Lec #11: Surveillance and Circumvention

Examining How the Great Firewall Discovers Hidden Circumvention

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Roadmap

- Surveillance / Censorship Location Doesn’t Matter!
  - The Great Cannon of China

- Is the GFW a country-wide, distributed NIDS?
  - Analyzing the Great Firewall of China Over Space and Time

- How is the GFW blocking Tor?
  - Examining How the GFW Discovers Hidden Circumvention Servers*

* Applied Networking Research Prize, IRTF 2016

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Surveillance / Censorship Location Doesn’t Matter!

- Why care about surveillance and censorship in other countries?
  - **Advocacy** is important

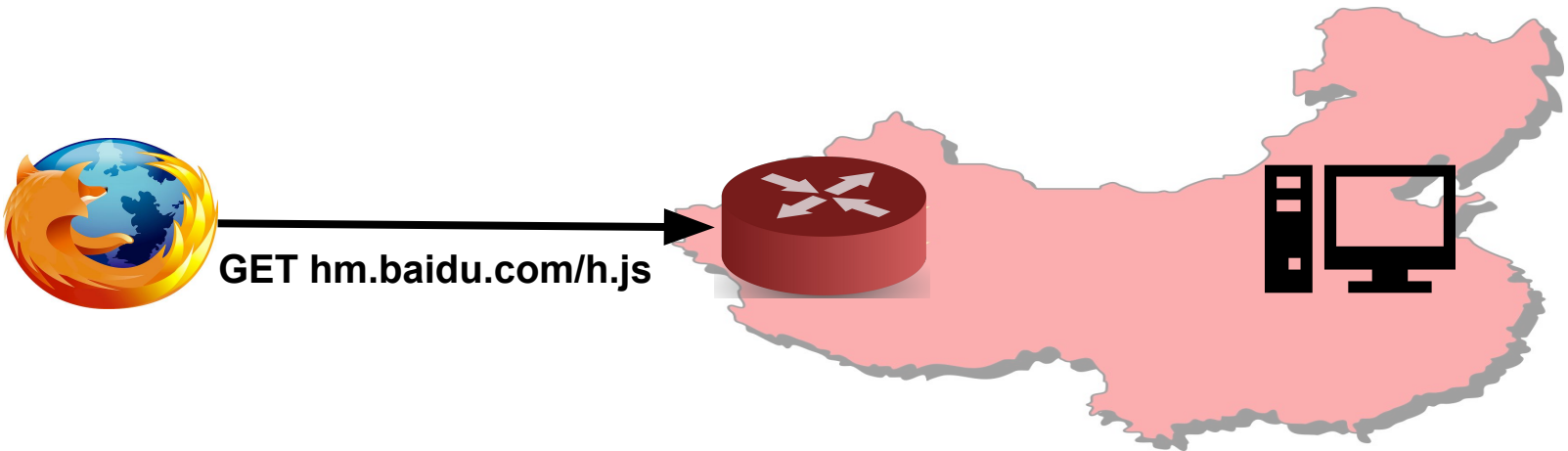
Surveillance / Censorship Location Doesn’t Matter!

- Why care about surveillance and censorship in other countries?
  - **Advocacy** is important
  - National firewalls can **harm international** traffic
  - GFW can cause harm → Great Cannon [1]

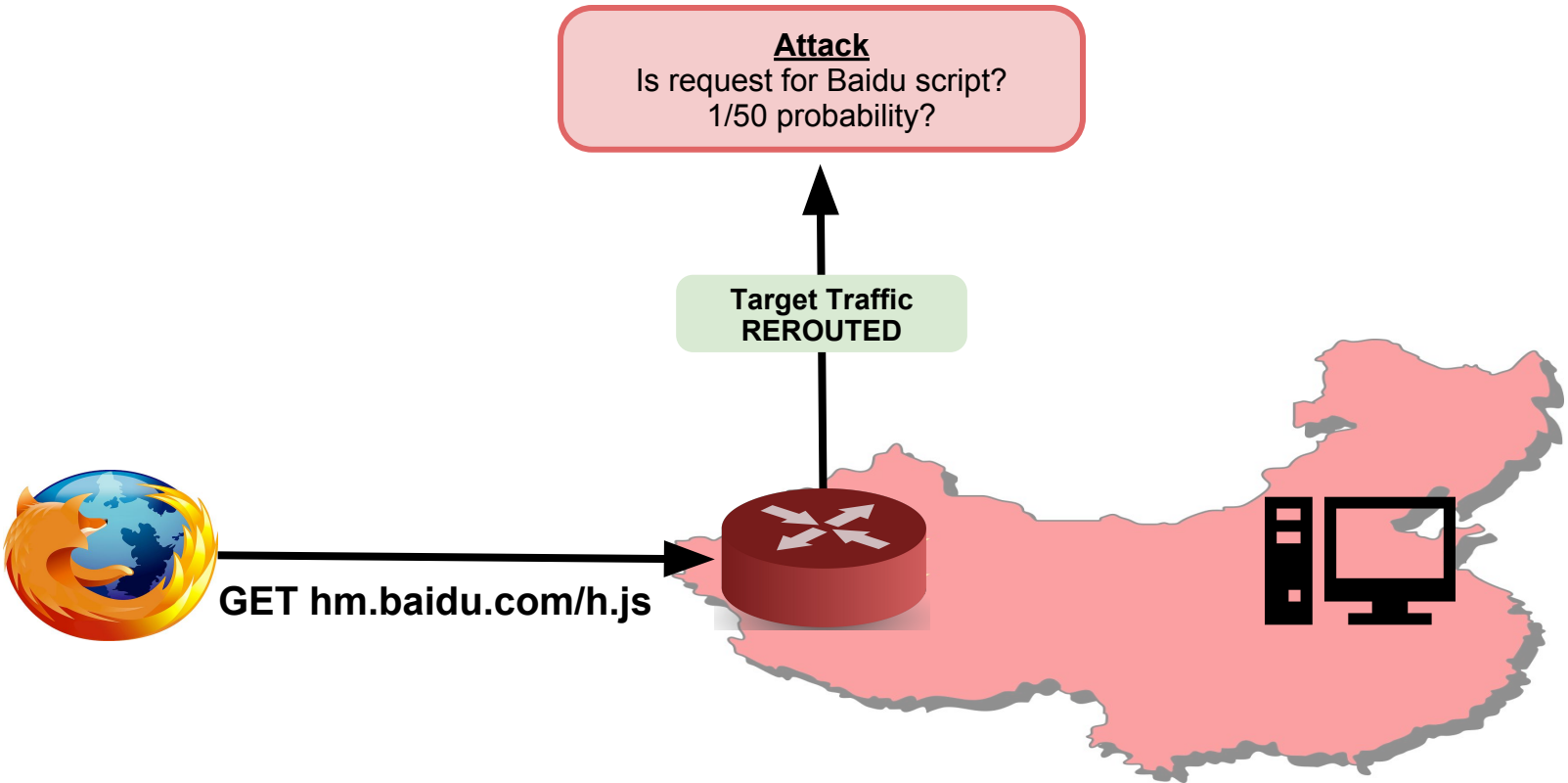
[1] **Analysis of China’s “Great Cannon”**
by B. Marczak, N. Weaver, J. Dalek, **R. Ensafi**, D. Fifield, S. McKune, A. Rey, J. Scott-Railton, R. Deibert and V. Paxson
(In: *USENIX FOCI’15*)

China's Attack Against GitHub

- The **Great Cannon** of China is an attack tool
- Target were hosters of **greatfire.org**
  - **GitHub** and **Cloudflare**



Great Cannon



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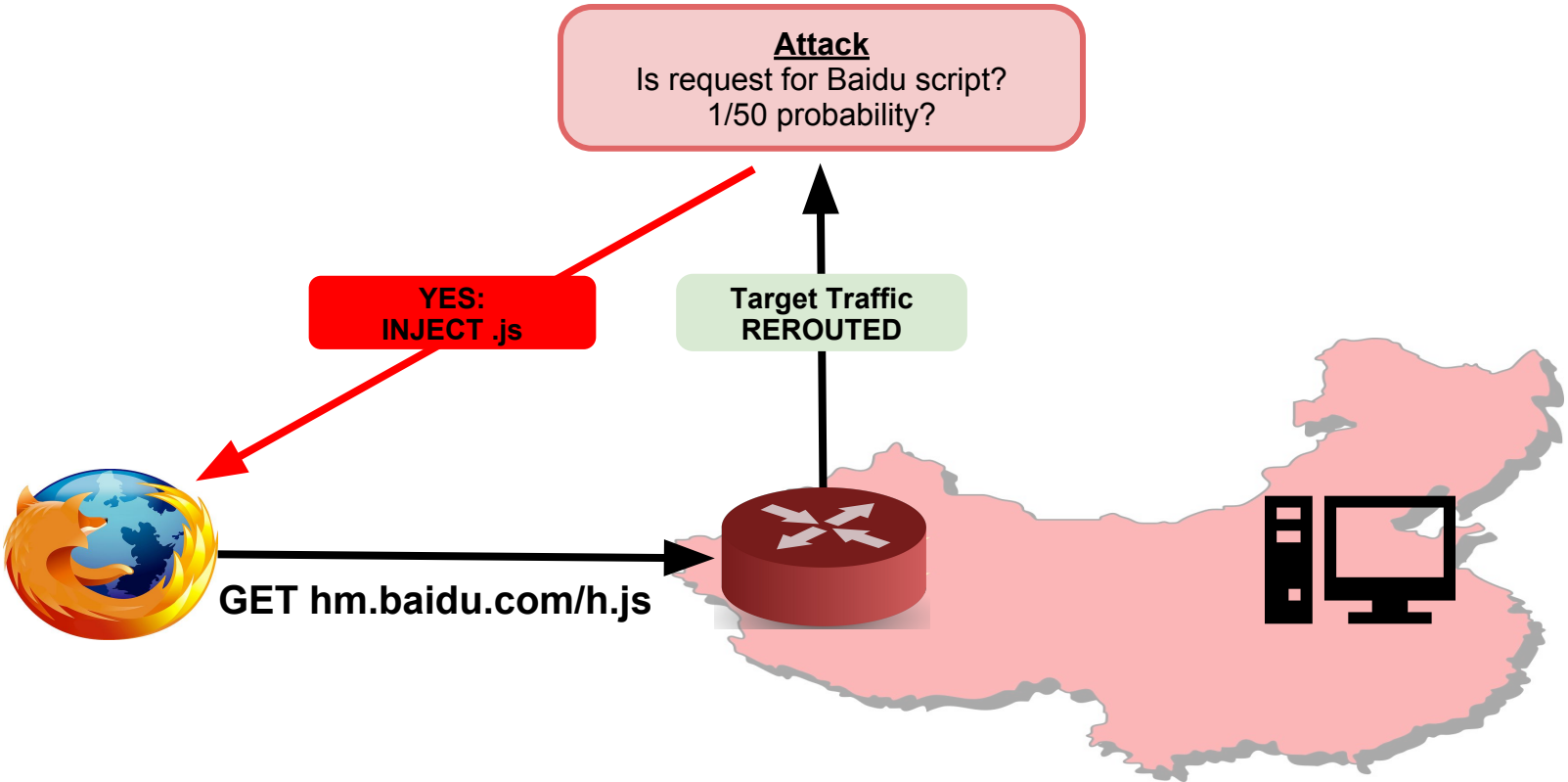

