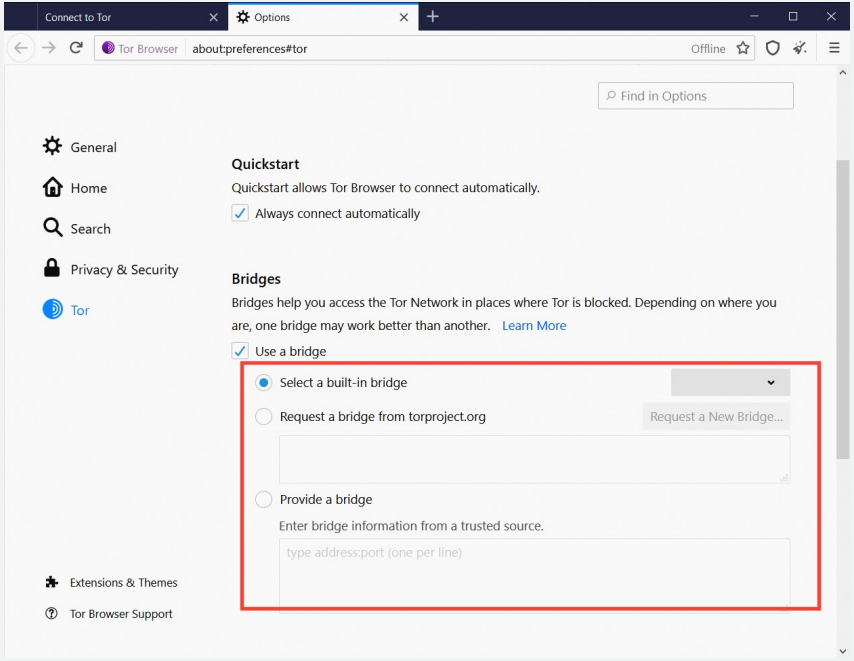

If this screen takes a long time and does not connect, you may need a bridge or pluggable transport

# Bridges and pluggable transports

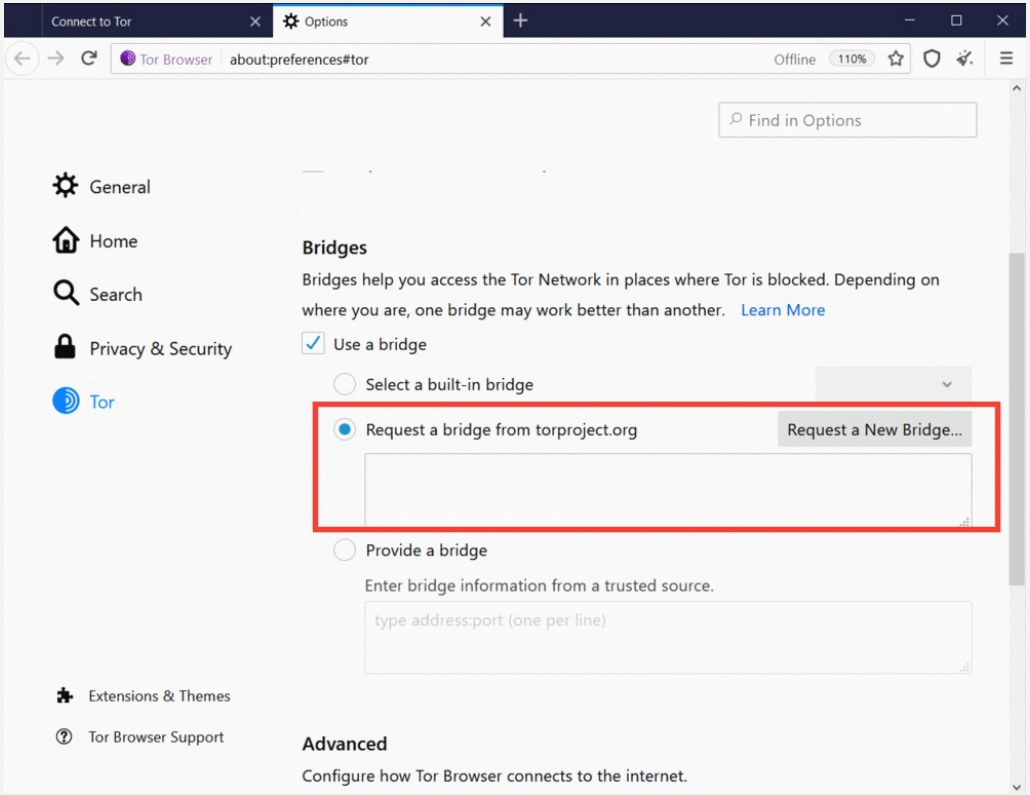
- Bridges are relays that are not listed publicly
- Get bridges directly from Tor Browser (moat)
- Or from the website https://bridges.torproject.org or send an email to bridges@torproject.org from a Gmail, or Riseup.net account
- Or get a bridge address from a trusted person
- Pluggable transports can be used like bridges to disguise Tor traffic (also called “built-in bridges”)

