IoTLS: Understanding TLS Usage in Consumer IoT Devices

Muhammad Talha Paracha, Northeastern University
Daniel D. Dubois, Northeastern University
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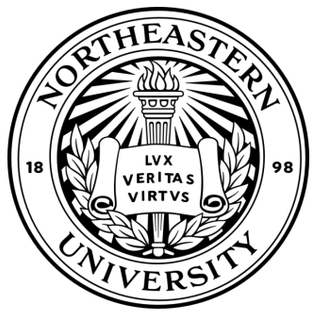
David Choffnes, Northeastern University



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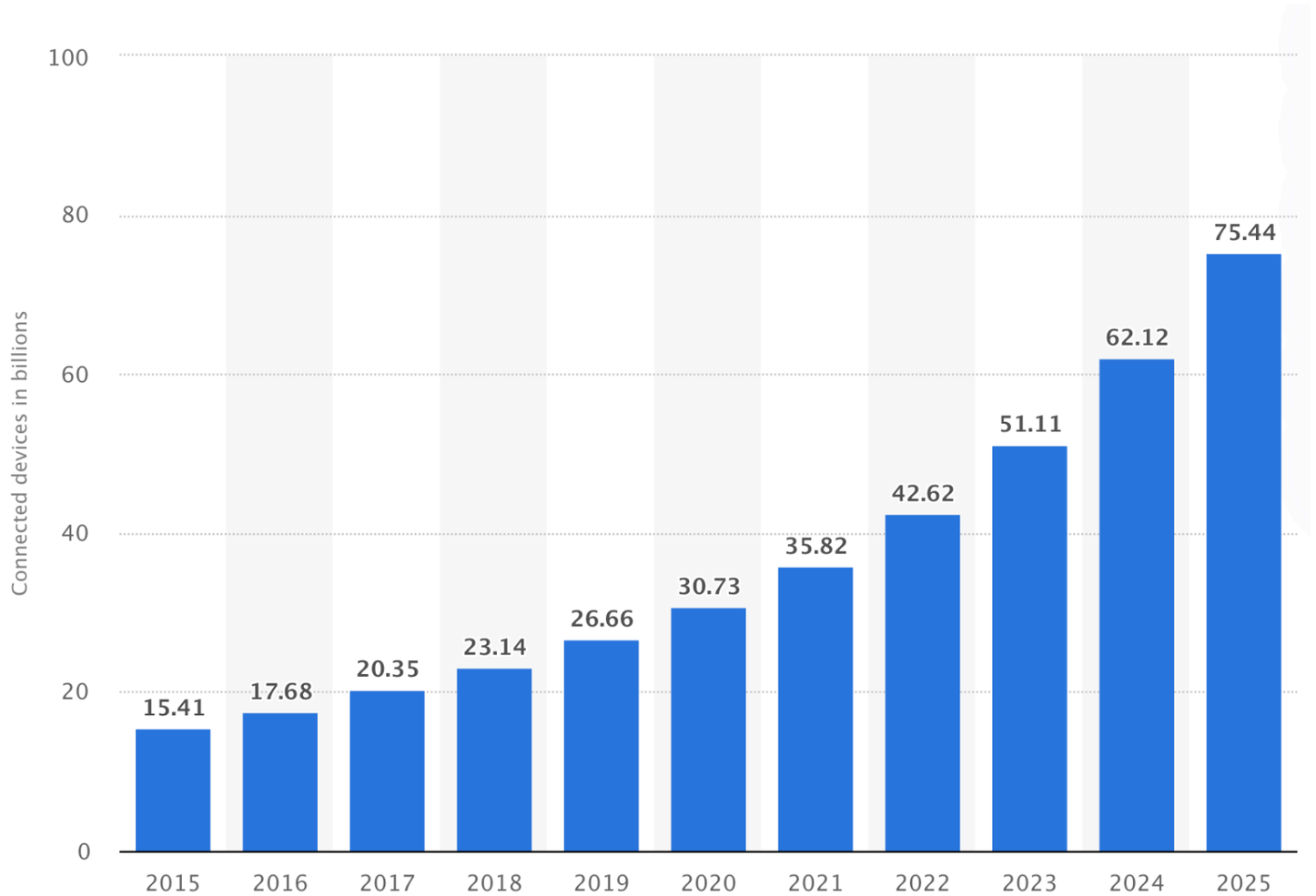
IoT privacy and security!

- IoT devices projected to be ~**75 billion** by 2025



Projected Growth of IoT Devices
([Statista])

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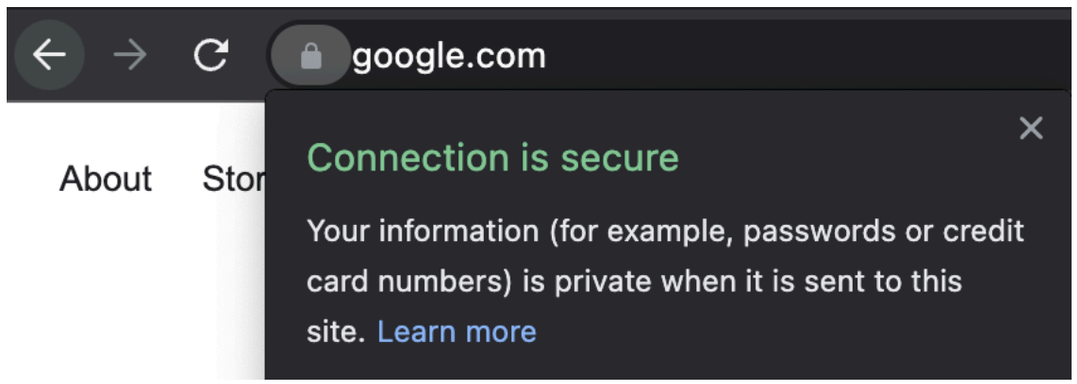
- TLS de-facto web protocol to provide **confidentiality**, **authenticity**, and **data integrity**



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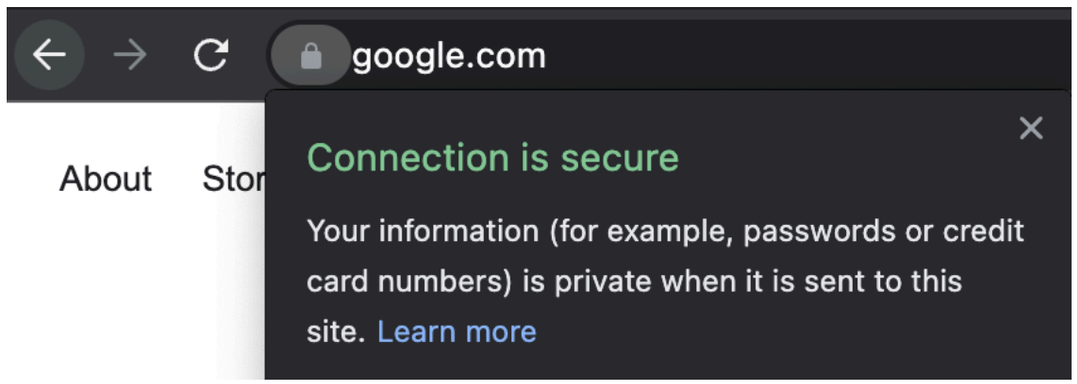

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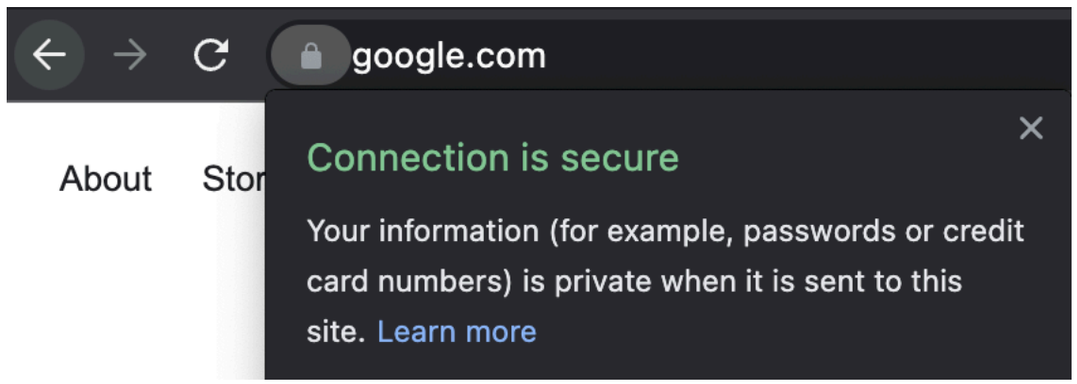