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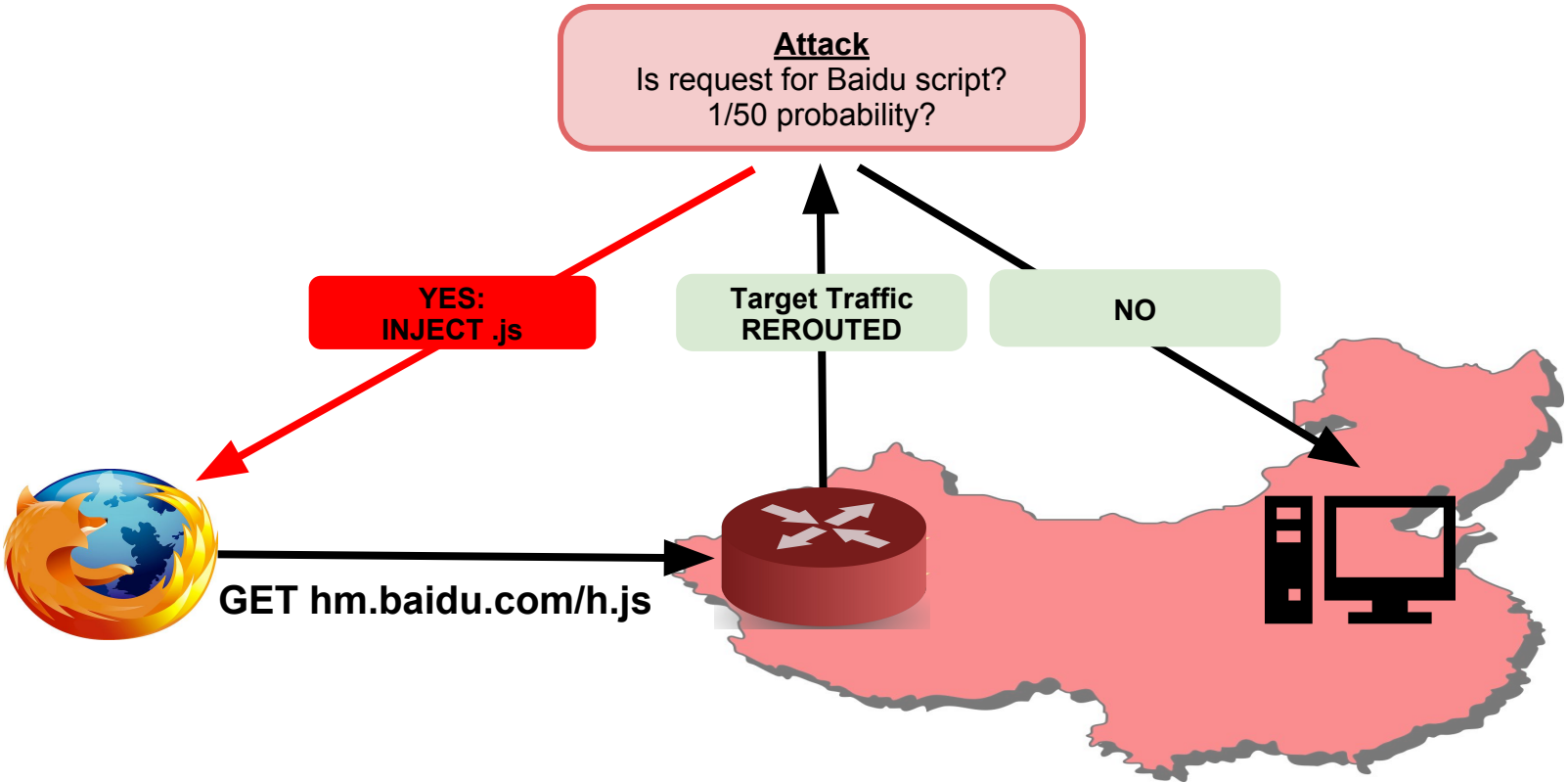

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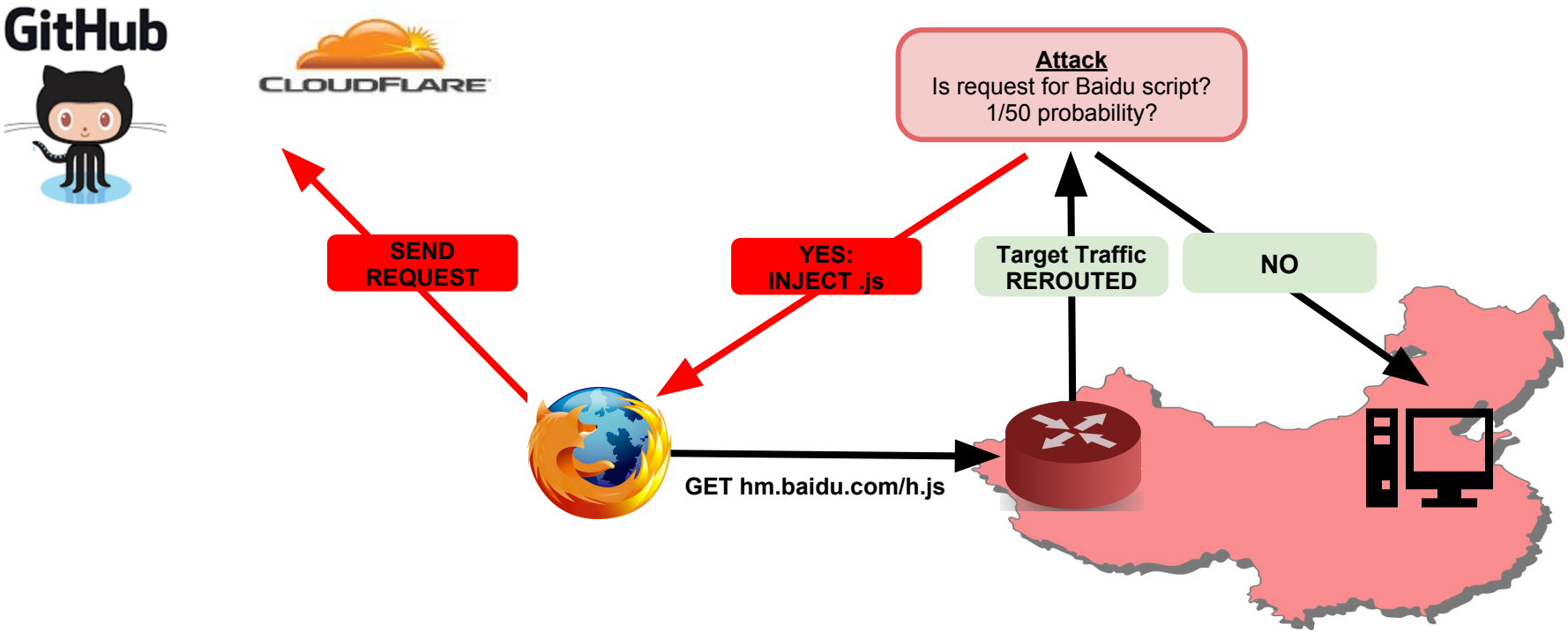
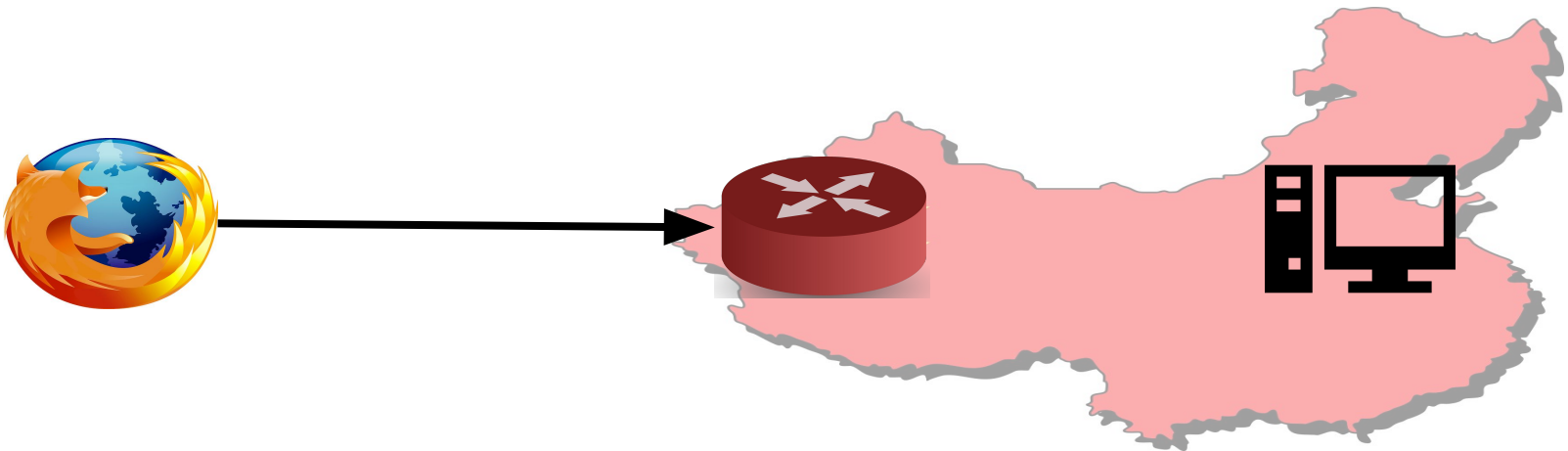


