Triplet Censors: Demystifying Great Firewall’s DNS Censorship Behavior

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†University of Massachusetts Amherst, ‡Stony Brook University
Overview

Questions about the DNS filtering of the Great Firewall of China

- What domains are blocked?
- What are the IPs used in the forged DNS responses?
- How are domains being blocked?
- Is the blocking consistent within China?
Methodology

Probing Machine (US) -> GFW DPI -> Host without DNS resolving functionality (China)

A www.unblocked.com?
A www.blocked.com?
Forged response

Infer that www.blocked.com is censored
Longitudinal Dataset

- Probing Machine (US)
- GFW DPI
- Host **without** DNS resolving functionality (China)

A www.unblocked.com?
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Forged reply

Infer that www.blocked.com is censored

12 times a day (every 2 hours)
Longitudinal Dataset

Probing Machine (US) ➔ GFW DPI ➔ Host without DNS resolving functionality (China)

A www.unblocked.com?
A www.blocked.com?
Forged reply

12 times a day (every 2 hours)
12 times a day (every 2 hours) September 2019 - May 2020.

2.8 billion DNS queries sent
1.8 billion DNS queries sent
119.6 million forged responses

Infer that
www.blocked.com is censored
Overview

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- What domains are blocked?
- What are the IPs used in the forged DNS responses?
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- Is the blocking consistent within China?
What domains are blocked

- Number of censored websites increases from 23,995 to 24,636
What domains are blocked

- Number of censored websites increases from 23,995 to 24,636
- A major drop partly due to a rule change: “*youtube.com” -> “*.youtube.com”
What domains are blocked - Categories

- What types of domains are mostly censored?

<table>
<thead>
<tr>
<th>Category</th>
<th>Censored %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proxy Avoidance</td>
<td>46.0</td>
</tr>
<tr>
<td>Personal Websites</td>
<td>43.0</td>
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<td>6.2</td>
</tr>
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<td>5.3</td>
</tr>
<tr>
<td>Instant Messaging</td>
<td>4.2</td>
</tr>
</tbody>
</table>

www.purevpn.com
www.hideipvpn.com
www.hideip.co
www.anonymizer.com
What domains are blocked - Categories

- What types of domains are mostly censored?

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*blogspot.com
*tumblr.com
Overview

Questions about the DNS filtering of the Great Firewall of China

- What domains are blocked?
- **What are the IPs used in the forged DNS responses?**
- How are domains being blocked?
- Is the blocking consistent within China?
IPs used in forged DNS responses

- How do these IPs change?
- Where do these IPs belong to?
IPs used in forged DNS responses

- How do these IPs change?
- Where do these IPs belong to?
- Drop on November 23, 2019
  - Before 1,510 IPs (41 ASes)
  - After 216 IPs (21 ASes)
IPs used in forged DNS responses

- Reachability of the 216 currently injected IPs over a week
- Connection scans for each IP
  - Port 80 and 443
IPs used in forged DNS responses

Probing Machine (US) — GFW DPI — Host without DNS resolving functionality (China)

- Iteration 1: A www.hideip.co?
  - Forged response IP 1

- Iteration 2: A www.hideip.co?
  - Forged response IP 2

- Iteration 3: A www.hideip.co?
  - Forged response IP 2

- Iteration 4: A www.hideip.co?
  - Forged response IP 3
IPs used in forged DNS responses

- GFW injects different set of IPs to censor different set of domains

<table>
<thead>
<tr>
<th>Group</th>
<th>Domains</th>
<th>IPs</th>
<th>Top categories %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>3</td>
<td>Proxy Avoidance 50.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Business 25.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Personal Websites 12.5%</td>
</tr>
<tr>
<td>2</td>
<td>53</td>
<td>4</td>
<td>Proxy Avoidance 36.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>News and Media 9.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Instant Messaging 7.5%</td>
</tr>
<tr>
<td>3</td>
<td>48</td>
<td>10</td>
<td>Proxy Avoidance 79.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Information Technology 10.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Info and Computer Security 2.1%</td>
</tr>
</tbody>
</table>