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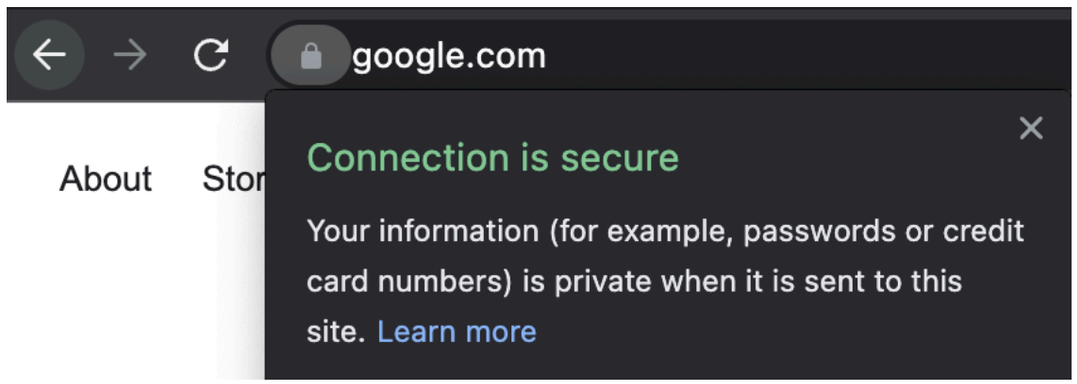

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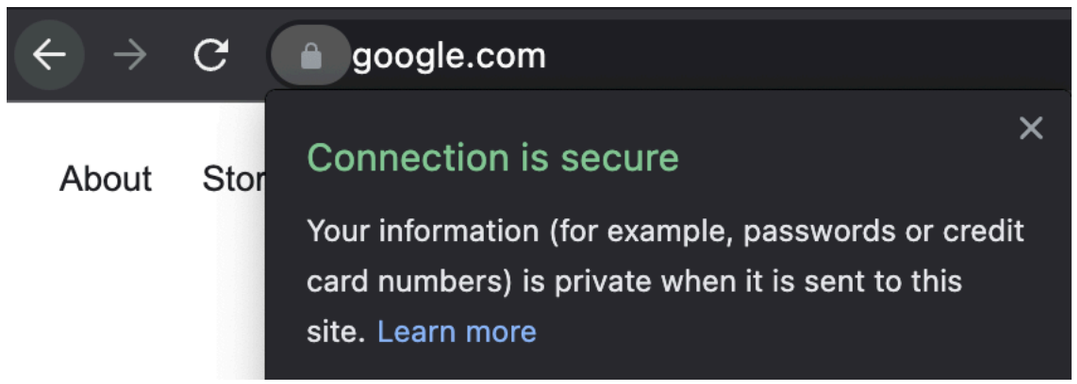

- Effective TLS usage means:

1. Using secure protocol version and features (e.g., TLS 1.2)
2. Properly validating certificate chains (e.g., trusted set of root certificates)
3. Adopting new features as the protocol evolves over time
   (e.g., TLS 1.3, modern ciphersuites)

How effective is TLS in IoT?

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Studying TLS in IoT devices poses new challenges compared to other environments:

Challenge	***Our approach***

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Studying TLS in IoT devices poses new challenges compared to other environments:

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1. Limited ways to trigger traffic	1. Automate device reboots using smart plugs
2. Limited vantage points	2. Uncontrolled experiments over a long period of time

Mon(IoT)r Lab at Northeastern University

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- 40 TLS-supporting consumer IoT devices across 7 categories:
  Cameras, TVs, Home Automation, Audio, Smart Hubs & Appliances

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- 40 TLS-supporting consumer IoT devices across 7 categories:
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- ~2 years of longitudinal data from January 2018 to March 2020

Key Results

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- Do devices ***securely establish*** TLS connections?

  ✓ Most devices use TLS 1.2

  ✓ No device uses insecure ciphersuites (ANON/NULL)

  ✗ Few devices upgrade to TLS 1.3 over time

  ✗ Few devices upgrade to modern ciphersuites (DH/ECDHE) over time

Key Results

- Do devices ***securely establish*** TLS connections?
- Do devices ***properly validate*** TLS certificates?

✗ 11 devices vulnerable to TLS interception attacks

✗ Devices do not appear to update their TLS root stores

Key Results

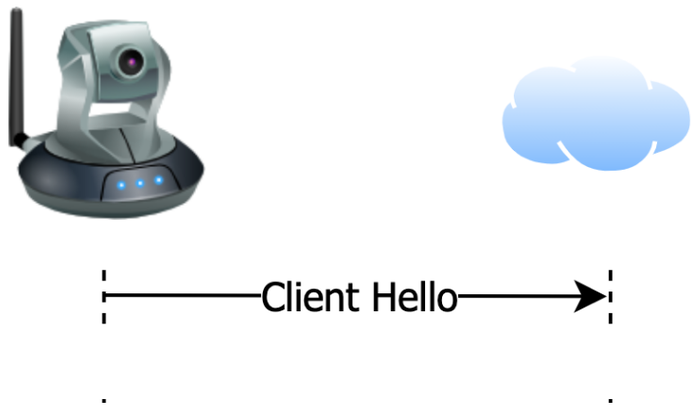
- Do devices ***securely establish*** TLS connections?
- Do devices ***properly validate*** TLS certificates?
- Do devices ***share TLS libraries*** with other clients?

  — Devices & applications from same vendor likely share TLS libraries.

Trusted root stores

Example TLS Handshake

Trusted root stores



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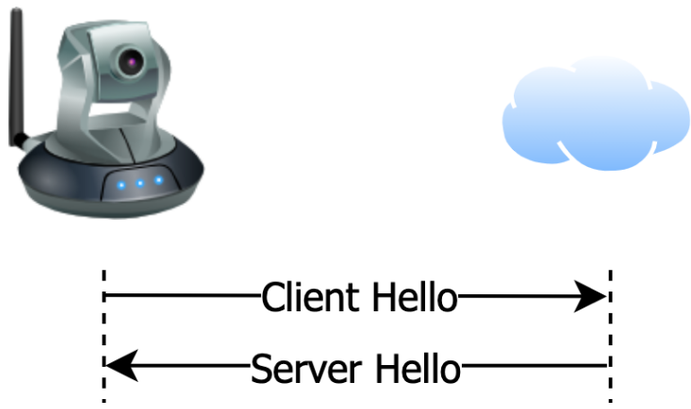

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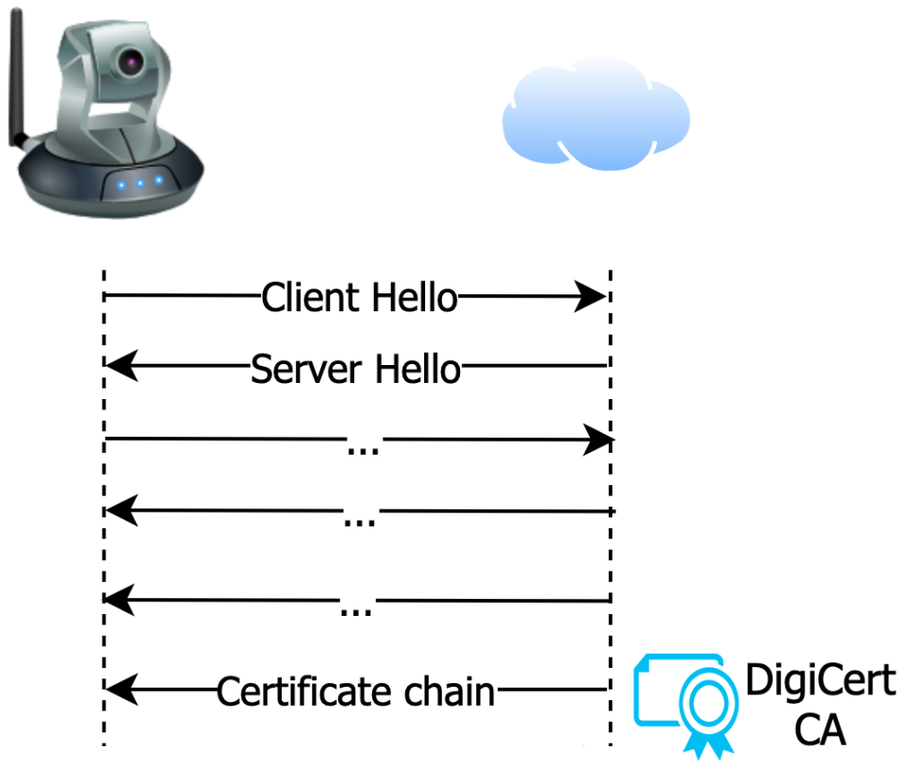