# Bridges and pluggable transports

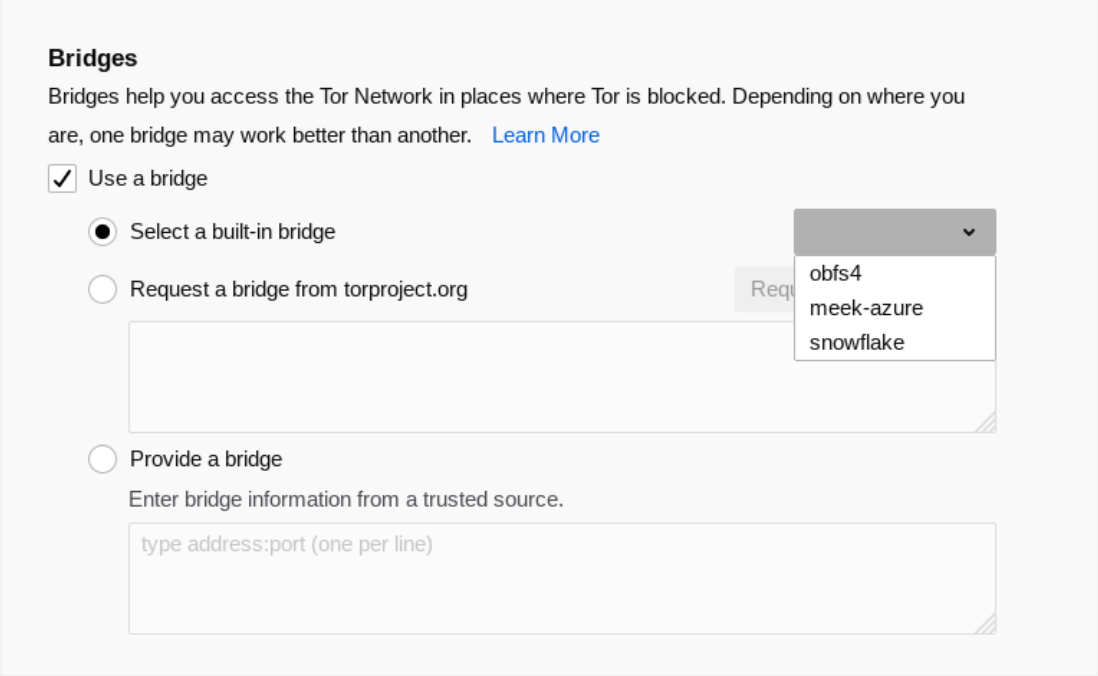


# Request a bridge



# Or select a built-in bridge



# Pluggable transports

- **obfs4**: makes Tor traffic look random; works in many situations including China (if not, try meek).
- **meek-azure**: makes it look like Microsoft traffic; works in China.
- **snowflake**: proxies traffic through temporary proxies using WebRTC (under development). https://snowflake.torproject.org

# obfs4 = ScrambleSuit, basically

- https://arxiv.org/pdf/1305.3199.pdf

**ScrambleSuit: A Polymorph Network Protocol to Circumvent Censorship**

Philipp Winter
Karlstad University

Tobias Pulls
Karlstad University

Juergen Fuss
Upper Austria University of Applied Sciences

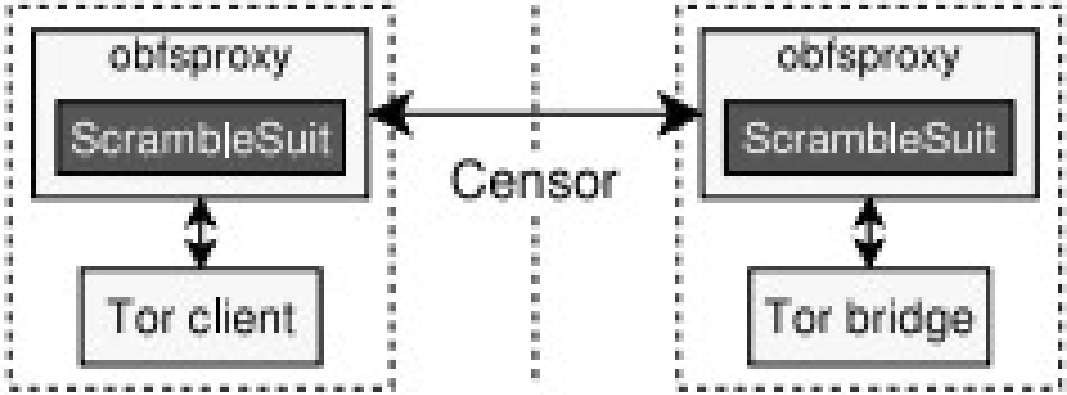



**Figure 2: ScrambleSuit is a module for obfsproxy which provides a SOCKS interface for local applications. The traffic between two obfsproxy instances is disguised by ScrambleSuit.**

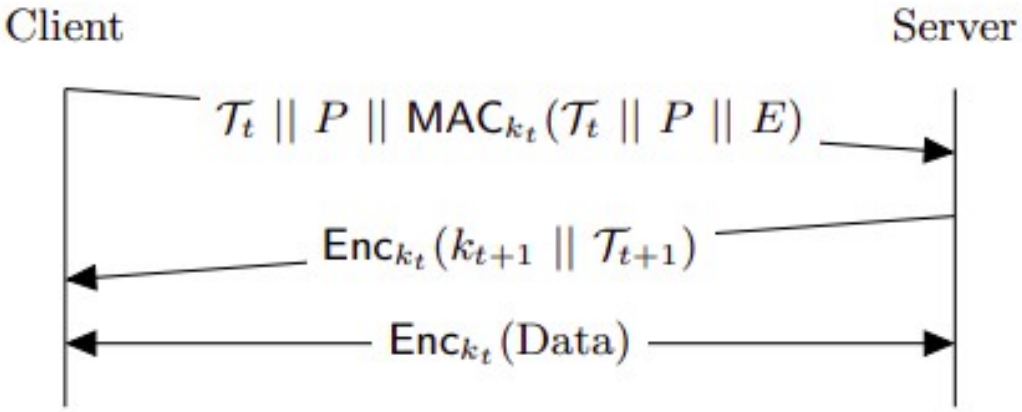
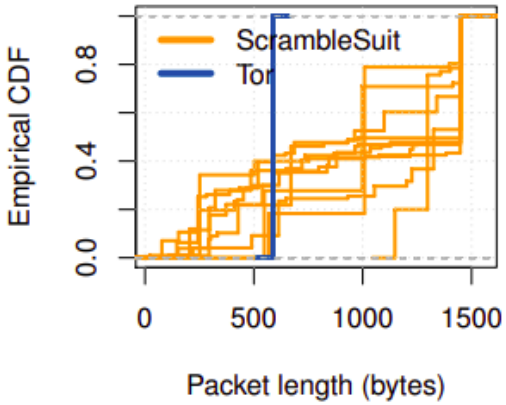



**Figure 4: The client redeems a valid session ticket $\mathcal{T}_t$ containing the master key $k_t$. The server responds by issuing a new ticket $\mathcal{T}_{t+1}$ for future use. Both parties then exchange application data.**

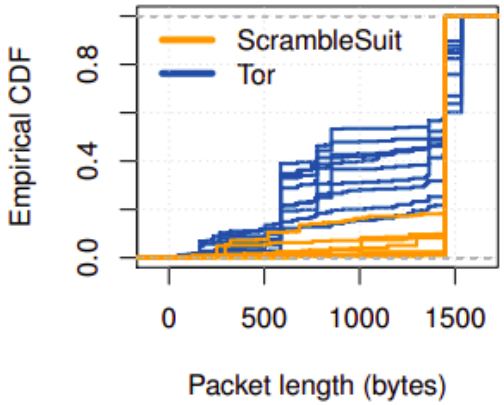
**Payload** By encrypting all ScrambleSuit traffic, we eliminate all payload fingerprints such as Tor's TLS cipher list [12].

