Active TLS Stack Fingerprinting:
Characterizing TLS Server Deployments at Scale

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Introduction

Three facts about the TLS:

1. It is currently the de facto standard for encrypted communication on the Internet
2. It is old, and it has grown to a complex ecosystem due to its continuous development
3. Thus, during the handshake the client and server capabilities must be exchanged.

→ This meta-data allows to fingerprint the TLS stack (config, implementations, and hardware)

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1. C. Labovitz, „Internet Traffic 2009-2019,” in Proc. Asia Pacific Regional Internet Conf. Operational Technologies, 2019.
2. P. Kotzias, A. Razaghpanah, J. Amann u.a., „Coming of Age: A Longitudinal Study of TLS Deployment,” in Proc. ACM Int. Measurement Conference (IMC), 2018.
Background

TLS Fingerprinting

- Collecting TLS characteristics (⇒ represented as fingerprint)
- Build a database mapping fingerprints with not directly related data, e.g.:

| Fingerprint    | Indicates                  |
|----------------|----------------------------|
| 771_1301_...   | IETF webserver             |
| 771_1302_...   | Nginx docker image         |
| 770_cf_...     | TrickBot CnC server        |
Background

Example TLS 1.3 handshake

Client Hello (CH) [ver., session info., Cipher Suites, _, Extensions {versions, ALPNs, ...}]

Server Hello (SH) [ver., session info., Cipher Suite, _, Extensions {version, ALPN, ...}]

Change Cipher Spec

Encrypted Extensions, Certificate, Certificate Verify, ..., Finished, [Application Data]

Changed Cipher Spec

..., Finished, [Application Data]

Application Data

Legend: fingerprintable server data, encrypted data
Motivation

Future Applications:

1. **Enhance existing Intrusion Detection Systems**
   Servers from network flows are fingerprinted on-demand and results compared with known malicious ones

2. **Internet-wide measurements**
   Security researchers use fingerprinting to find previously unknown threats

3. **Monitoring of own Servers**
   Deviations from a fingerprints baseline can indicate an unintended software change or a malware infection
Goals

Problem: Early fingerprints with default CHs were not distinctive enough

This was due to the question-answer design of TLS, e.g.:

- \text{TLS\_AES\_256\_GCM\_SHA384}
- \text{TLS\_CHACHA20\_POLY1305\_SHA256}
- \text{TLS\_AES\_128\_GCM\_SHA256}
- \text{TLS\_AES\_128\_CCM\_8\_SHA256}
- \text{TLS\_AES\_128\_CCM\_SHA256}
- ...

→ use unusual CHs that trigger distinguishable behaviors
→ find multiple CHs to increase the learned data
→ find a trade–off between learned data and scan costs (time and impact)
Methodology

Research Questions

1. How can we relate similar TLS server deployments?
2. How can we improve the effectiveness of our CHs?
3. What is the performance of actual fingerprinting use-cases?
Methodology

Constructing Fingerprints

Extract data such that similar deployments have the same fingerprint

- A handshake is represented textually, e.g.,

\[
\begin{array}{cccc}
\text{Cipher} & \text{Encrypted Extensions} & \text{Alerts} \\
771_{\text{1301}}_{\text{43.AwQ-51.23}}_{\text{0.-10.AAo...}}_{\text{18. <40}} & \\
\text{Version} & \text{Server Hello Extensions} & \text{Certificate Extensions} \\
\end{array}
\]

- The final TLS fingerprint is a combination of multiple handshakes, e.g.,

\[
771_{\text{1301}}\ldots, 771_{\text{1302}}\ldots, 770_{\text{fa}}\ldots, \ldots
\]
Effective Scanning Configurations

Research Questions

1. How can we relate similar TLS server deployments?
2. **How can we improve the effectiveness of our CHs?**
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Effective Scanning Configurations

**Challenge:** Without knowledge about the implementation of every TLS server, it is impossible to select the ideal CHs for fingerprinting.

→ However, we can optimize the effectiveness of the CHs

We propose and empiric design of CHs:

1. Measure the effectiveness with a metric (e.g., distinct fingerprints)
2. Perform measurement with a large amount of randomly generated candidates
3. Select the CHs that maximize the metric

This way we generated the **10 general-purpose CHs** used in the following analyses
Fingerprinting Use Cases

Research Questions

1. How can we relate similar TLS server deployments?
2. How can we improve the effectiveness of our CHs?
3. **What is the performance of actual fingerprinting use-cases?**
Fingerprinting Use Cases

Overview
Long-running study over 30 weeks with weekly measurements

Toplists
- Alexa Top 1 Million
- The Majestic Million

Blocklists
- abuse.ch Feodo Tracker
- abuse.ch SSL Blacklist

→ In total, we collected 104 Million fingerprints
Fingerprinting Use Cases

CDN Server Detection

CDNs enable us to evaluate the approach because

- they are a single actor deploying TLS servers on a large-scale (large amount of data samples)
- their servers can be verified (AS, HTTP headers, and x509 certificates) to get a ground-truth

→ Evaluated a CDN detection based on past observations per week

Metrics:

- Precision \( \frac{TP}{TP+FP} \): “correct classifications“
- Recall \( \frac{TP}{TP+FN} \): “detected CDN servers“
Fingerprinting Use Cases

CDN Server Detection

Note: The approach enabled us to detect off-net CDN servers in sometimes unexpected ASs
Fingerprinting Use Cases

CnC Server Detection

Fingerprinting allows to detect potentially malicious servers

- We analyzed new additions to the lists based on past information
- We considered how often a fingerprint is observed from CnC servers vs. from toplist servers
- This results in a score $\in [0, 1]$ how certain we are that we found a CnC server
- If the score was above a tune-able threshold, the server is classified as CnC server
Fingerprinting Use Cases

CnC Server Detection

→ Fingerprints work great if combined with additional indicators
Conclusion

- Proposed a selection of TLS handshake features and their encoding as fingerprint to relate servers
- Provided a methodology for finding effective CHs and 10 general-purpose CHs that maximize information extraction from servers
- Demonstrated the potential of Active TLS Stack Fingerprinting based on detecting CDN and CnC servers
- The approach resulted in more effective fingerprinting compared to related work JARM\(^3\)
- Open-sourced our data and code

https://active-tls-fingerprinting.github.io

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\(^3\) J. Althouse, A. Smart, R. Nunnally Jr. u. a., Easily Identify Malicious Servers on the Internet with JARM, 17. Nov. 2020. Adresse: https://engineering.salesforce.com/easily-identify-malicious-servers-on-the-internet-with-jarm-e95edac5255a.