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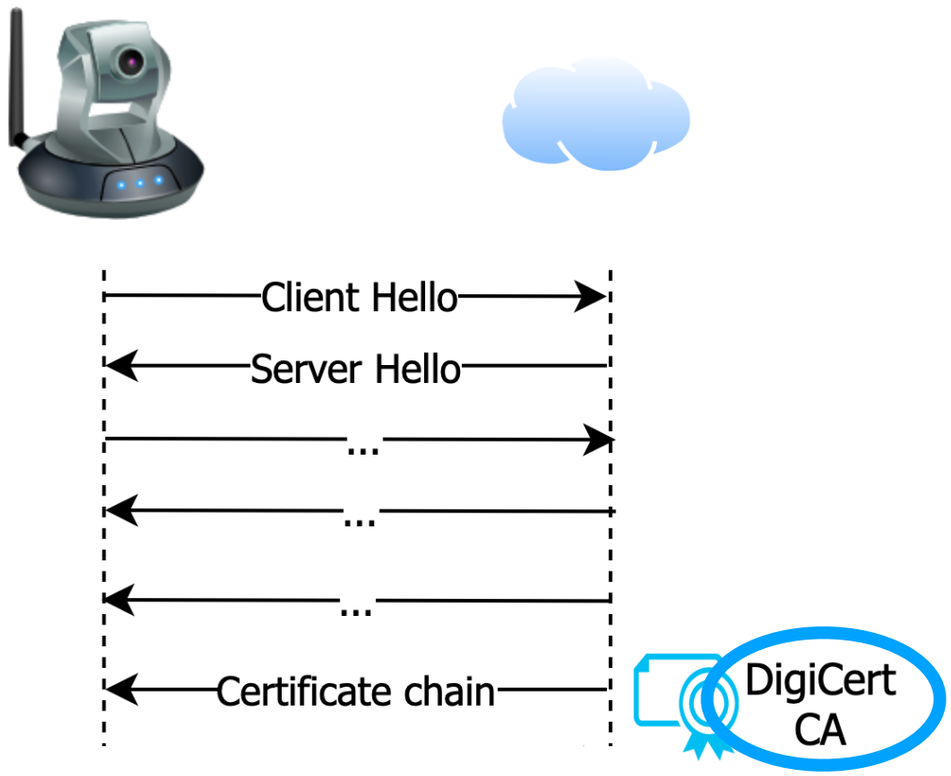

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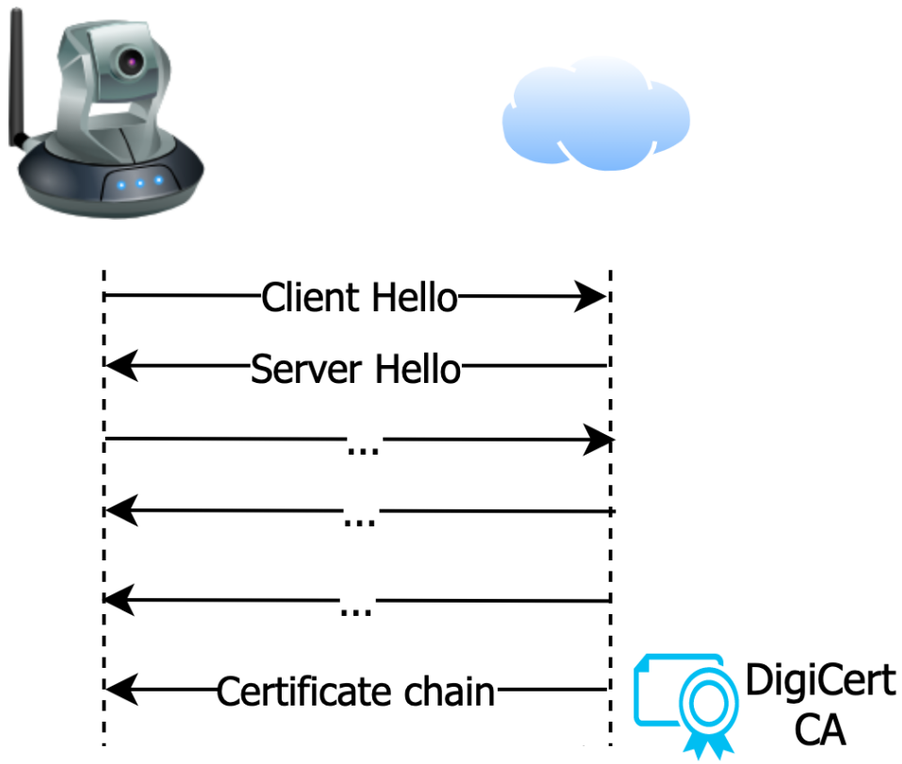

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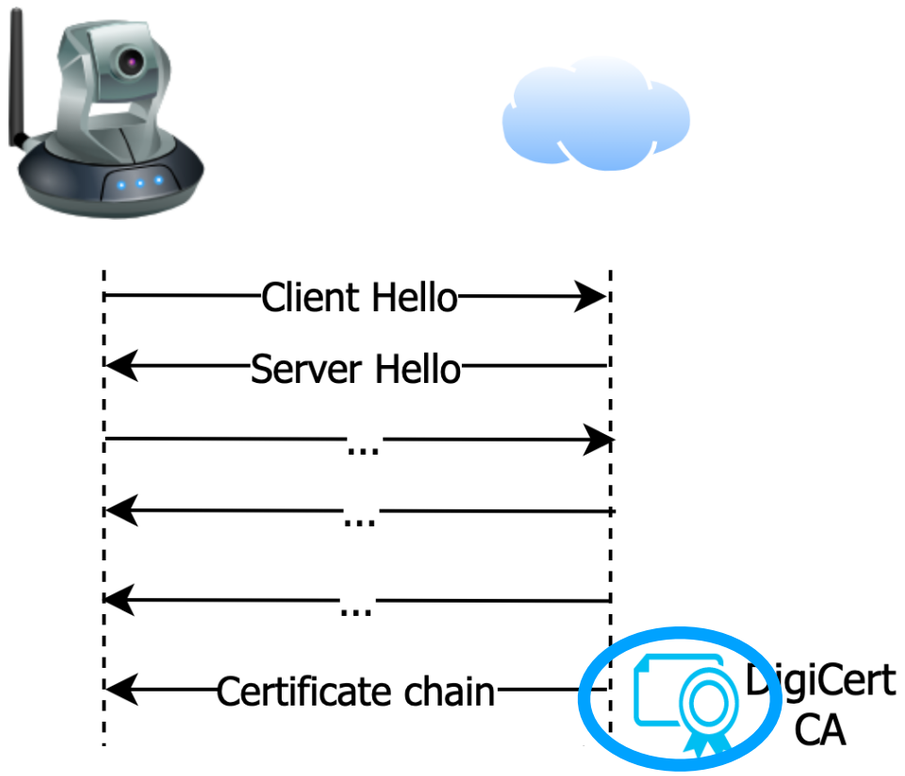

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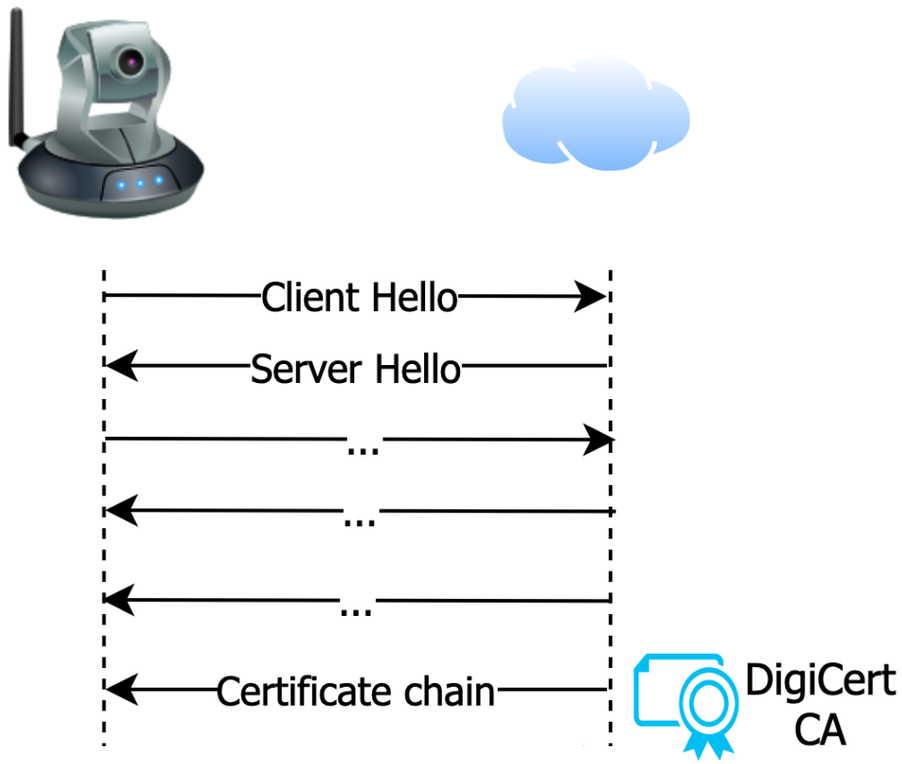