**Packet length distribution** Among other things, we seek to get rid of Tor's characteristic 586-byte packets [16, 36]. We do so by morphing Tor's packet length distribution to a randomly chosen distribution.

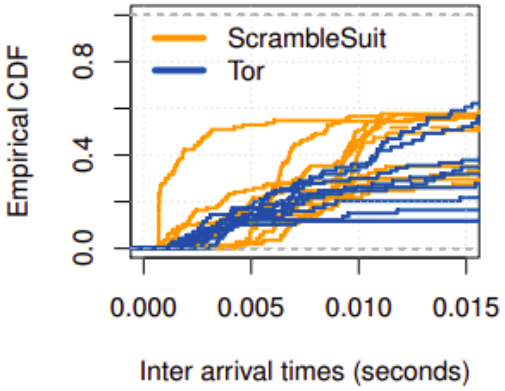
**Inter arrival times** Similar to the packet length obfuscation, we camouflage the inter arrival times by employing small and random sleep intervals before writing data on the wire.



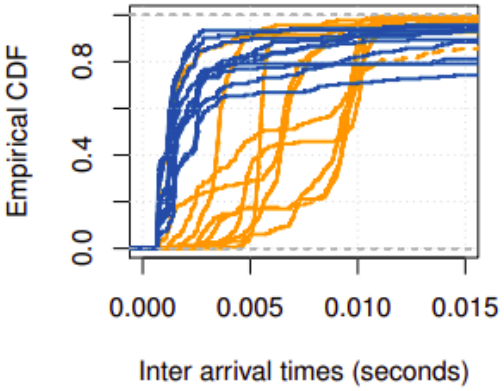

(a) Client-to-server.




(b) Server-to-client.




(c) Client-to-server.

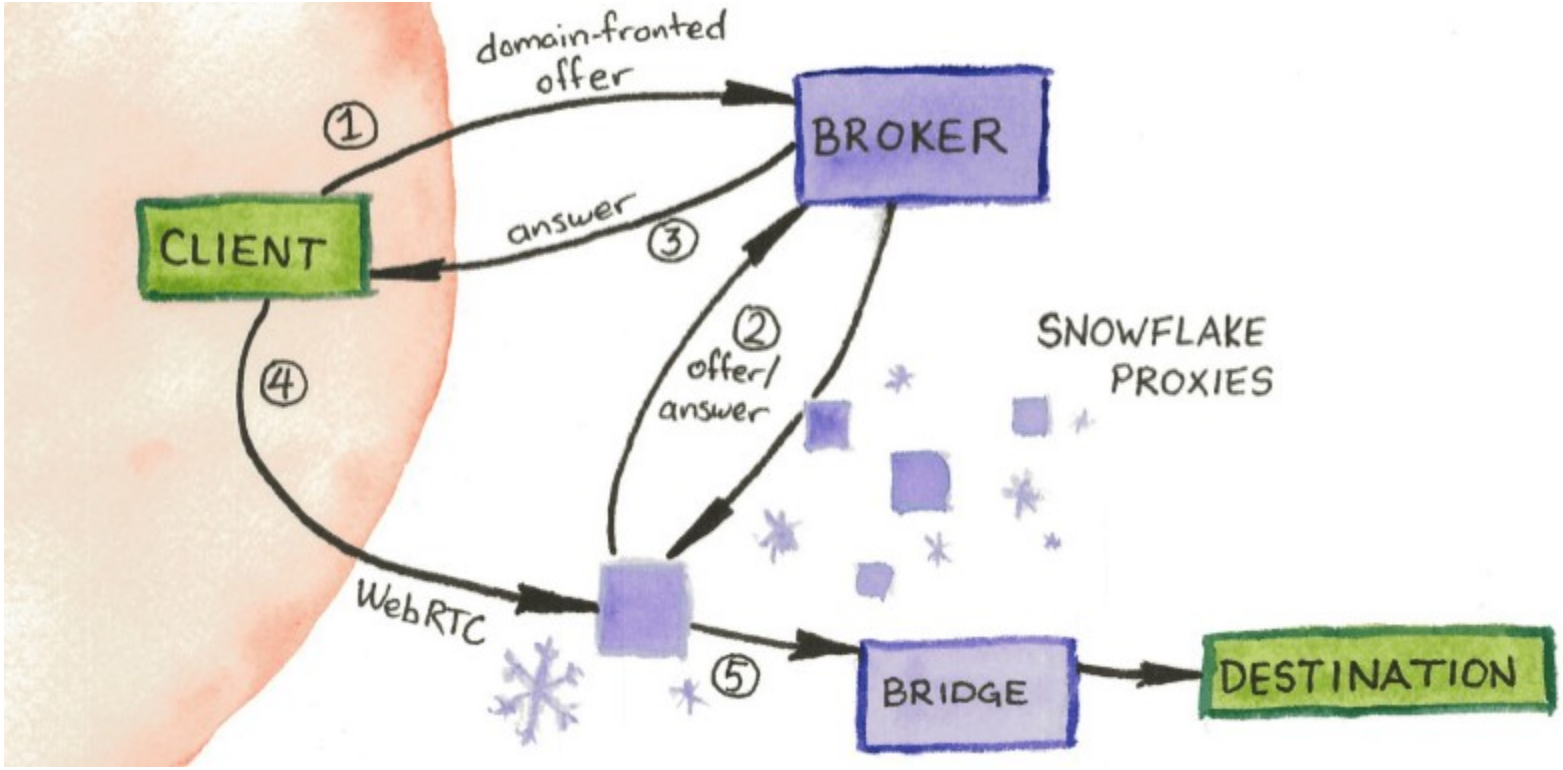



(d) Server-to-client.