Great Cannon for Targeted Exploitation



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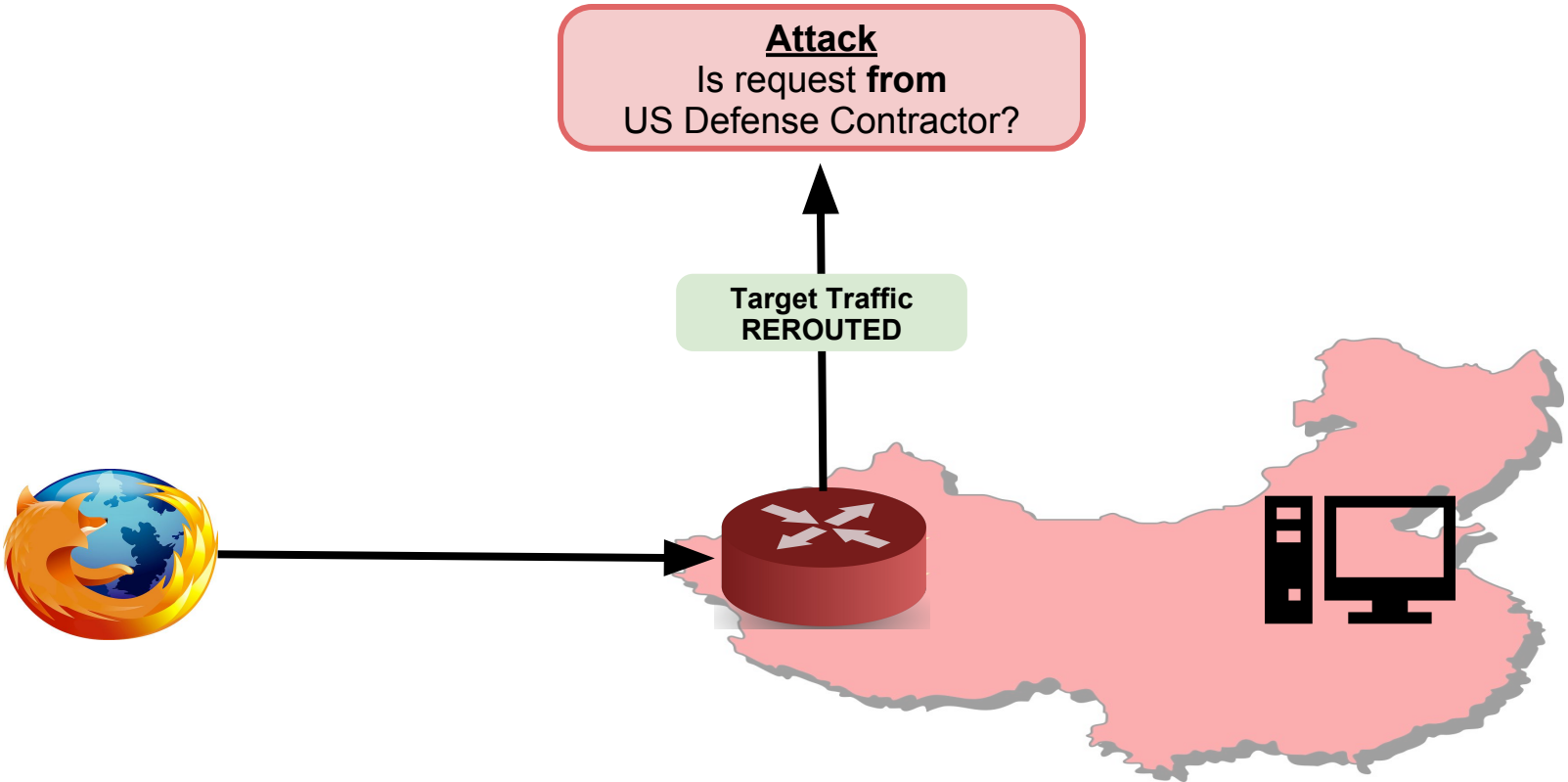
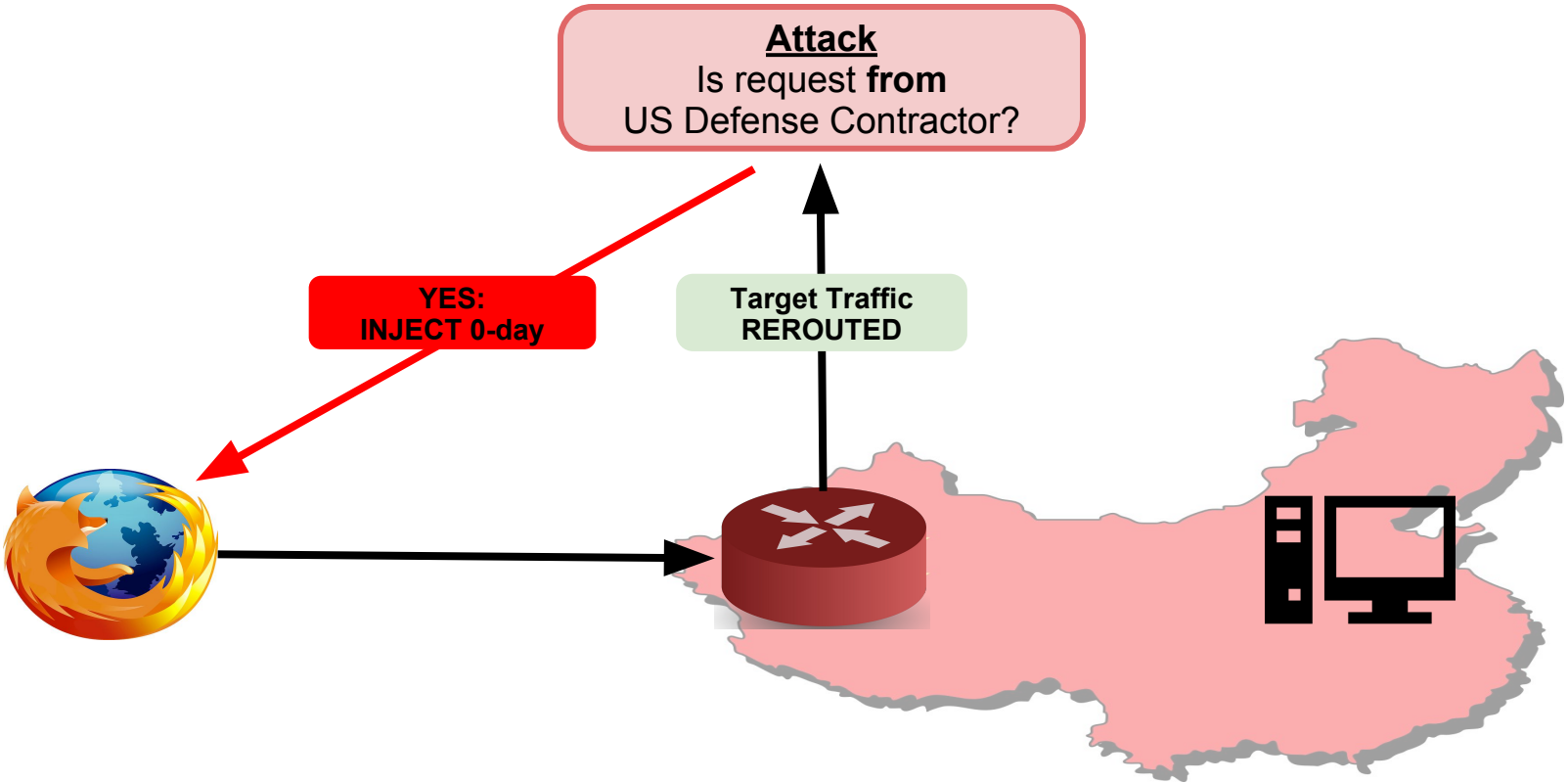


Great Cannon for Targeted Exploitation



Lessons Learned

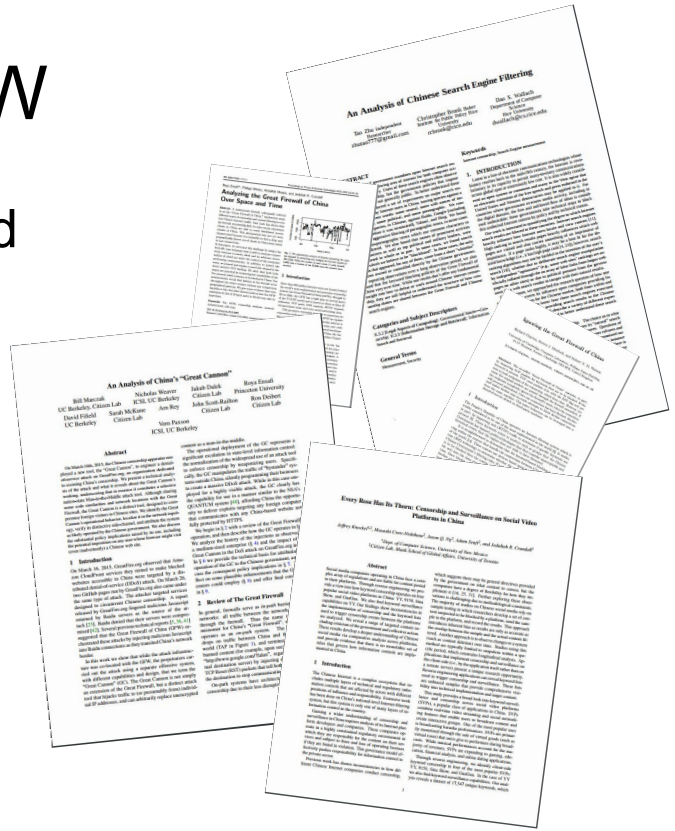
- Widespread deployment of **HTTPS crucial**
  - Particularly, we need HTTPS' **authentication** here, and not **encryption**

- Exploitation of plain text traffic **will not stop**

National Firewalls are powerful

Much Already Known About GFW

- Thanks to numerous research papers and blog posts, we know…
  - **What** is blocked
  - **How** it is blocked
- Is filtering centralized?



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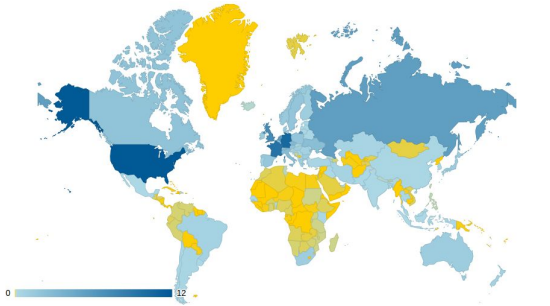
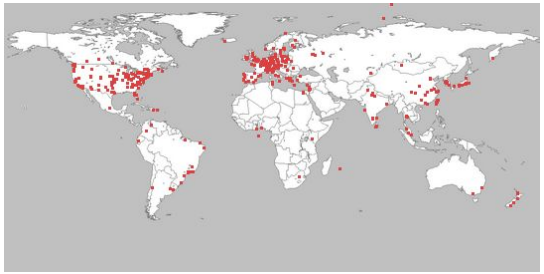
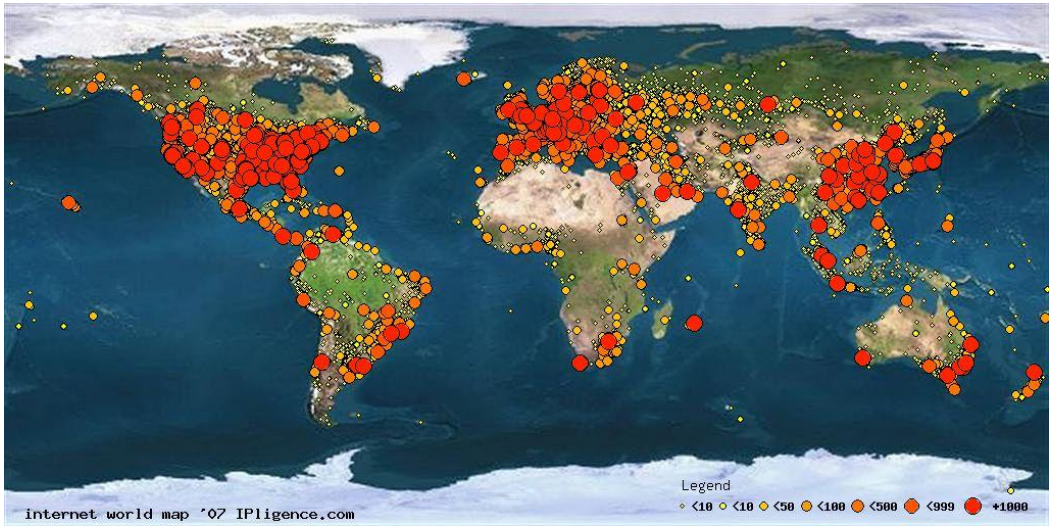
Is the GFW a Country-wide Distributed NIDS?

- Rent a **control machine** (VPS)
- Cooperate with **volunteers**
- **Not** always possible to rent VPS in interesting area



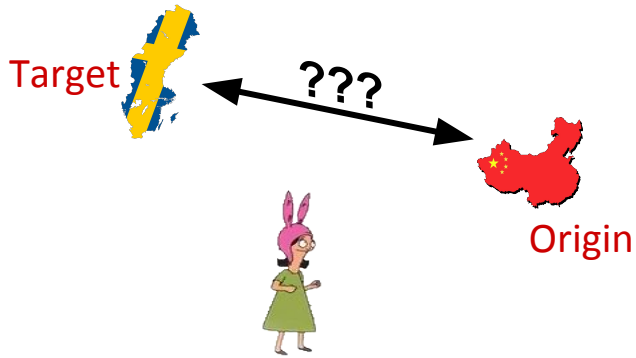


Side Channels to the Rescue!



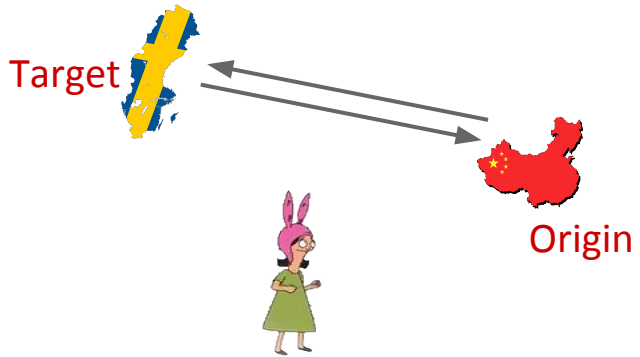
Solving the Vantage Point Problem

- Side channels turn **ordinary** machines into **vantage** points!