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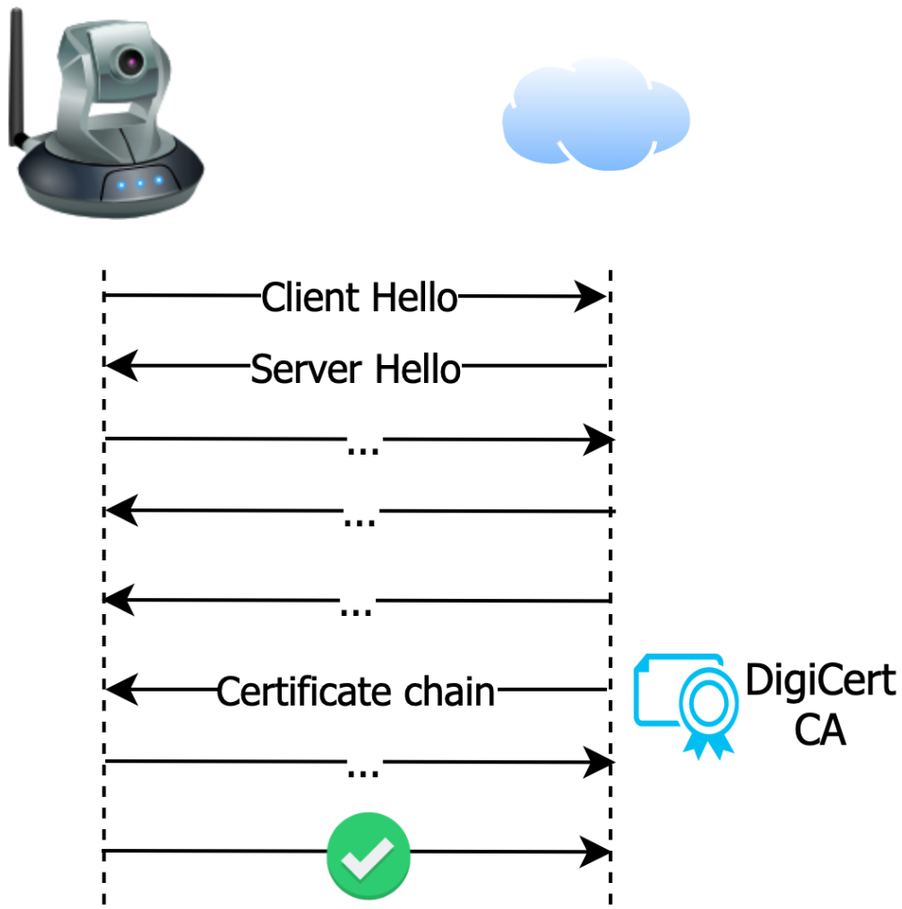

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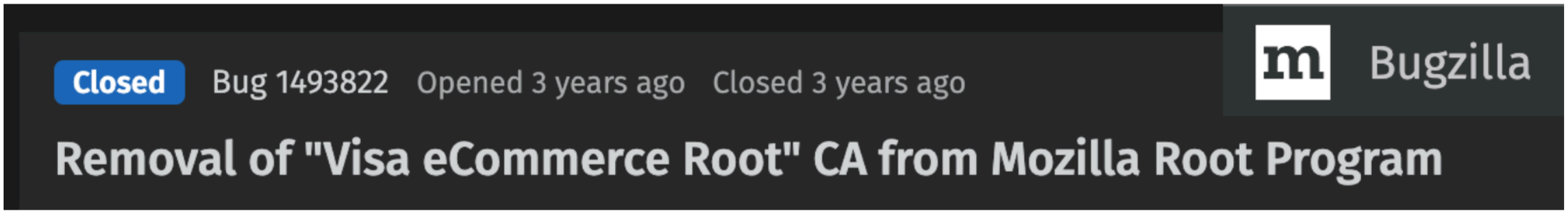

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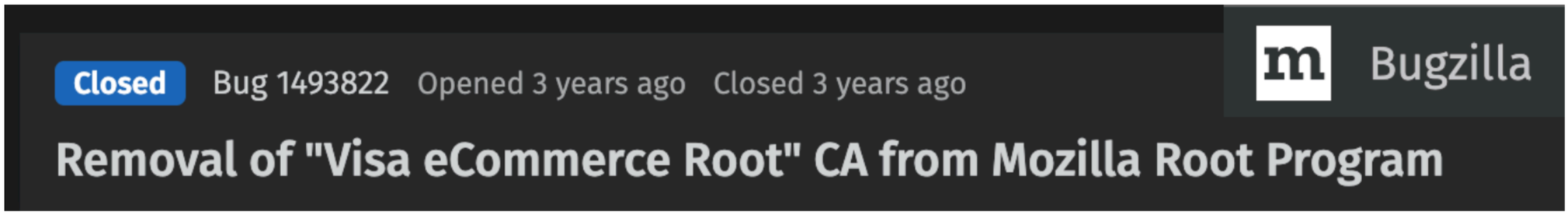
digicert®

Let's Encrypt

COMODO SSLCERTIFICATE



moz://a **Revoking Trust in Two TurkTrust Certificates**

Root stores exploration in IoT devices

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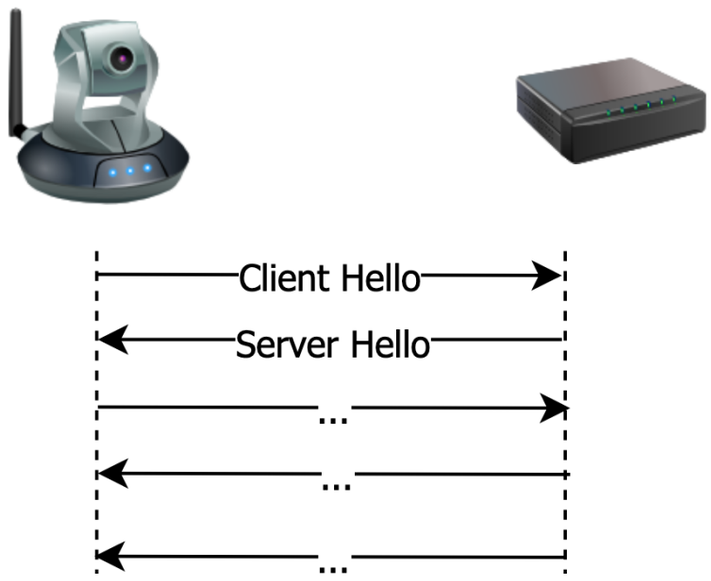

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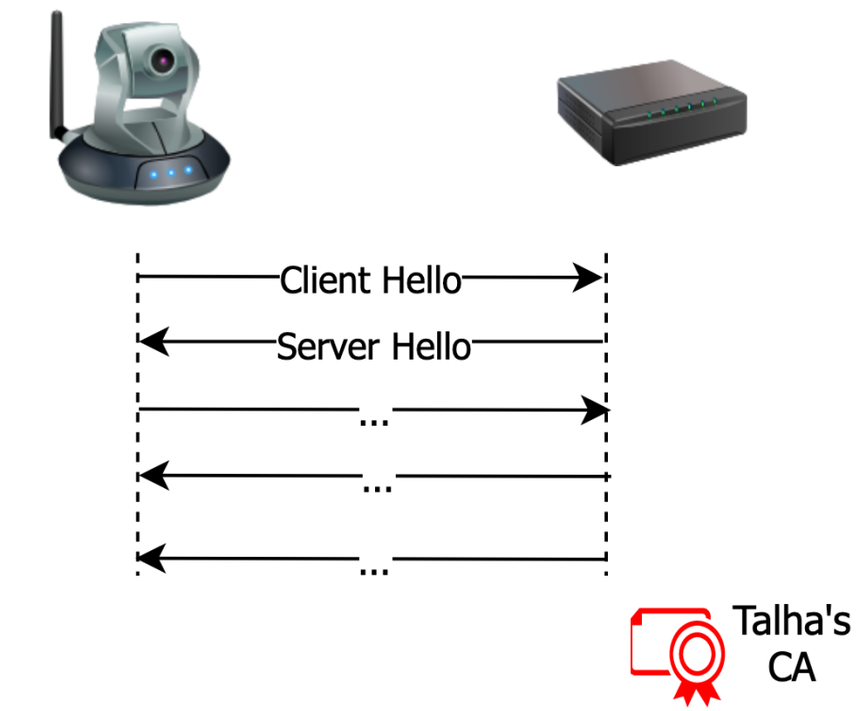