# meek

- “Domain fronting”
- Use a Content Distribution Network the censor won’t block
  - Costs money
  - Censors have a business relationship with CDNs

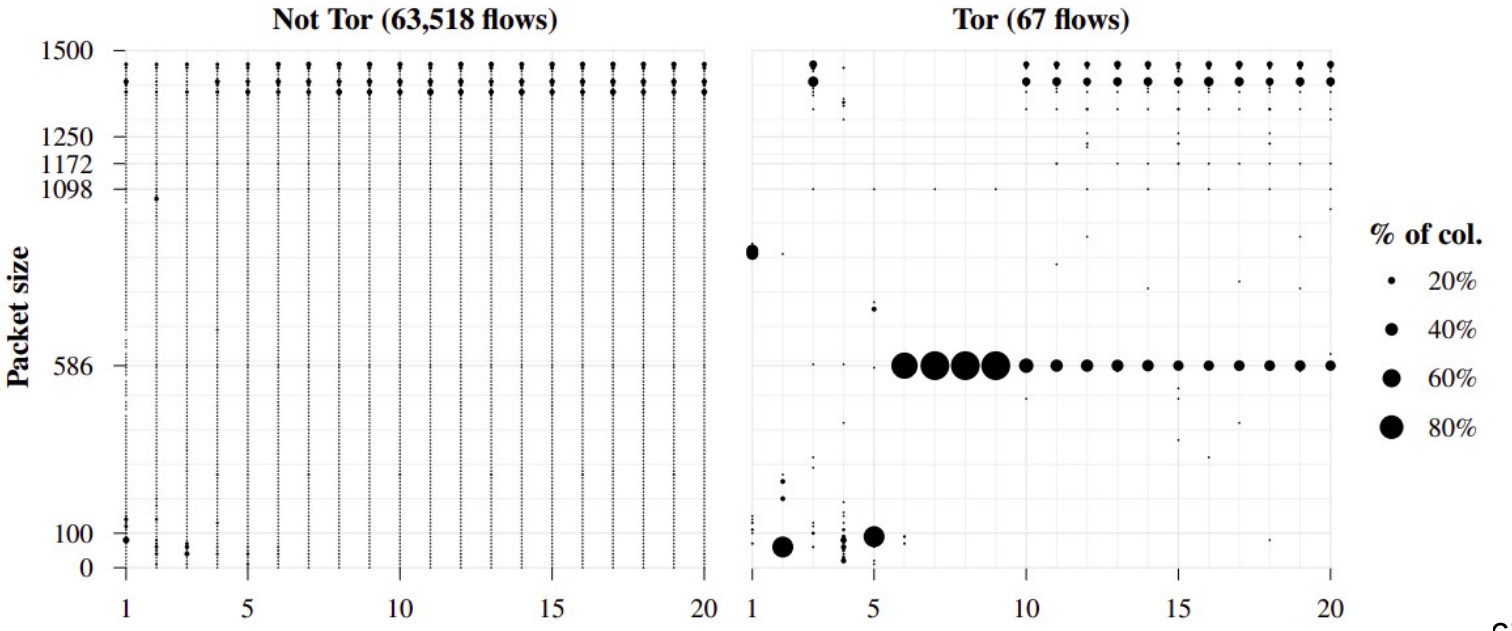
# https://snowflake.torproject.org/



# StegoTorus: A Camouflage Proxy for the Tor Anonymity System

Zachary Weinberg,[1,2] Jeffrey Wang,[3] Vinod Yegneswaran,[2] Linda Briesemeister,[2]
Steven Cheung,[2] Frank Wang,[3] and Dan Boneh[3]

[1]Carnegie Mellon University [2]SRI International [3]Stanford University



“apps and platforms” → “protocols”

# Two approaches

- Try to look nothing like the banned protocol that you are

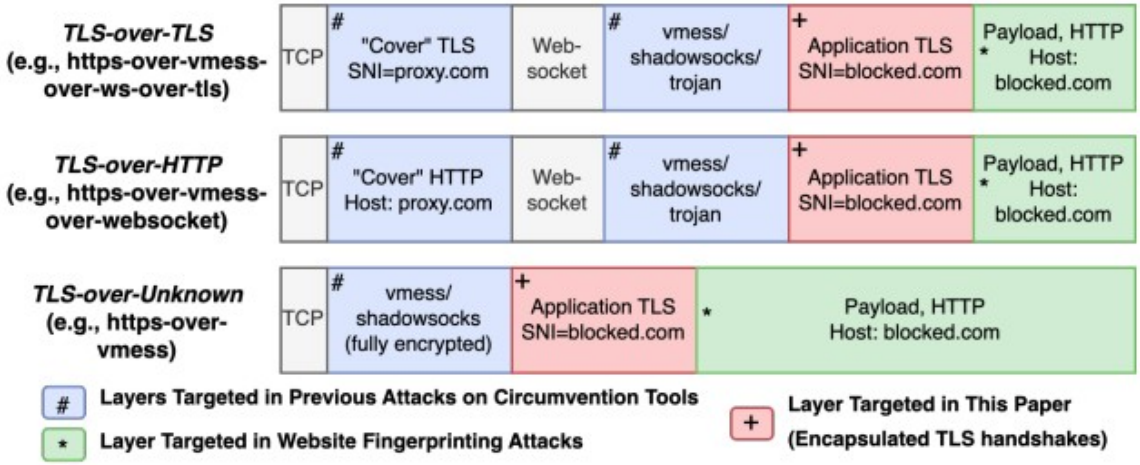
- Try to look like a protocol that everyone is using that is not banned