Idle Scan

- Idle Scan uses side channel techniques to bounce scans off of a “Target” host to stealthily scan an “Origin” [2]
- Spooky scan a.k.a Hybrid Idle scan can detect the **direction of blocking** between an Origin and a Target [3]

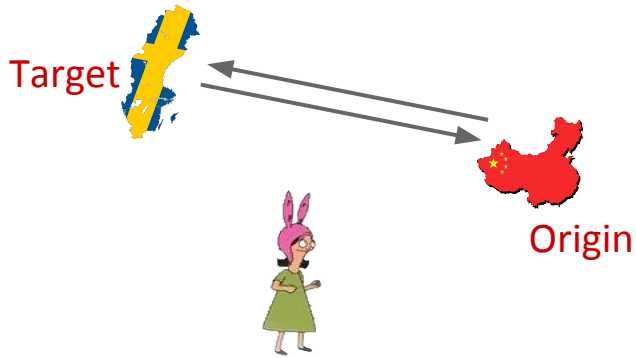


[2] **Idle Port Scanning and Non-interference Analysis of Network Protocol Stacks Using Model Checking**
by **Roya Ensafi**, J.Park, D. Kapur, and J. Crandall (In: *USENIX Sec’ 2010*)

[3] **Detecting Intentional Packet Drops on the Internet via TCP/IP Side Channels**
by **Roya Ensafi**, Jeffrey Knockel, Geoffrey Alexander, and Jedidiah R. Crandall (In: *PAM’14*)

Spooky Scan Requirements

- **Global IPID** machine for the Origin
- Target that has **open port**



Spooky Scan

No direction blocked

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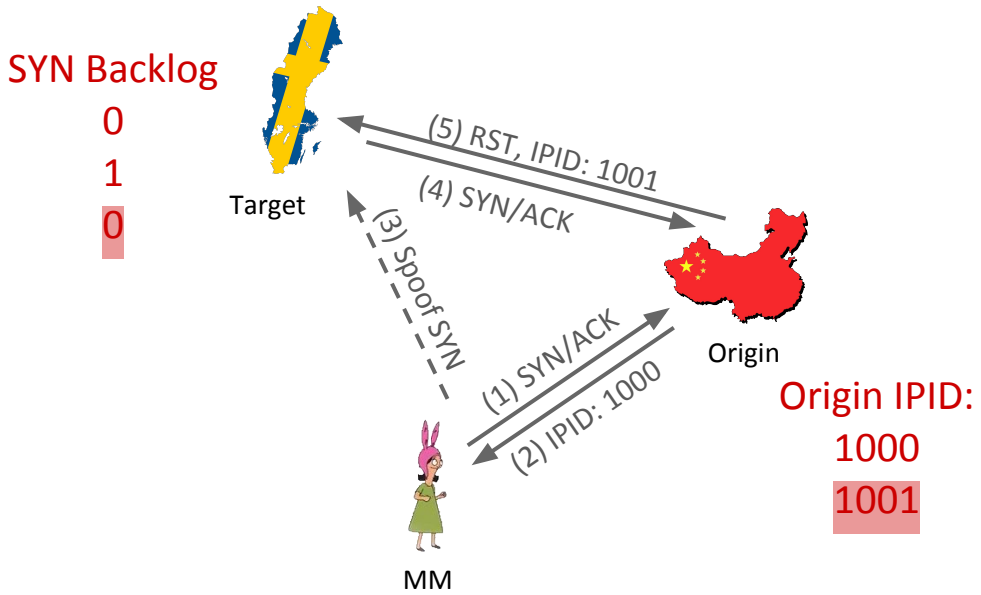
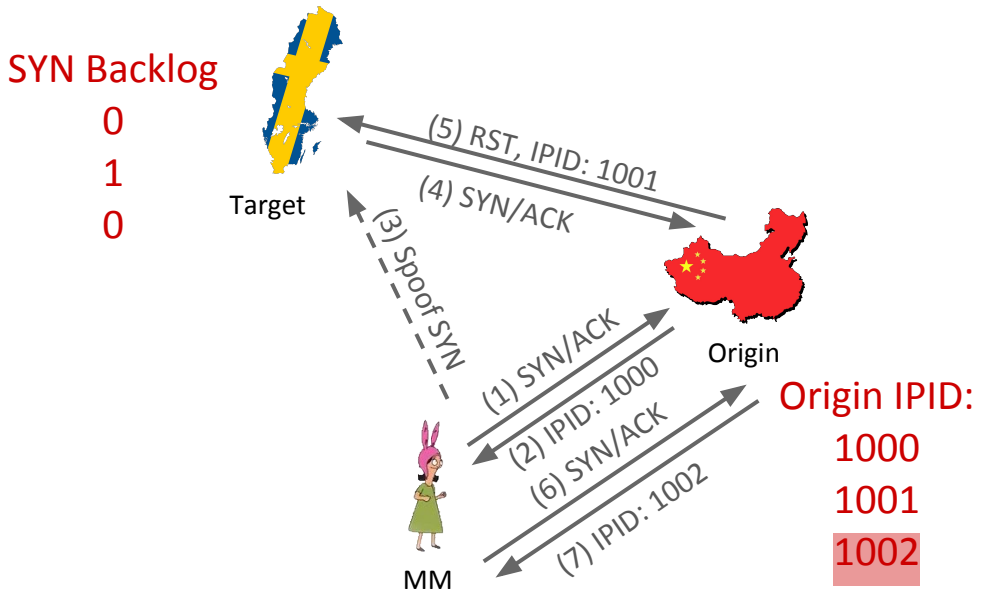


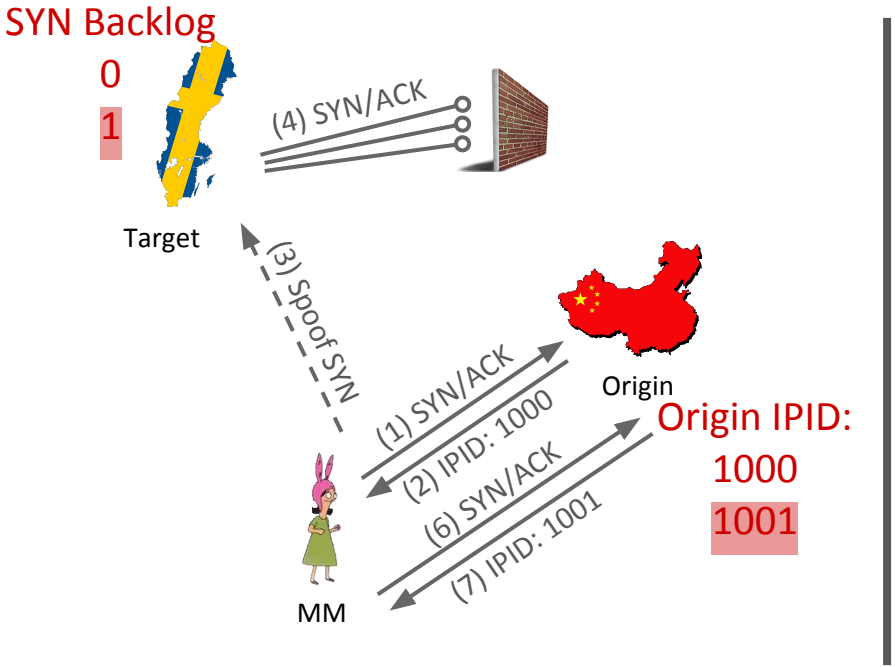
Spooky Scan

No direction blocked



Spooky Scan

Target to Origin Blocked



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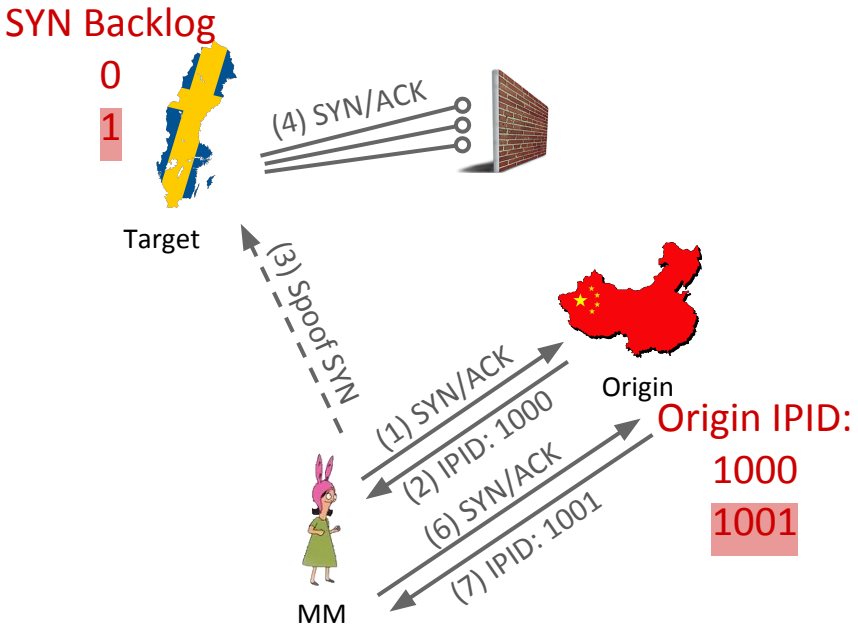
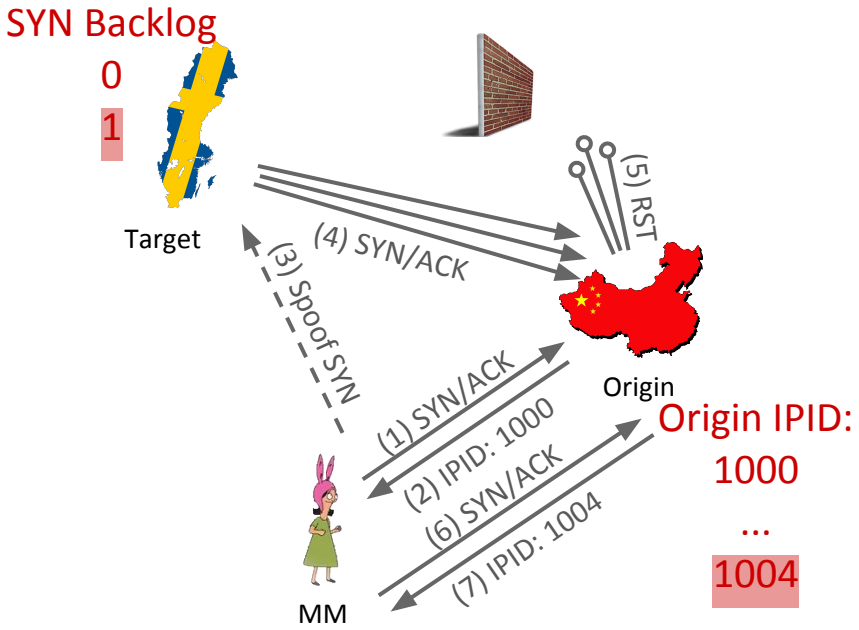
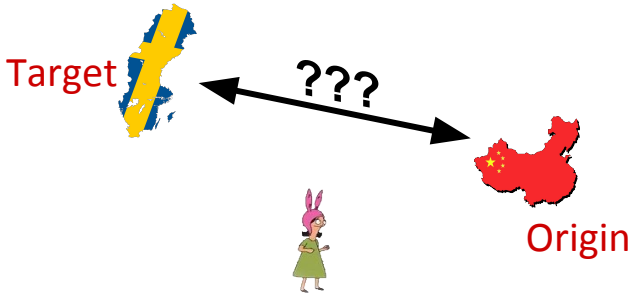