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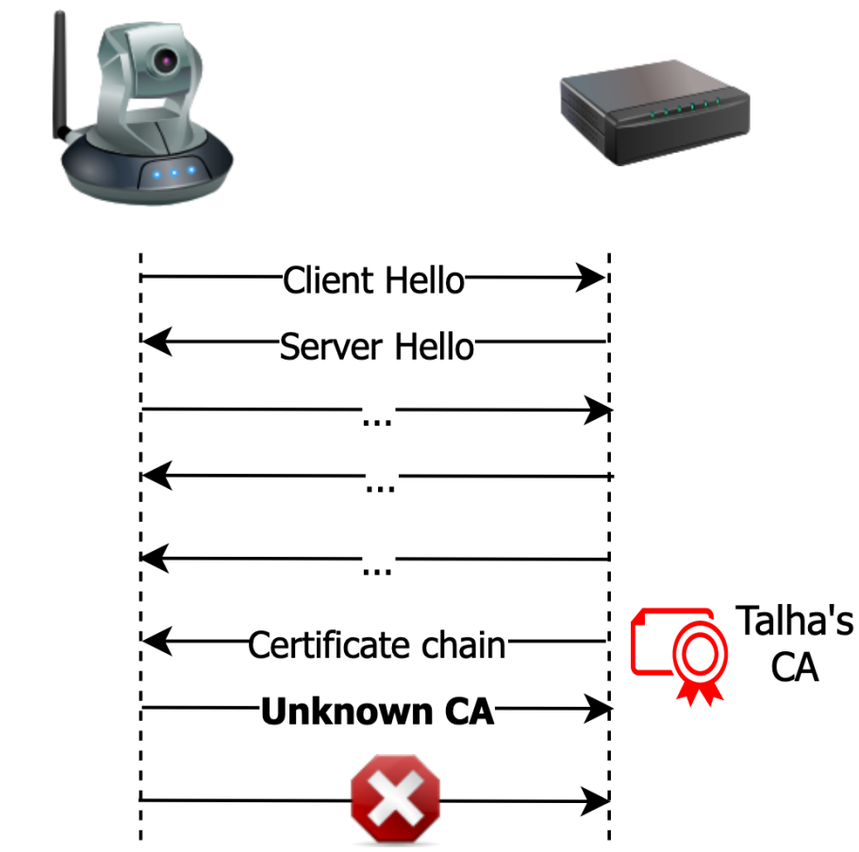

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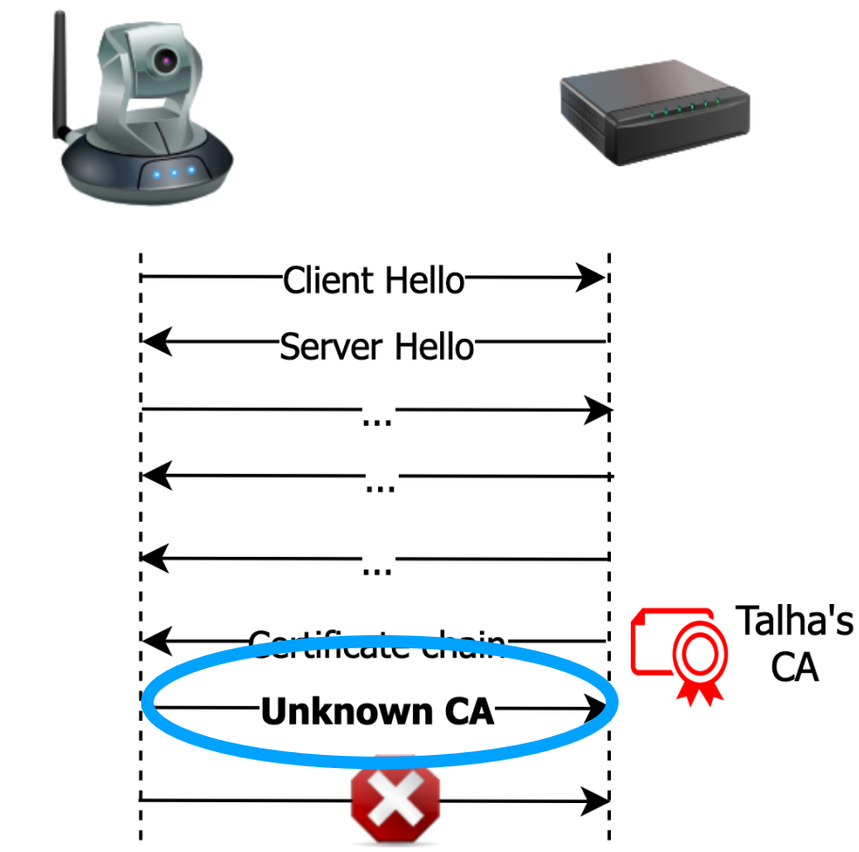

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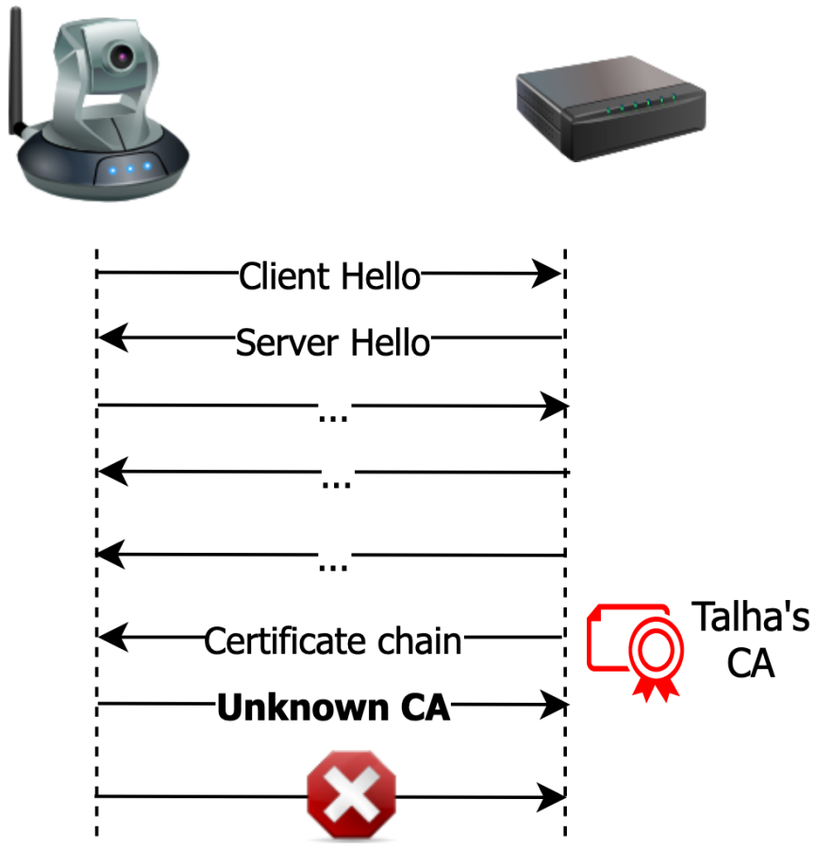

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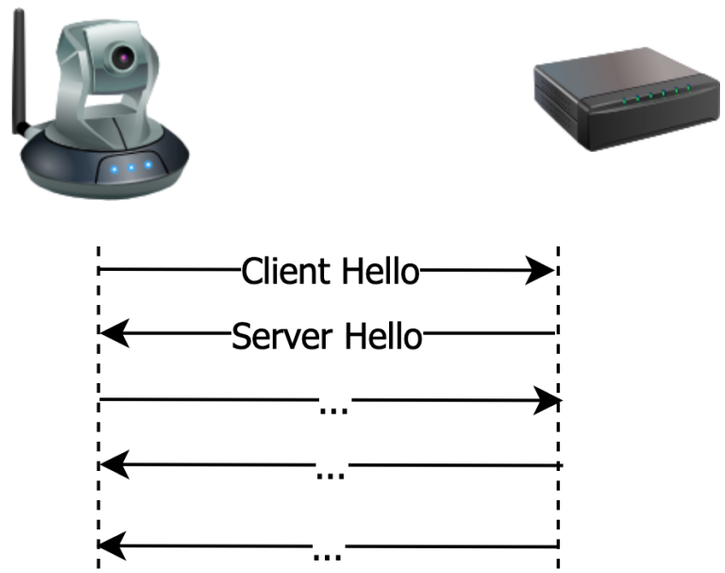