# Fingerprinting Obfuscated Proxy Traffic with Encapsulated TLS Handshakes

Diwen Xue* Michalis Kallitsis† Amir Houmansadr ‡ Roya Ensafi*

*University of Michigan †Merit Network, Inc. ‡ University of Massachusetts Amherst

USENIX Security 2024



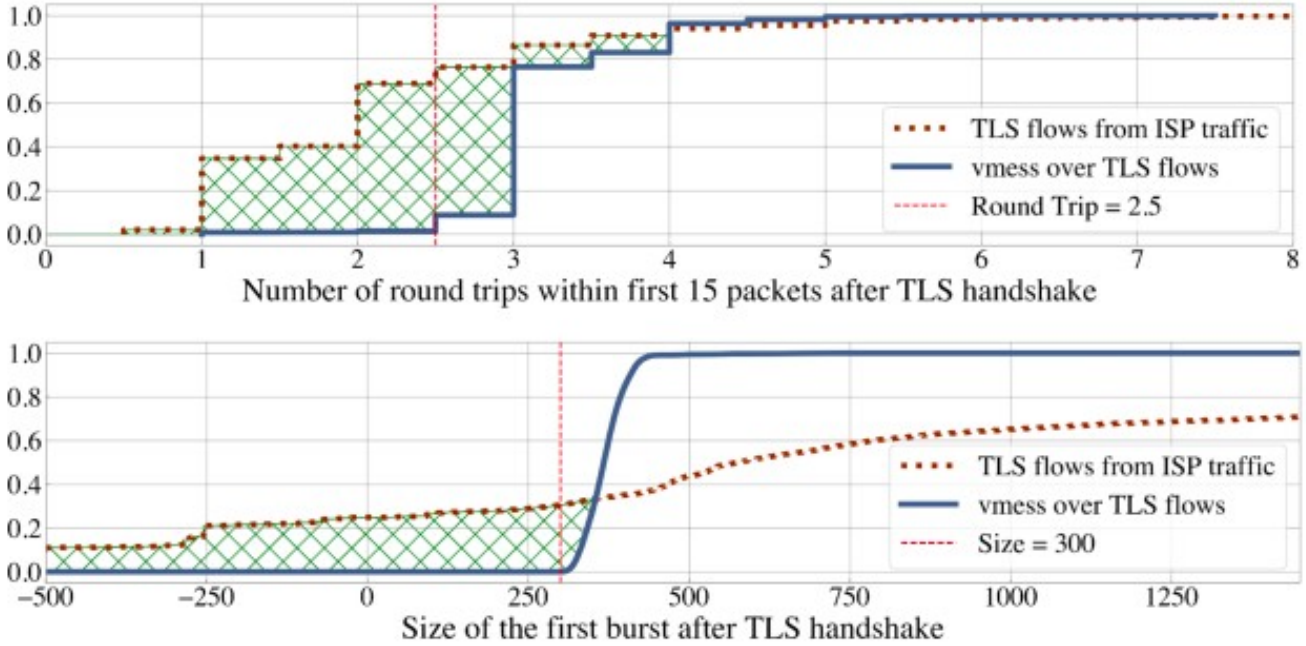



Figure 8: **Round trip count and size of first burst after TLS handshakes.** *TLS-over-TLS* requires more round trips and a larger initial burst due to a second (encapsulated) handshake. Shaded areas highlight dissimilarities that padding and multiplexing cannot obfuscate.

# Detecting VPN Traffic through Encapsulated TCP Behavior

Michelina Hanlon
Stanford University

Gerry Wan
Stanford University

Anna Ascheman
Stanford University

Zakir Durumeric
Stanford University

FOCI 2024

- **3WHS:** The presence of a three-way SYN, SYN-ACK, ACK handshake to open the connection (RFC 9293, Section 3.5).
- **500msACK:** The presence of an ACK packet generated within 500 ms of the arrival of a data segment (RFC 9293, Section 3.8.6.3).
- **2RMSS:** The presence of an ACK packet generated after the receival of 2×RMSS bytes of data, where RMSS is the maximum segment size (MSS) specified by the TCP endpoint receiving the segments (RFC 9293, Section 3.8.6.3).