Origin to Target Blocked

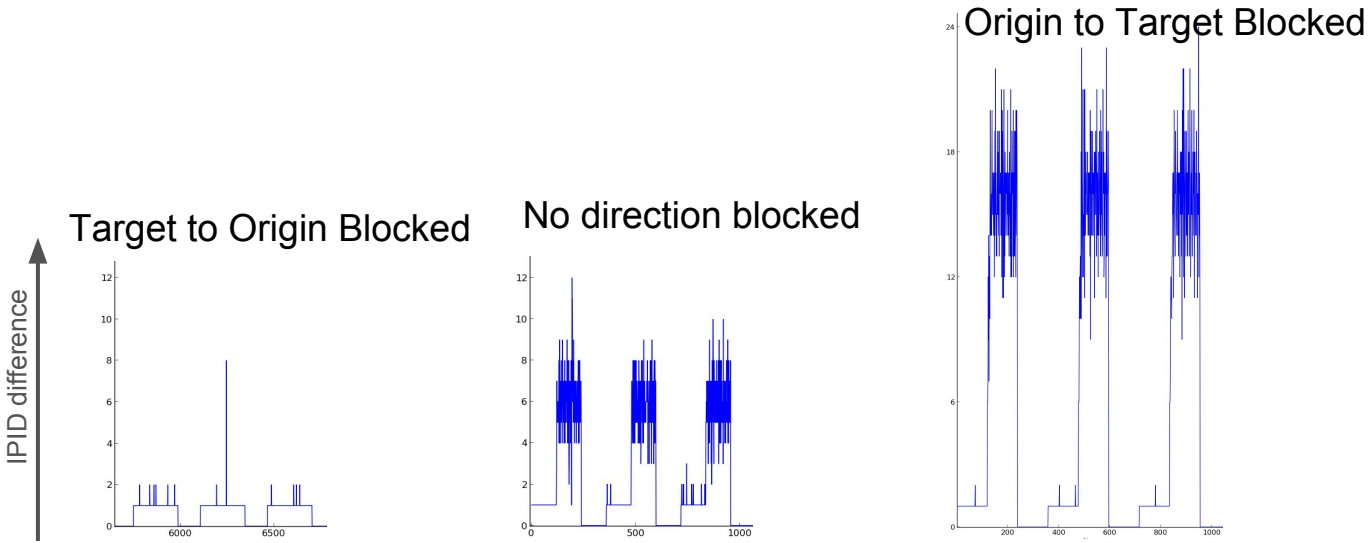


Real Data



Phase 1: just query IPID

Phase 2: send 5 spoofed SYN packets per sec & query IPID for 120 sec



Spooky scan is Used in Practice.

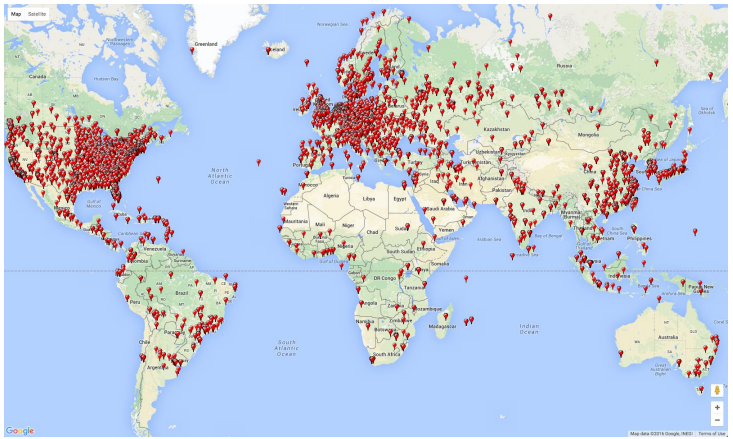
- Find **Global IPID** machines (list of origins)
- Find network you can **spoof** packets from
- Check if your targets satisfy necessary **requirements**
- Then, run the Spooky scan to detect the direction of blocking between origin and target

BOOM! DONE!

Remember the Challenges: Ethics, Scalability

- Side channels address **scalability**

- How can we address the **ethics** problem?
  - **Infrastructure** machines!



Can We Use Spooky Scan to Learn about GFW?

- Many **open questions** about the GFW and Tor
  - Does censorship of Tor differ for users in different regions?
  - Does filtering depend on **when and**

    where you are?
  - Does blocking **change** from one ISP to another?

- Revisit **old beliefs** about the GFW
  - Is the GFW a country-wide distributed NIDS?

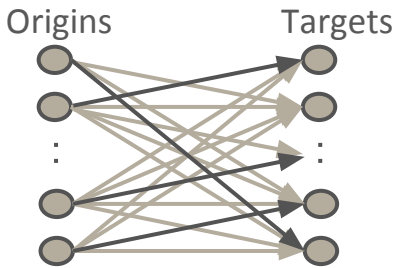
[4] **Analyzing the Great Firewall of China Over Space and Time**
by **Roya Ensafi**, P. Winter, A. Mueen, and J. Crandall (In: *PETS'15*)

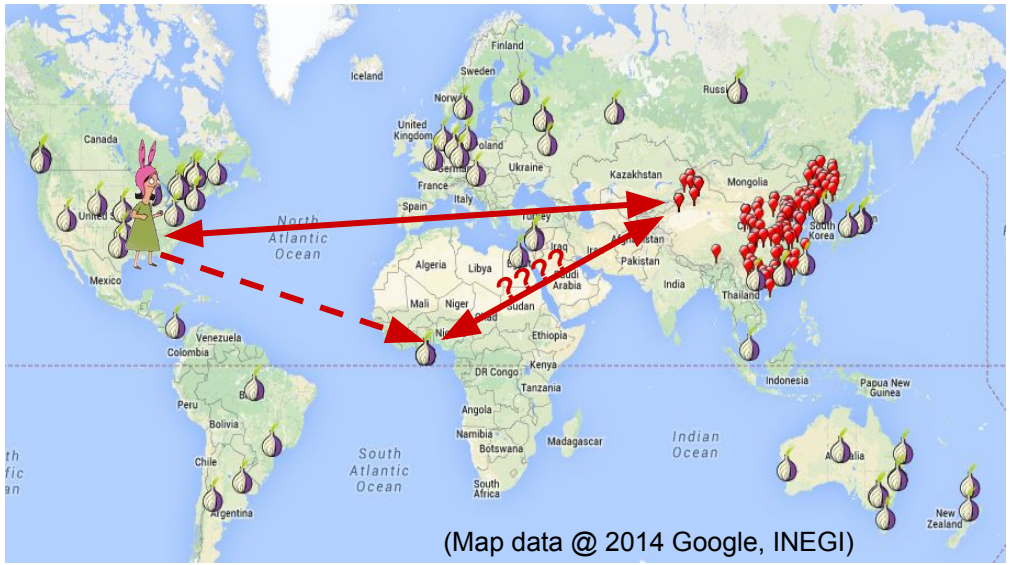
Methodology - Relays and Origins

(Map data @ 2014 Google, INEGI)

Methodology - Machines Under Our Control

- We ran Hybrid Idle Scans for **27 days**
- Each pair of origins and servers were tested **hourly for a day**





Results: No Obvious Geographical Pattern

- No **geographical** or **topological** pattern is visible. Instead, the distribution matches the geographic Internet penetration patterns of China.

- More in Ensafi et.al. PETS ‘15

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How is the GFW blocking Tor?

We focus on the **GFW** and **Tor**

- GFW is a **sophisticated censorship system**
- Tor has a long history of being used for **circumventing government censorship**

Censorship Arms Race: GFW vs. Tor

Use **public Tor network** to circumvent GFW

Time

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Download consensus and **block relays**

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Use **DPI** to detect Tor **TLS handshake**

Fingerprinting the Tor TLS Handshake

- TLS handshake is **unencrypted** and **leaks information**
- Tor's use of TLS has some **peculiarities**
  - X.509 certificate life times
  - Cipher suites
  - Randomly generated server name indication (e.g., www.6qgoz6epdi6im5rvxnlx.com)
- GFW looks (at least) for **cipher suites** in the **TLS client hello**

Censorship Arms Race: GFW vs. Tor

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Use **public Tor network** to circumvent GFW

Introduce **private bridges**, whose distribution is **rate-limited**

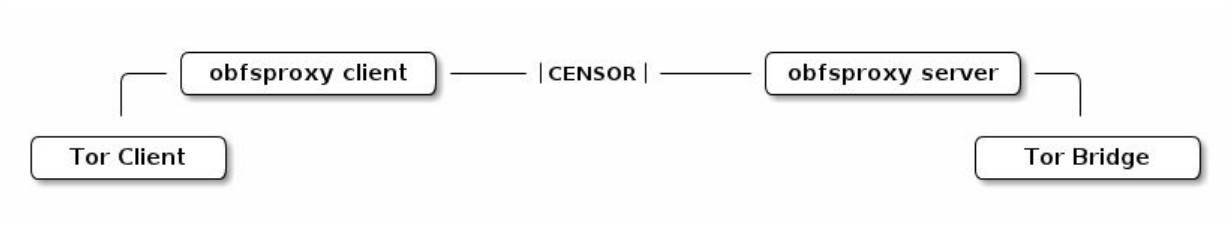
Introduce **pluggable transports** to hide Tor's handshake: obfs2, obfs3

Download consensus and **block relays**

Use **DPI** to detect Tor **TLS handshake**

Tor Pluggable Transport

- Pluggable transports are drop-in modules for traffic obfuscation
- Many modules have been written, but we focus on
  - **obfs2** (First deployed module)
    - First 20 bytes can be used to detect Tor traffic with high confidence.
  - **obfs3** (obfs2's successor)
    - Makes Tor traffic look like a uniformly random byte stream



Encryption Reduces Blocking Accuracy

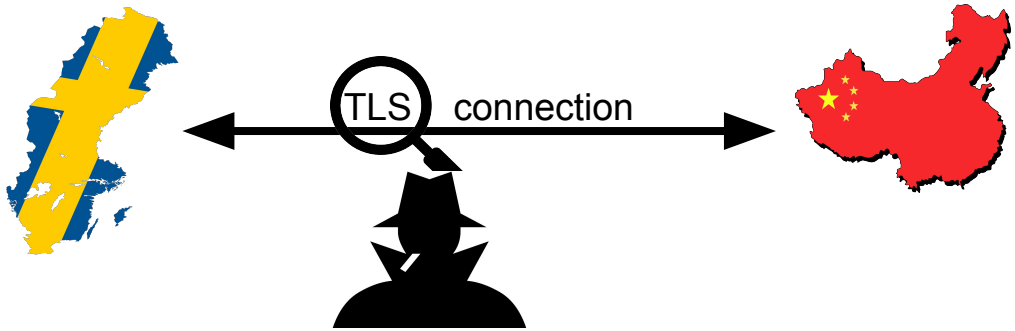
- Detection of pluggable transports is **uncertain**
  - Implies false positives → **collateral damage**

Encryption Reduces Blocking Accuracy

- Detection of pluggable transports is **uncertain**
  - Implies false positives → **collateral damage**
- GFW added **active probing** to complement the DPI fingerprinting

How does GFW Block Tor Hidden Circumvention Servers?