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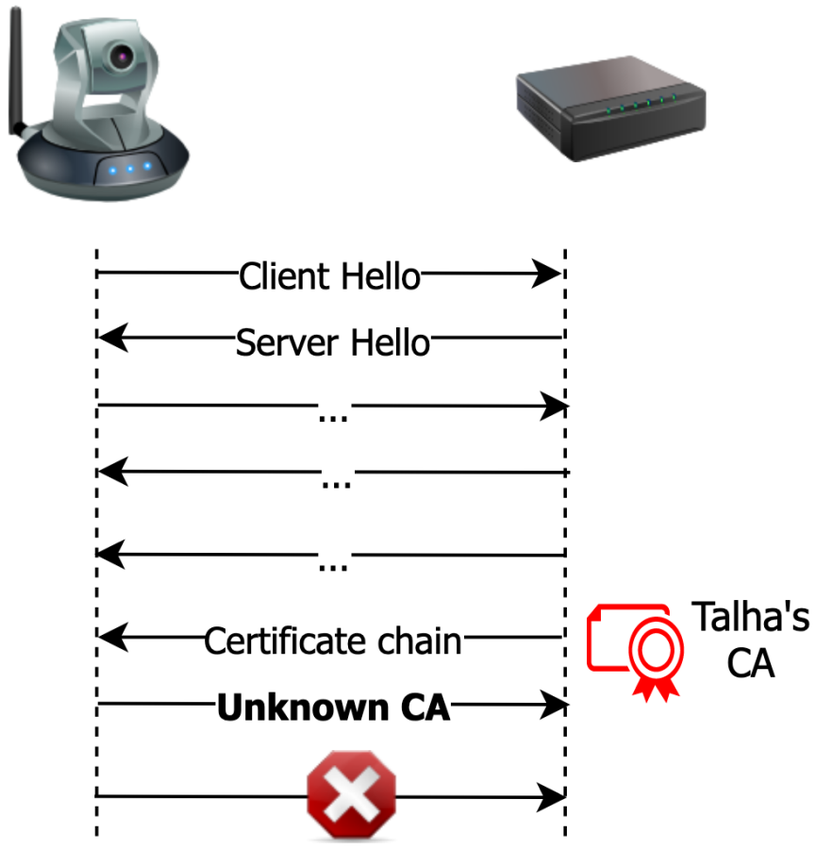

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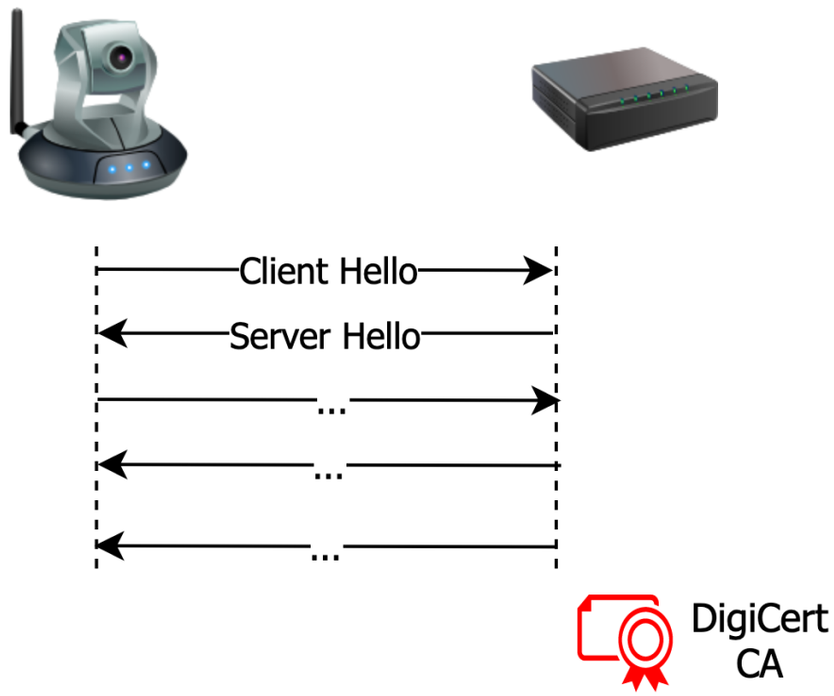

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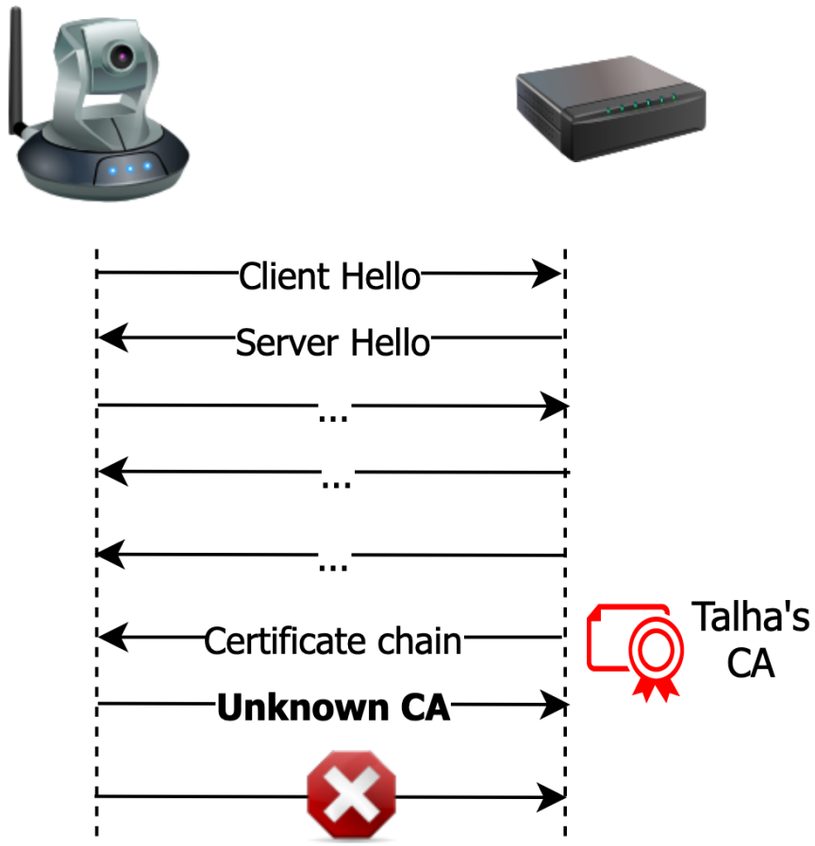

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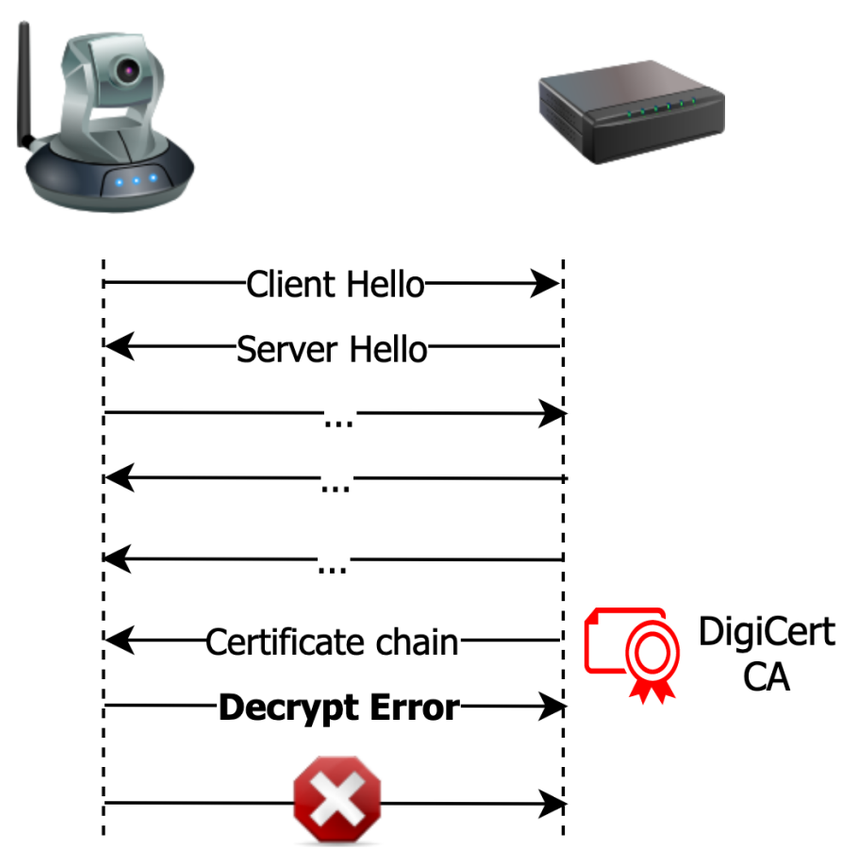