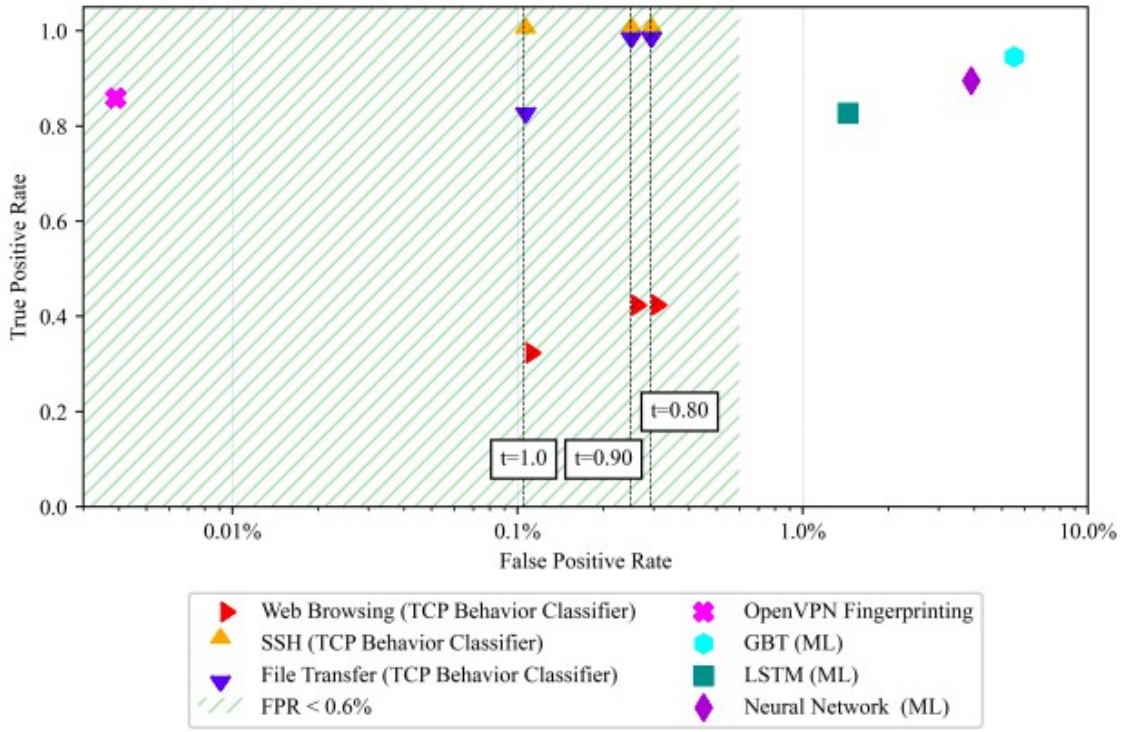



**Figure 1: Classifier Results ($t = 1.00, 0.90, 0.80$; $W = 100$).** The TPR against the FPR of our classifier (broken down by traffic category) and alternative VPN detection methods. Our protocol-agnostic classifier achieves a FPR an order of magnitude lower than ML detection techniques.

# The Discriminative Power of Cross-layer RTTs in Fingerprinting Proxy Traffic

NDSS 2025

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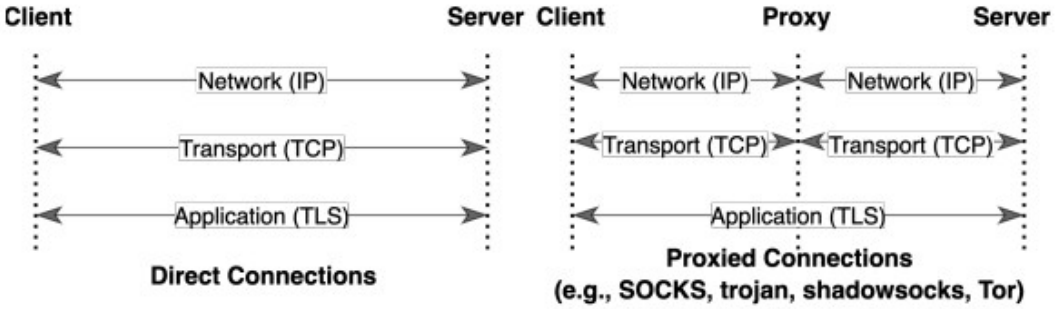


Fig. 2: **Protocol layerings in Direct vs. Proxied Connections**. In proxied connections, transport sessions terminate at the proxy, whereas the application layer connection remains end-to-end. ◇

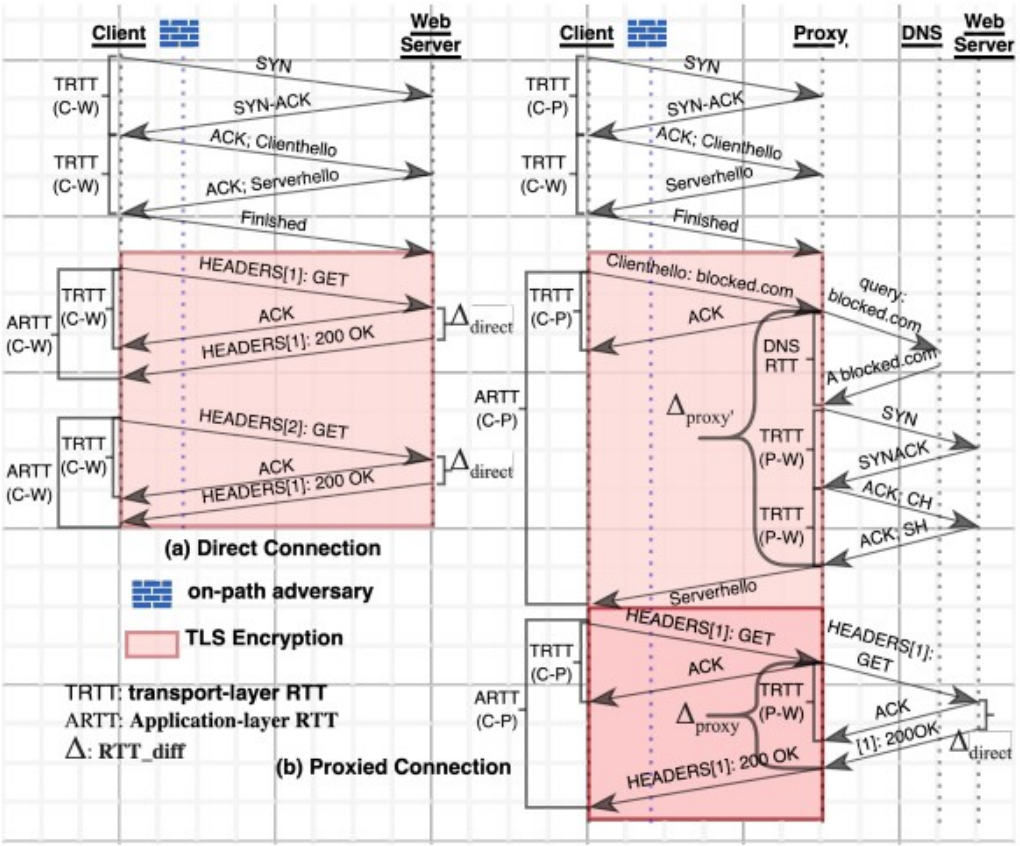


Fig. 3: **Sequence timing diagram for (a) direct HTTPS session vs. (b) TLS-based proxy (vless-over-tls) session.** For the proxied connection, we observe a much higher discrepancy in transport vs. application-layer delay as the sessions at two layers terminate at different endpoints (proxy and the web server, respectively). ◇