1. Network monitoring (e.g., switch mirror port)



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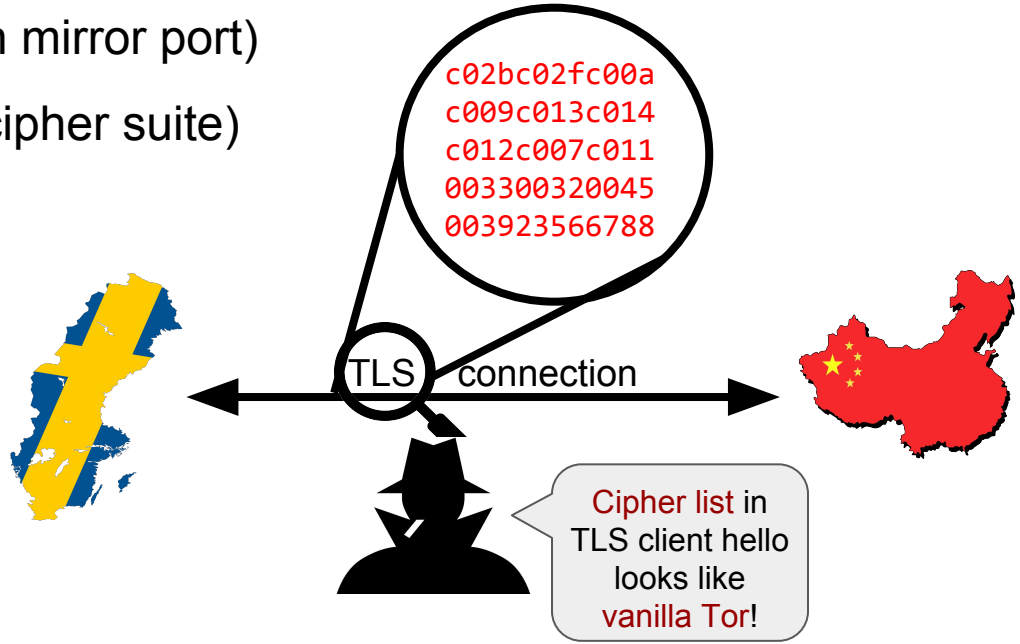

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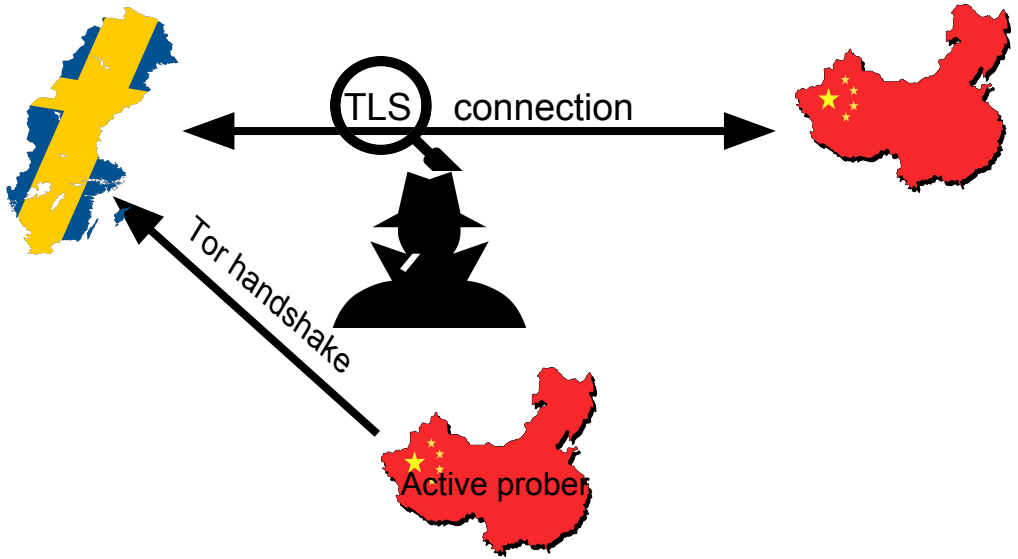

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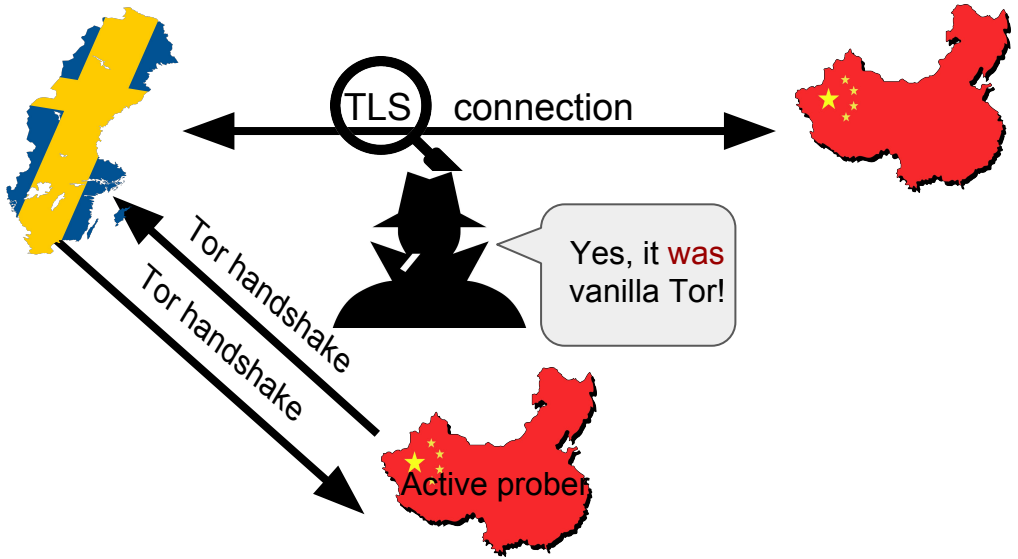

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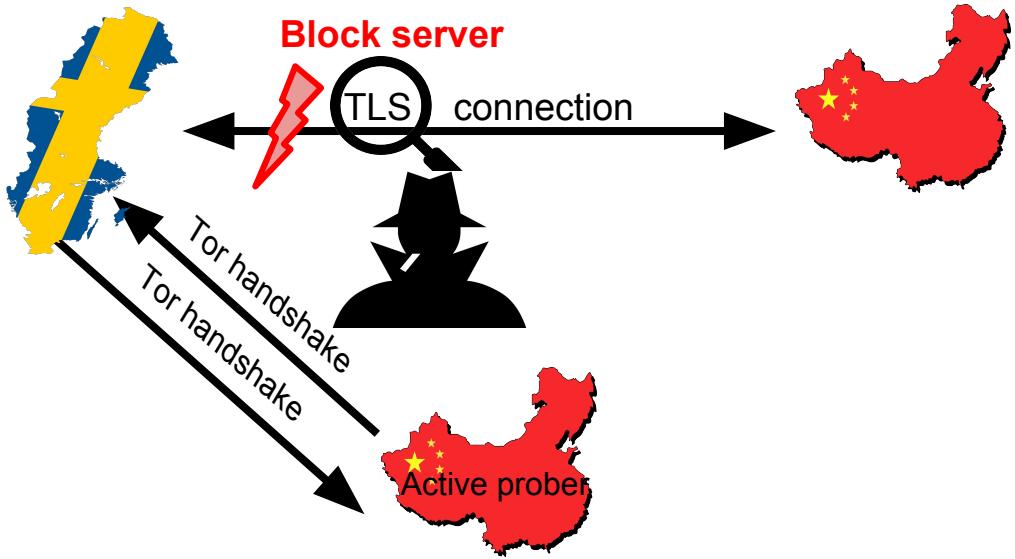
3. **Actively probing server to verify suspicion**
4. Blocking server



Censorship Arms Race: GFW vs. Tor

Time

Use **public Tor network** to circumvent GFW

Introduce **private bridges**, whose distribution is **rate-limited**

Introduce **pluggable transports** to hide the handshake such as obfs2, obfs3

Download consensus and **block relays**

Use **DPI** to detect Tor **TLS handshake**

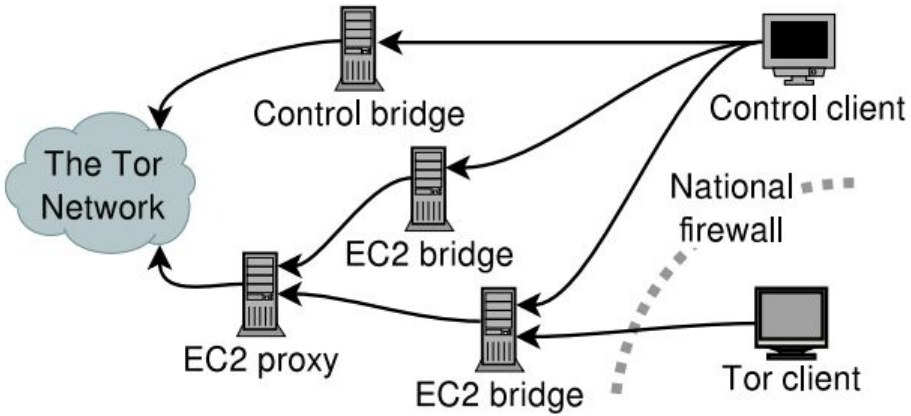
Use **DPI** + **Active probing**

Many Questions about Active Probing are Unanswered!

- We set out to answer: [5]
  - **Implementation**, i.e., how does it block?
  - **Architecture**, i.e., how is a system added to China's backbone?
  - **Policy**, i.e., what kind of protocols does it block?
  - **Effectiveness**, i.e., what's the degree of success at discovering Tor bridges?

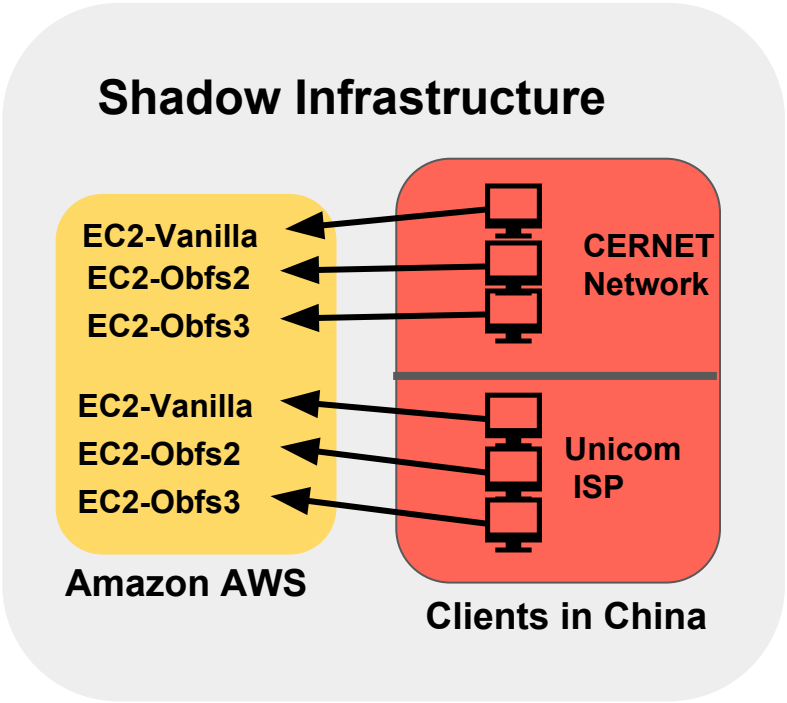
[5] **How the Great Firewall discovers hidden circumvention servers**
By **Roya Ensafi,** D. Fifield, P. Winter, N. Feamster, N. Weaver, and V. Paxson (In: *IMC'15*)

How Can We Design Measurements?