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</tr>
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<tbody>
<tr>
<td>4</td>
<td>33</td>
<td>4</td>
<td>Search Engines 96.9%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>Unknown 1.8%</td>
</tr>
<tr>
<td>6</td>
<td>~24K</td>
<td>197</td>
<td>Personal Websites 76.7%</td>
</tr>
<tr>
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Characterizing GFW’s DNS Injection

- GFW injects different set of IPs to censor different set of domains

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How are domains being blocked

Probing Machine (US) → GFW DPI → Host in China without DNS resolving functionality

- A www.google.sm?
- 3 forged responses

Why >1 response?
How are domains being blocked

- Each injector maintains a different blacklist
How are domains being blocked

- Each injector maintains a different blacklist
- Each injector has a unique fingerprint

<table>
<thead>
<tr>
<th>Injector</th>
<th>Description</th>
</tr>
</thead>
</table>
| 1        | DNS: TTL=60; AA=1  
  IP: DF=0  
  incrementing IP TTL |
| 2        | DNS: AA=0  
  IP: DF=1  
  randomized IP TTL |
| 3        | DNS: AA=0  
  IP: DF=0; ID=0  
  fixed IP TTL |
## How are domains being blocked

- Relation between IP/Domain groups and the injectors

<table>
<thead>
<tr>
<th>Injector</th>
<th>Description</th>
<th>Count</th>
<th>Unique Count</th>
<th>Total Count</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DNS: TTL=60; AA=1; IP: DF=0 incrementing IP TTL</td>
<td>4</td>
<td>33</td>
<td>4</td>
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Fingerprinting the GFW Injectors

- IPID and IP TTL patterns under when sending queries rapidly

(a) Injector 1

(b) Injector 2

(c) Injector 3
Localizing the GFW Injectors

<table>
<thead>
<tr>
<th>Probing Machine (US)</th>
<th>GFW (16 hops from sender)</th>
<th>Receiver in China (25 hops from sender)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TTL = 1,2,..,15</td>
<td></td>
</tr>
<tr>
<td>0 response</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TTL = 16,17,..,24</td>
<td></td>
</tr>
<tr>
<td>2 responses</td>
<td></td>
<td>Injector 1 + 2</td>
</tr>
<tr>
<td></td>
<td>TTL = 25,26,..,28</td>
<td></td>
</tr>
<tr>
<td>2 responses</td>
<td></td>
<td>Injector 1 + 2</td>
</tr>
<tr>
<td></td>
<td>TTL &gt;= 29</td>
<td></td>
</tr>
<tr>
<td>3 responses</td>
<td></td>
<td>Injector 1 + 2 + 3</td>
</tr>
</tbody>
</table>

- It appears one of the injectors is 29 hops away from the sender, while the receiver is actually just 25 hops away from the sender.
- Same strange results remain when repeating the experiment from 7 different locations outside of China to the same receiver.
- Why?
Localizing the GFW Injectors

- Mirroring IP TTL

*Assuming that the routing paths are symmetric
Localizing the GFW Injectors

Probing Machine (US)

Injector 1

Injector 2

Injector 3

A www.google.sm ?

3 forged responses

No difference in arrival time
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Is the blocking consistent within China

1. Select 36,629 IP prefixes belonging to Chinese organizations from CAIDA.
2. Select one non-responding IP for each prefix at random.
   a. In total, we get 36,146 non-responding Chinese IPs (417 ASes).
3. Issue 100 sensitive queries for www.google.sm to all selected IPs from one single point outside of China.
Is the blocking consistent within China

- Only 8.4% of prefixes (114 ASes) receive no DNS injections.
Summary

- The GFW injects different sets of IPs to censor different groups of domains
- We have fingerprinted 3 GFW injectors
  - All of them appear to share the same injection point
  - Injector 1’s IPID and IP TTL are associated with injection sequence
  - Injector 3’s IP-TTL echoing behavior has implications on using TTL-limited probe packets to localize GFW injectors
- Observed DNS injections on 91.6% of the 36K Chinese IP prefixes

We have released all our code and datasets at https://gfw.report/publications/foci20_dns/en/
gfw.report@protonmail.com (B0C6 EB19 DA7C EAA3)