# Is Custom Congestion Control a Bad Idea for Circumvention Tools?


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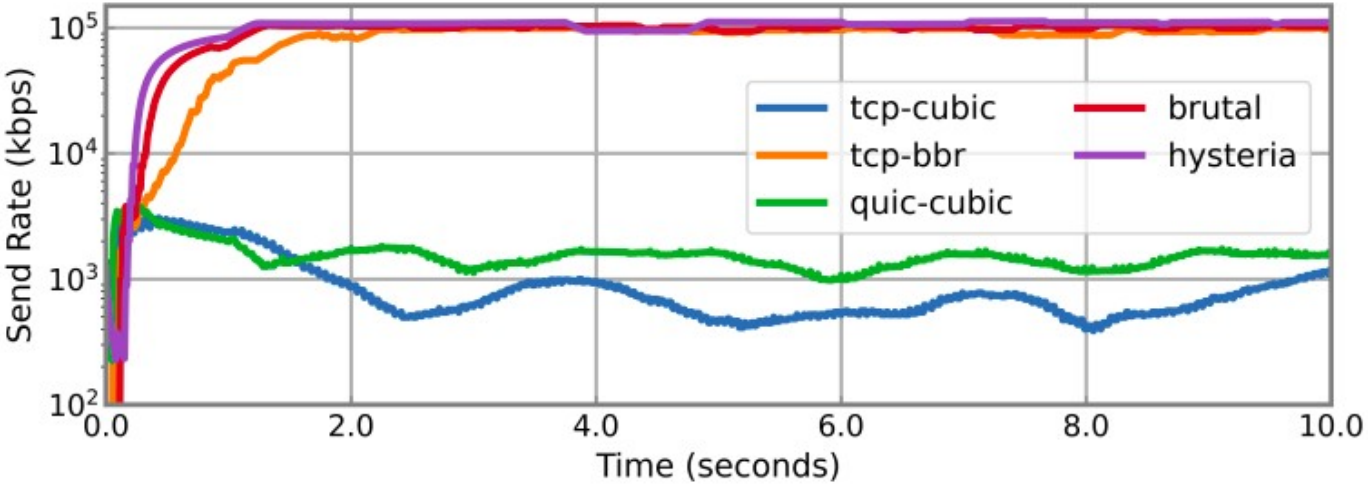
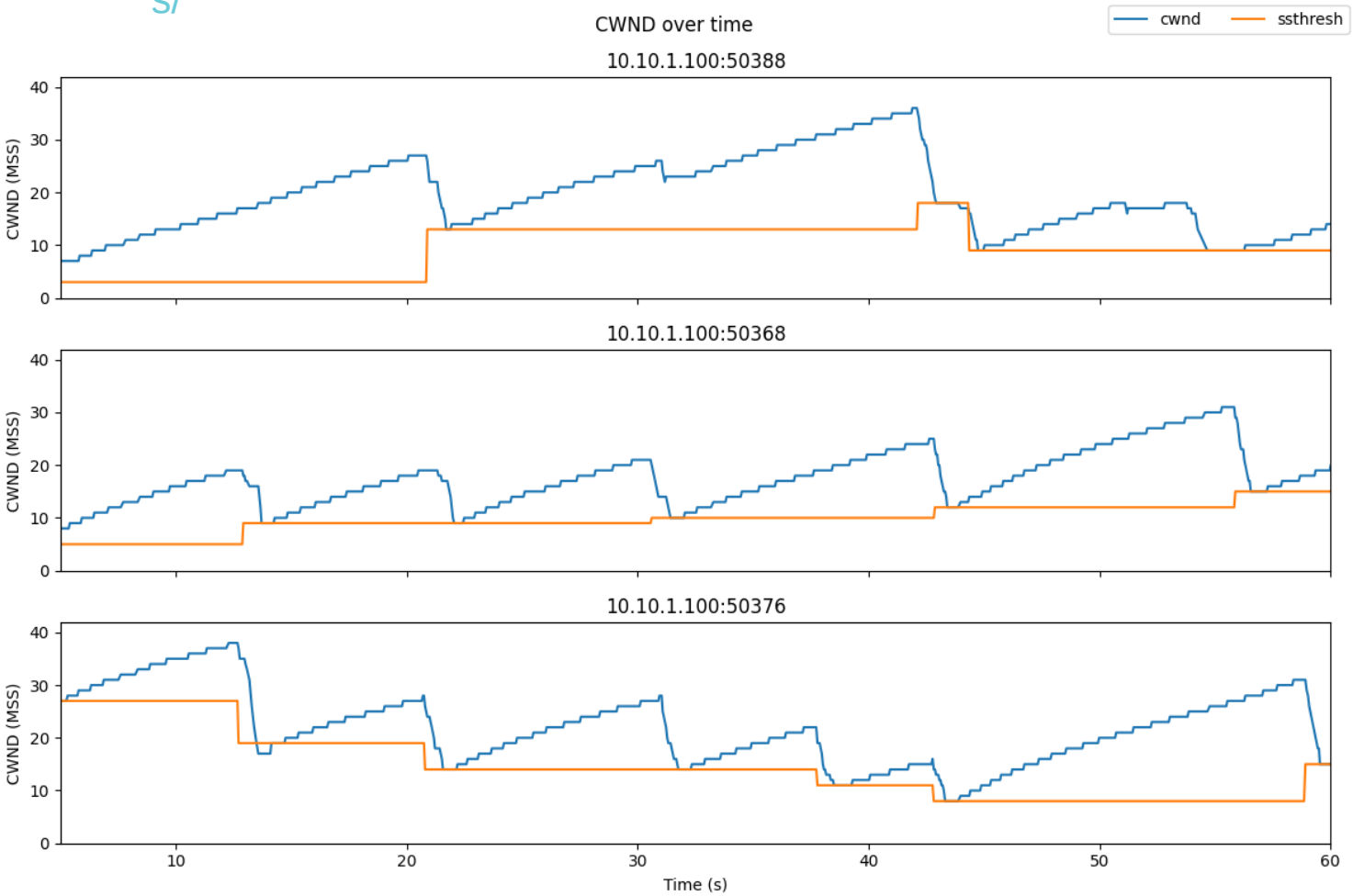
(FOCI 2025)



https://witestlab.poly.edu/blog/tcp-congestion-control-basics/



# Does the DPI need to be nearly perfect *w.r.t.* false positives and false negatives?

- Can shut down VPNs at critical times
- Can collect data about connections over a long period of time
  - https://censorbib.nymity.ch/pdf/Wails2024a.pdf
  - correlate with other data (like financial or social graph information)?
- Can use laws as a deterrent
- Can perform active probing, forensic analysis of confiscated devices, *etc.*
  - *E.g.,* in Brazil: daily fine of fifty thousand reals (US$9,104) for users who bypass the ban with a VPN