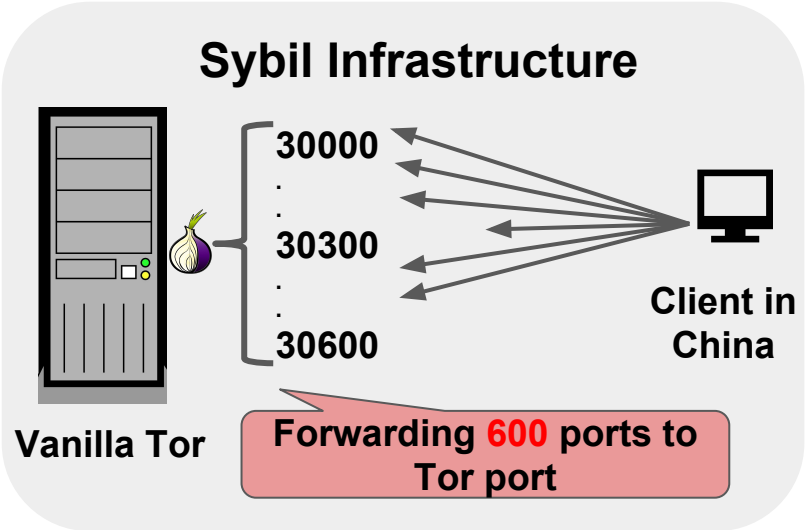
Overview of Our Datasets:

- Clients in China **repeatedly connected** to bridges under our control
- Pcap files of both the clients and the bridges



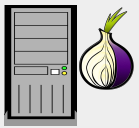
Overview of Our Datasets:

- **Redirected 600 ports to Tor port**
- Client in China connects to 600 ports
- Pcap files of both the client and the relay



Overview of Our Datasets:

- Web server that also runs a Tor bridge located in US
- Web server logs dating back to Jan 2010



Server Log Analysis

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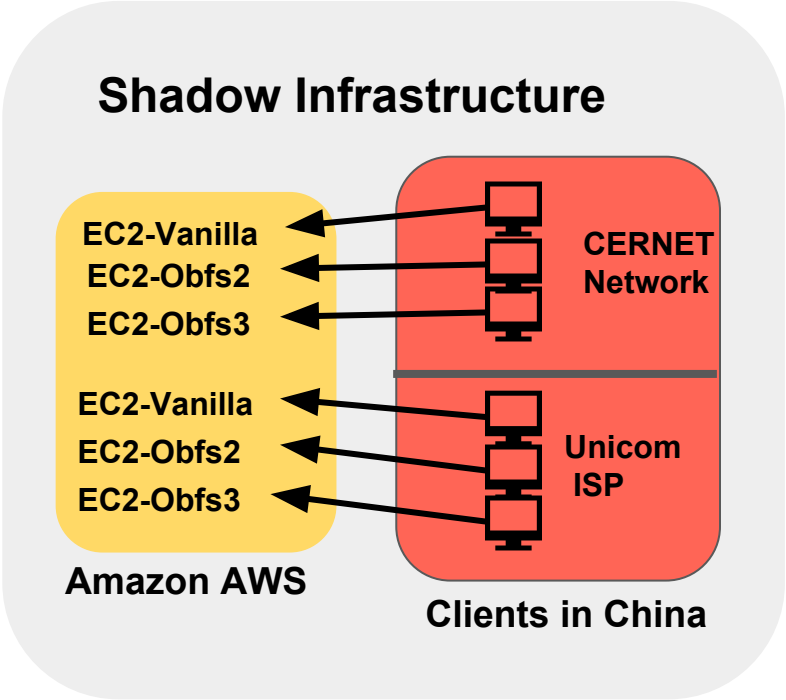

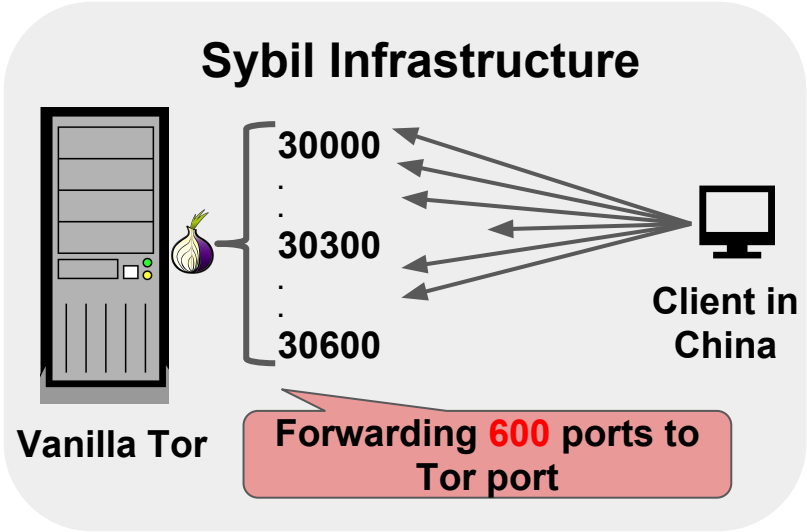

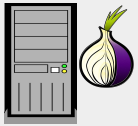

Server Log Analysis

Application logs of a web server that also runs a Tor bridge since 2010.

How to Distinguish Probers from Genuine Clients?

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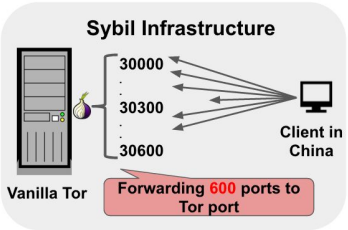
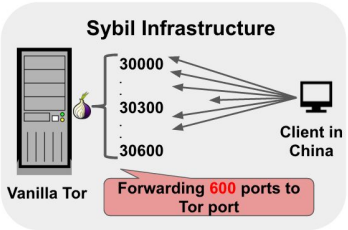


- Detecting probers in Sybil dataset is easy,
  - Probers:
    - Visited our vanilla Tor bridge after our client established connections
    - Originated from China

How to Distinguish Probers from Genuine Clients?



- Detecting probers in Sybil dataset is easy,
  - Probers:
    - Visited our vanilla Tor bridge after our client established connections
    - Originated from China

- For the other datasets, we adopt an algorithm:
  - If the cipher suites is in the TLS client hello => Vanilla bridge probes
  - If the first 20 bytes can reveal Obfs2 => Obfs2 bridges probers
  - ...

How Many Unique Probers did We Find?

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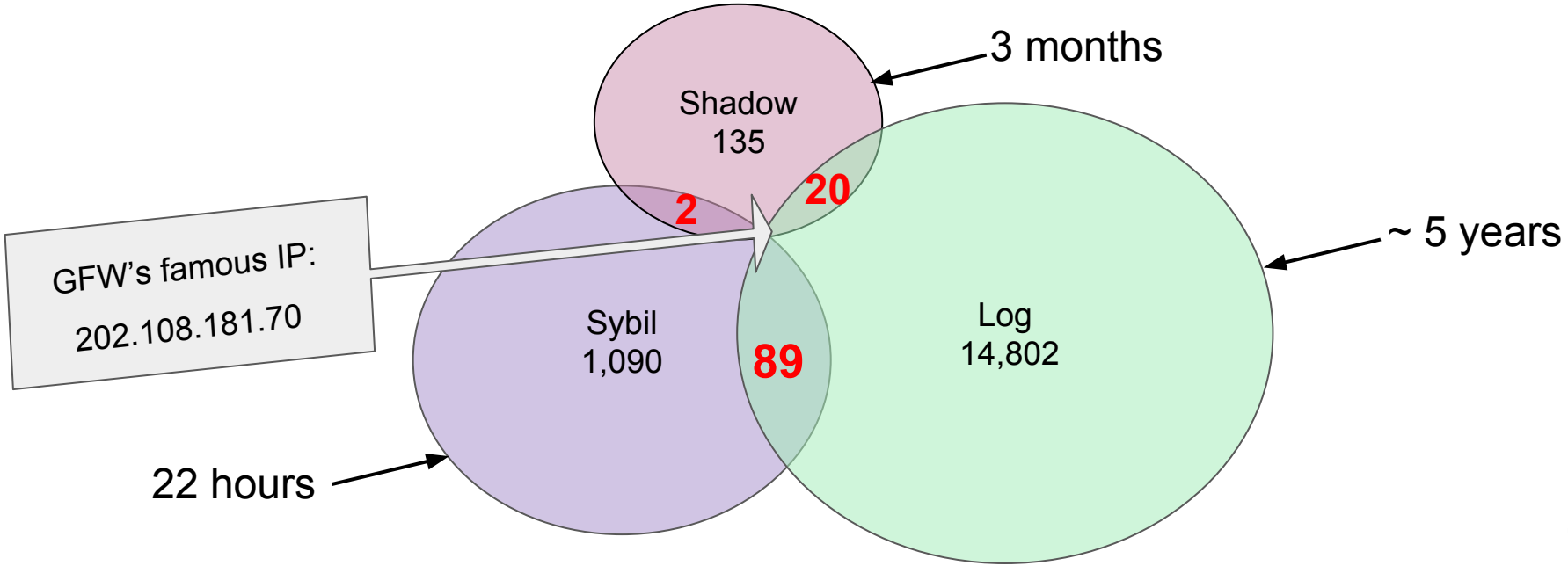
- Using **Sybil**, **Shadow** and **Log** dataset
  - In total, we collected **16,083** unique prober IP addresses



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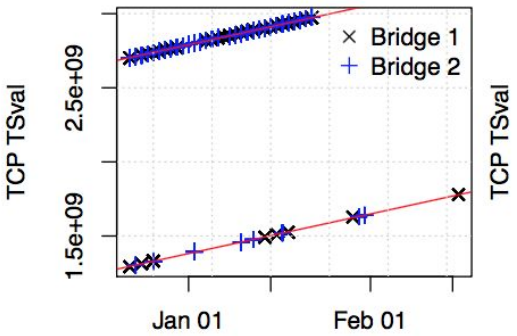
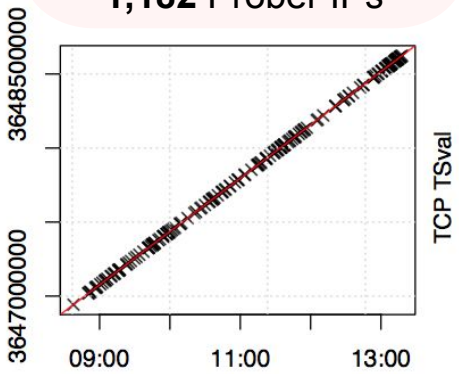
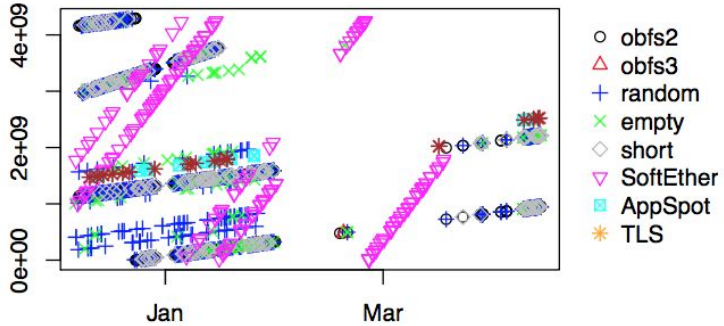
Shadow exp. with **158** Prober IPs



Sybil exp. with **1,182** Prober IPs

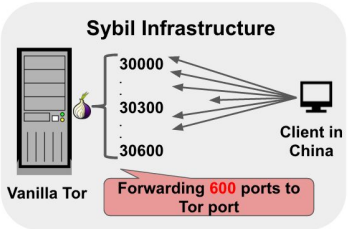


Log dataset with **14,912** Prober IPs



Can We Fingerprint Active Probers?