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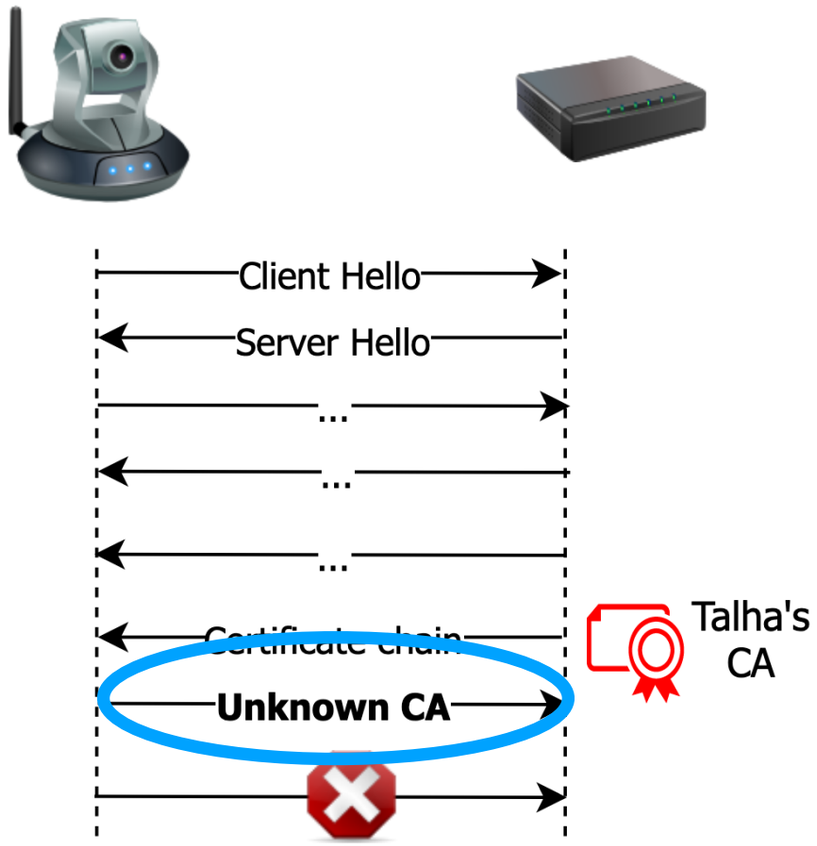

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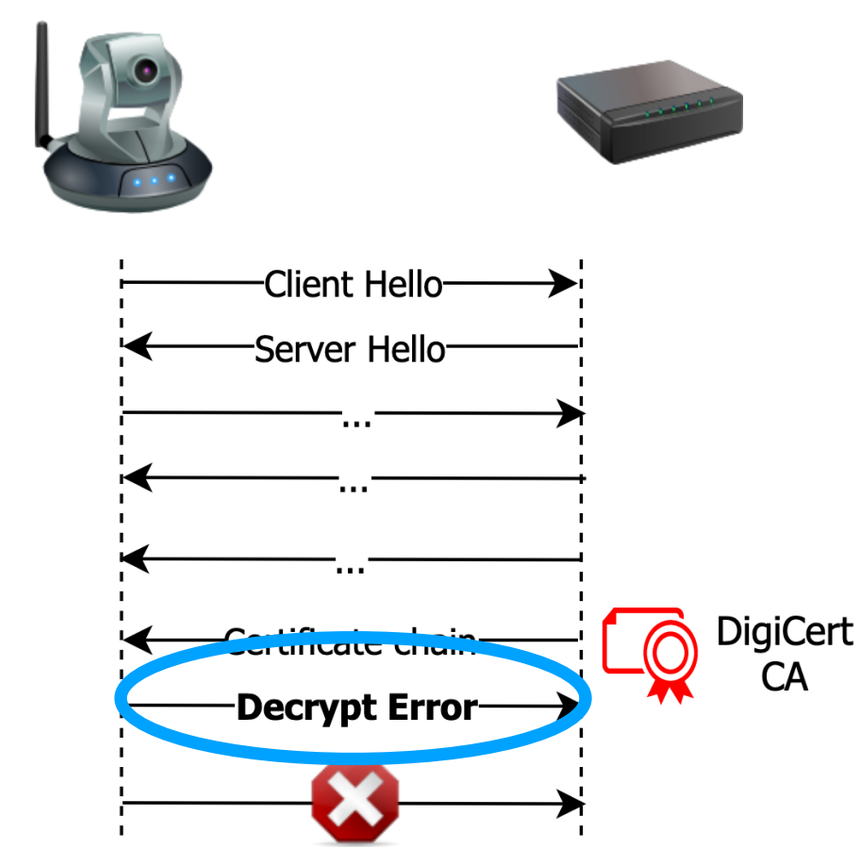

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- Extracted historical root stores from 4 major root stores (Ubuntu, Android, Mozilla, and Microsoft)
- Generated two sets of CA certificates:
  - *Commonly-trusted certificates* — certs available in latest versions of all platforms
  - *Deprecated certificates* — certs that were removed from one or more stores over time

Do IoT devices use *commonly-trusted* root certificates?

Device	Commonly-trusted certs (total = 122)
Google Home Mini	
Amazon Echo Plus	
Amazon Echo Dot	
Amazon Echo Dot 3	
Wink Hub 2	
Roku TV	
LG TV	
Harman Invoke	

Do IoT devices use *commonly-trusted* root certificates?

Device	Commonly-trusted certs (total = 122)
Google Home Mini	100%
Amazon Echo Plus	98%
Amazon Echo Dot	98%
Amazon Echo Dot 3	90%
Wink Hub 2	92%
Roku TV	91%
LG TV	93%
Harman Invoke	82%

Do IoT devices use *deprecated* root certificates?

Device	Deprecated certs (total = 87)
Google Home Mini	
Amazon Echo Plus	
Amazon Echo Dot	
Amazon Echo Dot 3	
Wink Hub 2	
Roku TV	
LG TV	
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Do IoT devices use *deprecated* root certificates?

Device	Deprecated certs (total = 87)
Google Home Mini	6%
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- All devices trust some *deprecated* root certificates
- Devices likely do not update their root stores
- All 8 devices trust at least one CA certificate that is **explicitly distrusted** by Firefox or Chrome (e.g, *TurkTrust, WoSign*)

Conclusion!

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- Mix of good and bad news about TLS usage in IoT devices

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ABSTRACT

Consumer IoT devices are becoming increasingly popular, with most leveraging TLS to provide connection security. In this work, we study a large number of TLS-enabled consumer IoT devices to shed light on how effectively they use TLS, in terms of establishing secure connections and correctly validating certificates, and how observed behavior changes over time. To this end, we gather more than two years of TLS network traffic from IoT devices, conduct active probing to test for vulnerabilities, and develop a novel black-box technique for exploring the trusted root stores in IoT devices by exploiting a side-channel through TLS *Alert Messages*. We find a wide range of behaviors across devices, with some adopting best security practices but most being vulnerable in one or more of the following ways: use of old/insecure protocol versions and/or ciphersuites, lack of certificate validation, and poor maintenance of root stores. Specifically, we find that *at least* 8 IoT devices still include distrusted certificates in their root stores, 11/32 devices are vulnerable to TLS interception attacks, and that many devices fail to adopt modern protocol features over time. Our findings motivate the need for IoT manufacturers to audit, upgrade, and maintain their devices' TLS implementations in a consistent and uniform way that safeguards all of their network traffic.

CCS CONCEPTS

• **Security and privacy** → **Network security**; **Embedded systems security**; • **Networks** → *Network measurement*; **Network security**;

1 INTRODUCTION

Consumer Internet-of-Things (IoT) devices such as voice assistants, smart TVs and video doorbells are popular, with their prevalence projected to be 75 billion by 2025 [14]. Most IoT devices rely on TLS, the de facto secure transport protocol, to provide confidentiality, integrity and authenticity of their network communications [26]. Numerous prior works have shown that TLS security properties can be compromised due to development errors (e.g., [31]), insecure configurations (e.g., [39]), and outdated clients (e.g., [20]). While TLS usage has been studied extensively in mobile applications and web browsers (e.g., [47], [49], [37]), there is little insight into its effectiveness in the IoT ecosystem (e.g., [26]).

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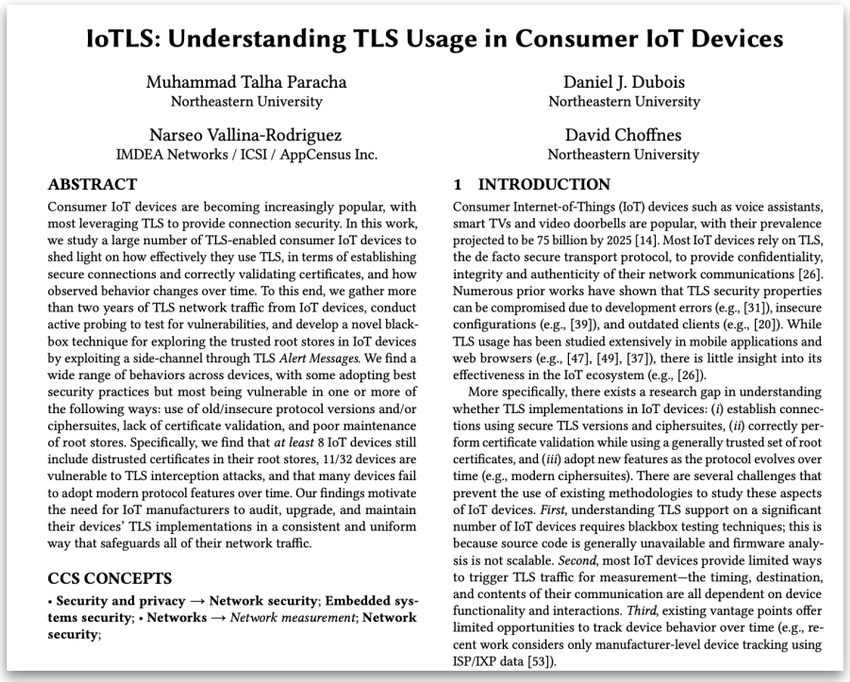
Conclusion!