# OpenVPN is Open to VPN Fingerprinting

Diwen Xue, Reethika Ramesh, and Arham Jain, *University of Michigan;*
Michalis Kallitsis, *Merit Network, Inc.;* J. Alex Halderman, *University of Michigan;*
Jedidiah R. Crandall, *Arizona State University/Breakpointing Bad;* Roya Ensafi,
*University of Michigan*

https://www.usenix.org/conference/usenixsecurity22/presentation/xue-diwen

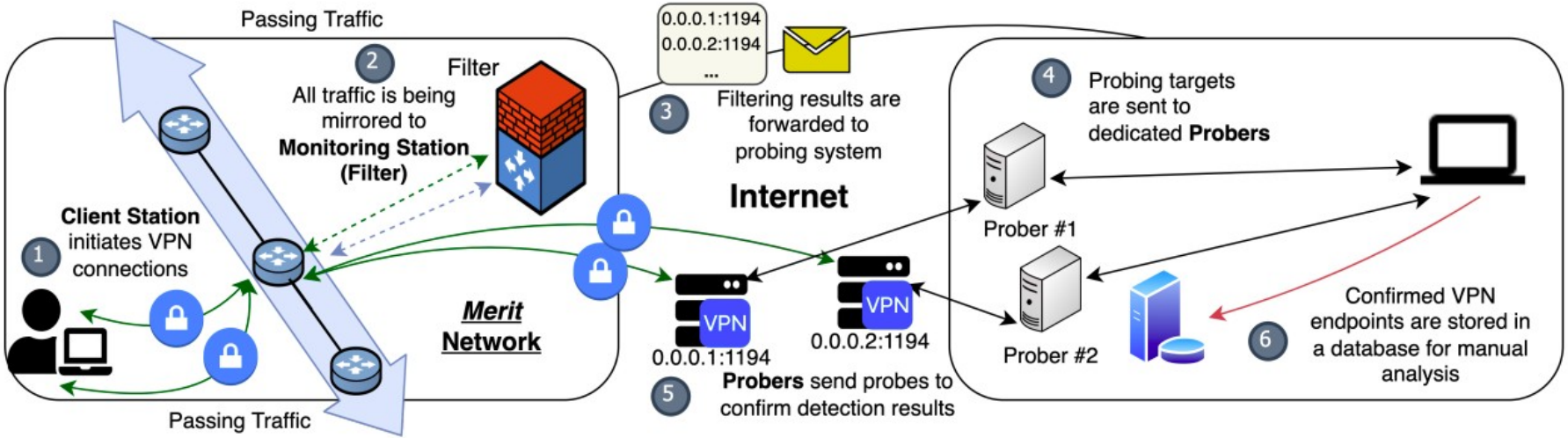
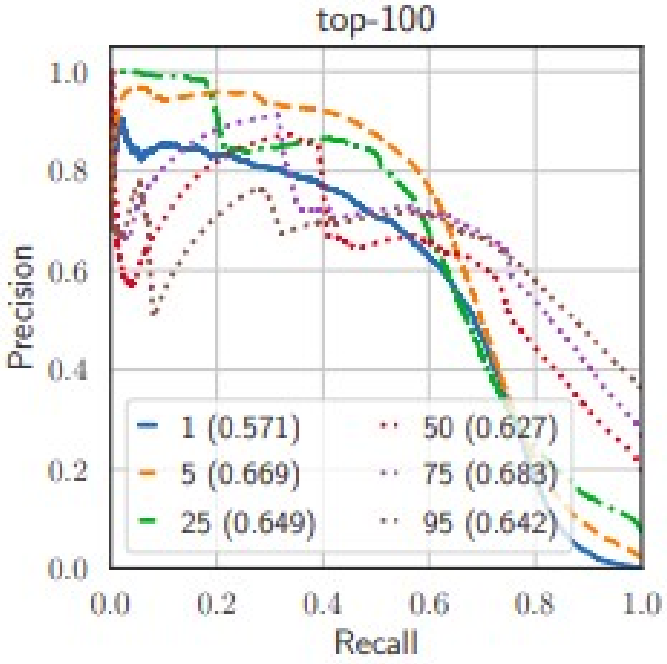



Figure 2: **Framework Deployment on *Merit*** Steps: (1) Client connects to VPN servers. (2) VPN connections, along with passing traffic, are being mirrored to the *Filter*. (3) *Filter* forwards server IP of suspected connections to the probing system. (4) Targets are sent to each dedicated *Probers*. (5) *Probers* send probes asynchronously. (6) Connections confirmed by probing are logged.

# Online Website Fingerprinting: Evaluating Website Fingerprinting Attacks on Tor in the Real World

Giovanni Cherubin, *Alan Turing Institute;* Rob Jansen, *U.S. Naval Research Laboratory;* Carmela Troncoso, *EPFL SPRING Lab*

https://www.usenix.org/conference/usenixsecurity22/presentation/cherubin


top-100
Precision
Recall
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
1 (0.571)
5 (0.669)
25 (0.649)
50 (0.627)
75 (0.683)
95 (0.642)

# Websites *vs.* webpages

- Website fingerprinting is knowing that you're going to https://en.wikipedia.org, webpage fingerprinting is knowing that you're going to https://en.wikipedia.org/wiki/Operation_Sundevil
- Device fingerprinting, browser fingerprinting, *etc.* are also an issue for VPNs and Tor.

# Takeaways

- You should check out Tor
  - Also check out OONI
- Tor hidden services are cool
- Designing privacy, anonymity, and anti-censorship tools is a fascinating research problem