- TCP layer → ISN
  - TCP uses 32-bit initial sequence numbers (**ISNs**)
  - Protects against **off-path attackers**
  - Attacker must guess correct ISN range to inject segments
  - Every SYN segment should have **random** ISN



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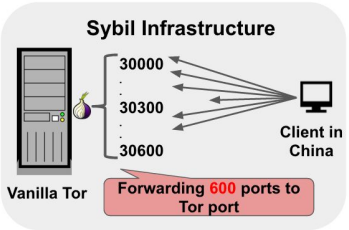

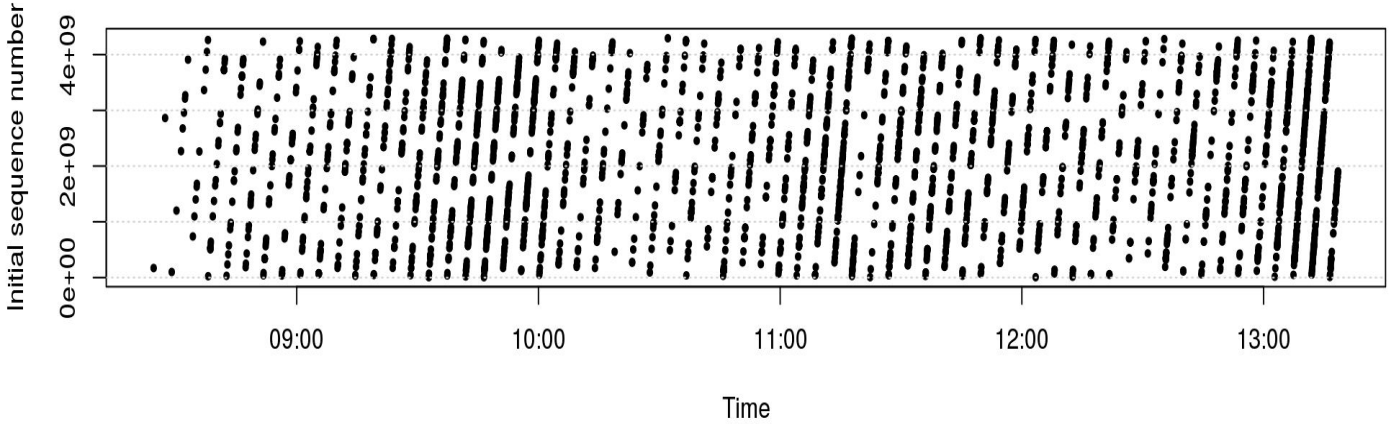

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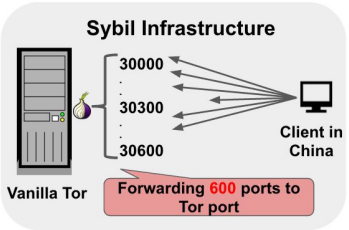

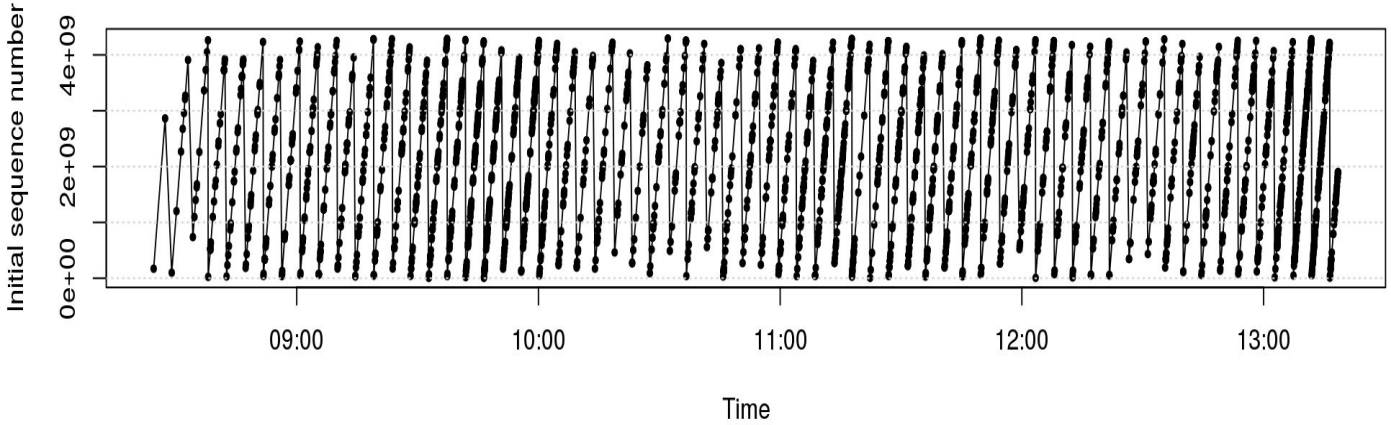

What do These Patterns Mean?

- Active probing connections **leak shared state**
  - ISNs, TSval, source ports, ...
- GFW likely operates only **few physical systems**
- Thousands of IP addresses are controlled by **central source**
- Does does not seem like off-the-shelf networking stack
- User space TCP stack?

How Quickly do Active Probes Show Up?

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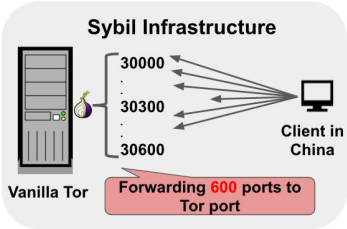
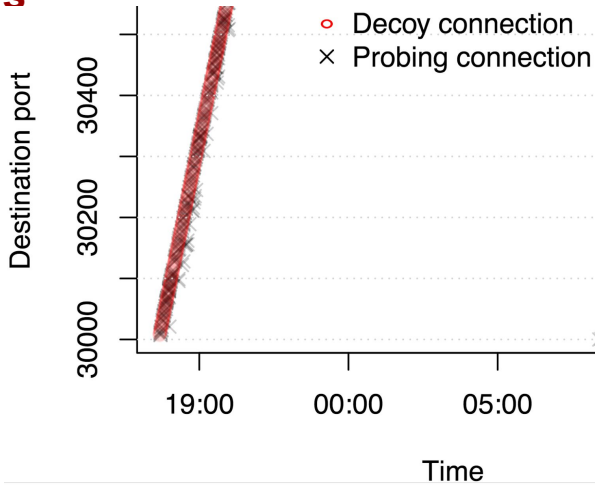


- Sybil dataset shows that system now works in **real time**
  - Median delay between Tor connection and subsequent probing connection is **~500ms**
  - **1,182** distinct probes just in 22 hs



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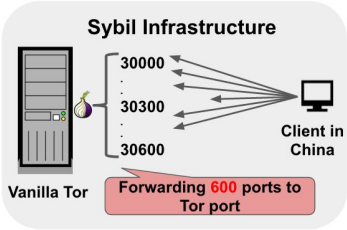

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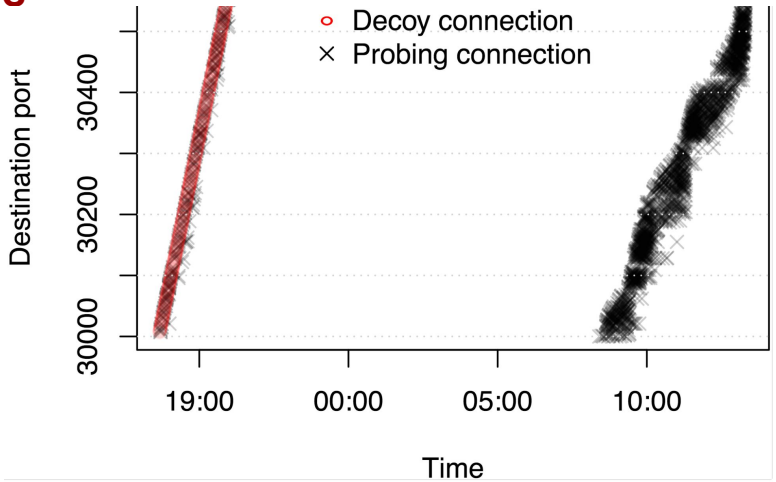
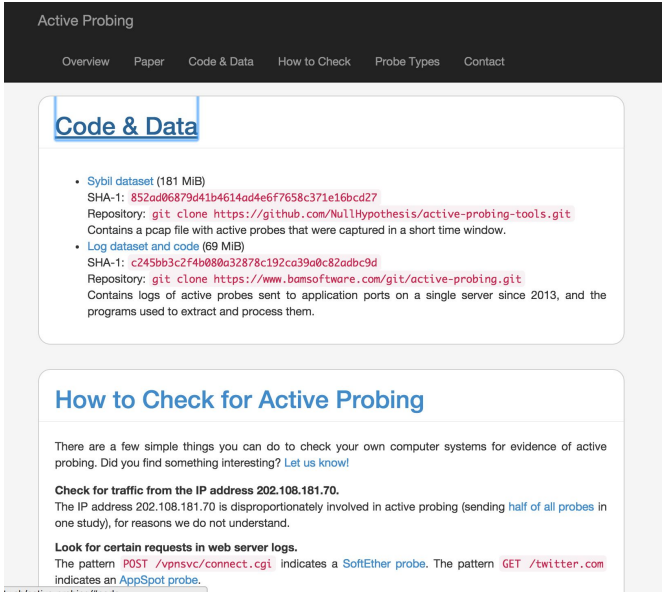


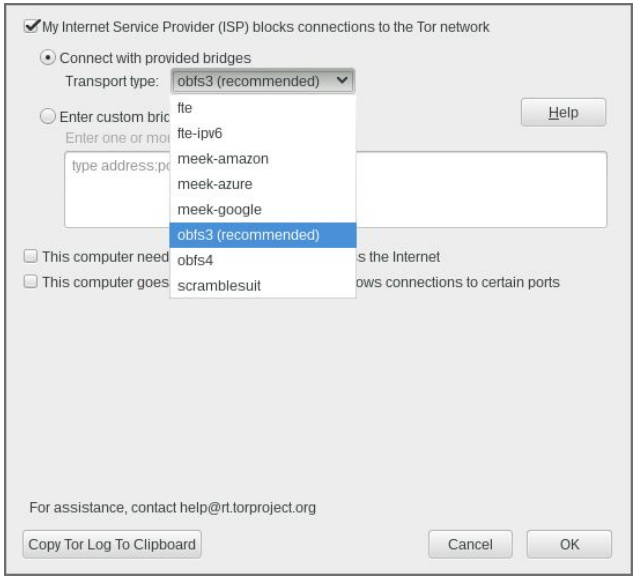
What Other Protocols are Probed?

- **SSH**: In 2011, not anymore?
- **VPN**: OpenVPN occasionally, SoftEther
- **AppSpot**: To find GoAgent?
- Anything else?



Pluggable Transports that Work in China

- **ScrambleSuit and Obfs4**
  - Clients must prove knowledge of **shared secret**
- **meek**
  - Tunnels traffic over **CDNs** (Amazon, Azure, Google)
- **FTE**
  - Shapes ciphertext based on **regular expressions**
- More is in the making!
  - WebRTC-based transport



Summary of Key Findings

- GFW “**hijacks**” many IP addresses, controls them centrally
  - Important for future threat models
- Censorship system is **modular**
  - Tor’s **pluggable transports** caused GFW to build **pluggable censorship**
- System now works in **real-time**

Trolling the GFW: Block List Exhaustion

```
for ip_addr in “$ip_addrs”; do
  for port in $(seq 1 65535); do
    timeout 5 tor --usebridges 1 --bridge “$ip_addr:$port”
  done
done
```

One /24 network can add 16 million blocklist entries

Lessons Learned (1/2)

- GFW **not perfect**... and **does not have** to be!
  - Good enough if 99% of users are affected
  - 1% will **always** be able to circumvent anyway

- **Information asymmetry** makes our job hard
  - Circumvention code and designs often **fully transparent**
  - GFW, however, **fully opaque**

Lessons Learned (2/2)

- Biggest **challenges** often **not technical**
  - Usability of Tor Browser
  - How do we **broadcast** what pluggable transports work?

- We don’t always get our threat models right
  - Our adversary isn’t **omniscient computer scientist**
  - Our adversary is **underpaid** and just wants to **get job done**

- Project page: https://www.cs.princeton.edu/~rensafi/projects/active-probing/
- **Log** and **Sybil** data sets are available online
- Contact: rensafi@cs.princeton.edu
- Twitter: @_ _royaen_ _