- Mix of good and bad news about TLS usage in IoT devices
- Longitudinal TLS handshake data + controlled experimentation data + analysis software **publicly available**



IoTLS: Understanding TLS Usage in Consumer IoT Devices

Muhammad Talha Paracha
Northeastern University

Daniel J. Dubois
Northeastern University

Narseo Vallina-Rodriguez
IMDEA Networks / ICSI / AppCensus Inc.

David Choffnes
Northeastern University

ABSTRACT

Consumer IoT devices are becoming increasingly popular, with most leveraging TLS to provide connection security. In this work, we study a large number of TLS-enabled consumer IoT devices to shed light on how effectively they use TLS, in terms of establishing secure connections and correctly validating certificates, and how observed behavior changes over time. To this end, we gather more than two years of TLS network traffic from IoT devices, conduct active probing to test for vulnerabilities, and develop a novel black-box technique for exploring the trusted root stores in IoT devices by exploiting a side-channel through TLS *Alert Messages*. We find a wide range of behaviors across devices, with some adopting best security practices but most being vulnerable in one or more of the following ways: use of old/insecure protocol versions and/or ciphersuites, lack of certificate validation, and poor maintenance of root stores. Specifically, we find that *at least* 8 IoT devices still include distrusted certificates in their root stores, 11/32 devices are vulnerable to TLS interception attacks, and that many devices fail to adopt modern protocol features over time. Our findings motivate the need for IoT manufacturers to audit, upgrade, and maintain their devices' TLS implementations in a consistent and uniform way that safeguards all of their network traffic.

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• **Security and privacy** → **Network security**; **Embedded systems security**; • **Networks** → *Network measurement*; **Network security**;

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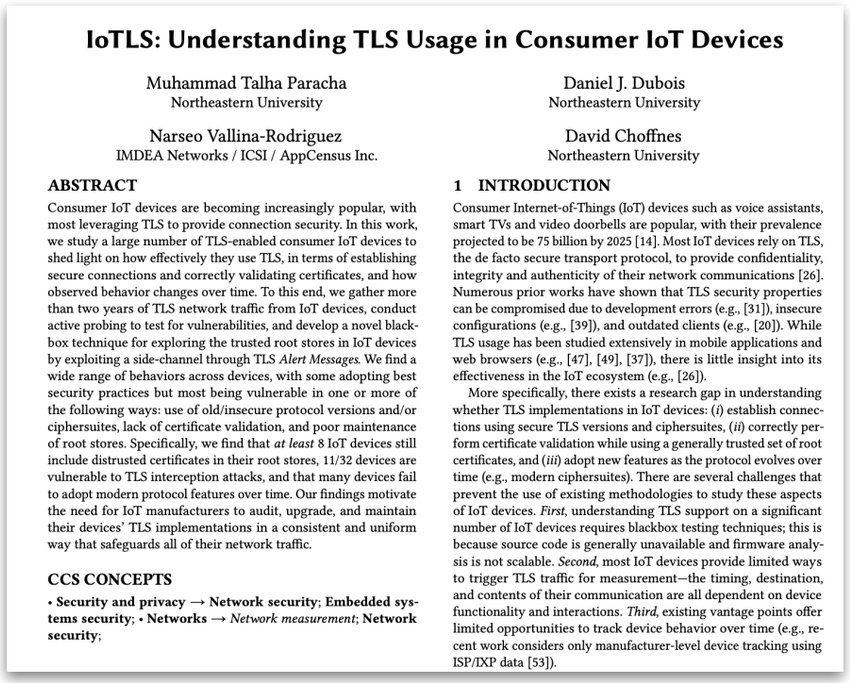

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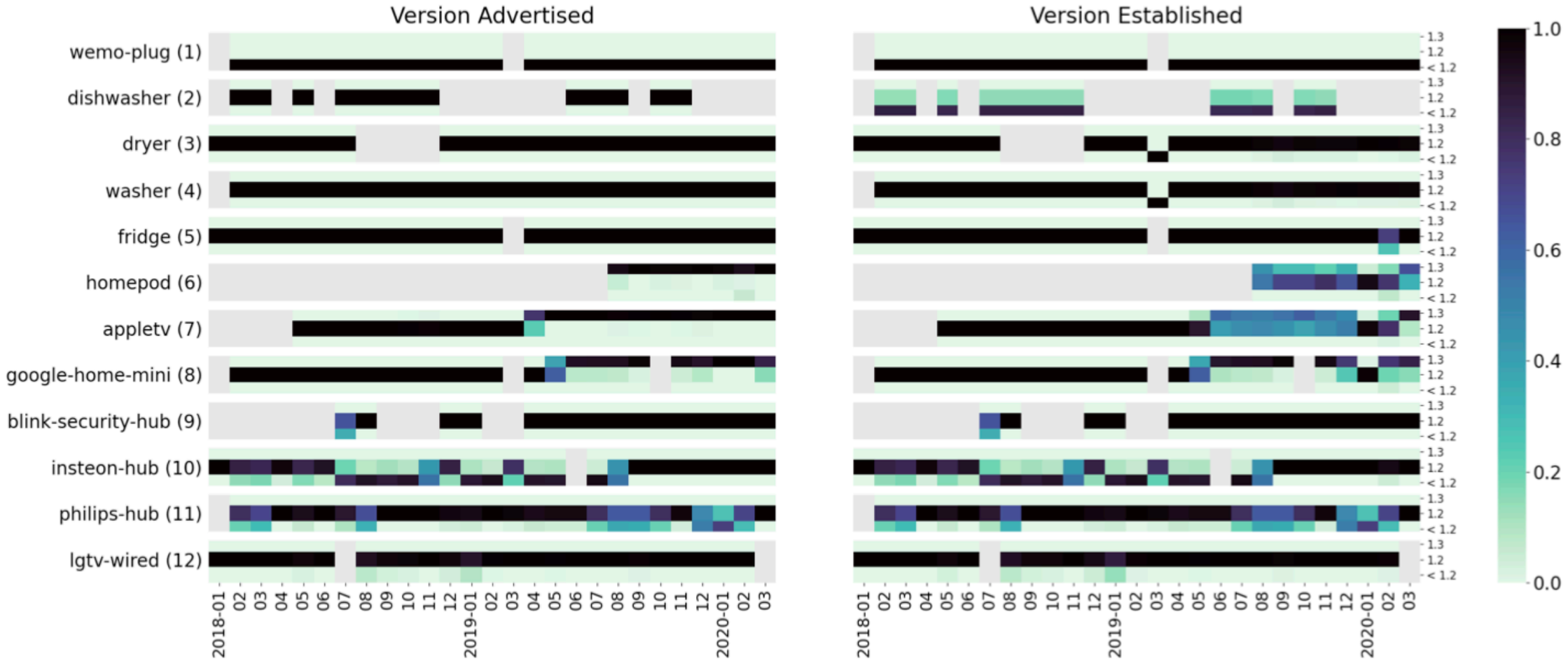
END

Mon(IoT)r Lab at Northeastern University

Table 1: List of the 40 TLS-supporting devices in our study. (*) denotes devices used only in *passive* experiments.

Cameras (n = 7)	Smart Hubs (n = 7)	Home Automation (n = 7)	TV (n = 5)	Audio (n = 7)	Appliances (n = 7)
Blink Camera*	Blink Hub	Smartlife Bulb	Fire TV	Google Home Mini	GE Microwave
Amazon Cloudcam*	Smartthings Hub	Smartlife Remote	Samsung TV*	Amazon Echo Plus	Samsung Washer*
Zmodo Doorbell	Philips Hub	Meross Dooropener	LG TV	Amazon Echo Dot	Samsung Dryer
Yi Camera	Wink Hub 2	TP-Link Bulb	Roku TV	Amazon Echo Dot 3	Samsung Fridge
D-Link Camera	Sengled Hub*	Nest Thermostat	Apple TV	Amazon Echo Spot	Smarter iKettle
Amcrest Camera	Switchbot Hub	TP-Link Plug		Harman Invoke	Behmor Brewer
Ring Doorbell*	Insteon Hub*	Wemo Plug		Apple HomePod	LG Dishwasher*

RQ1: TLS Connection Security (Passive)



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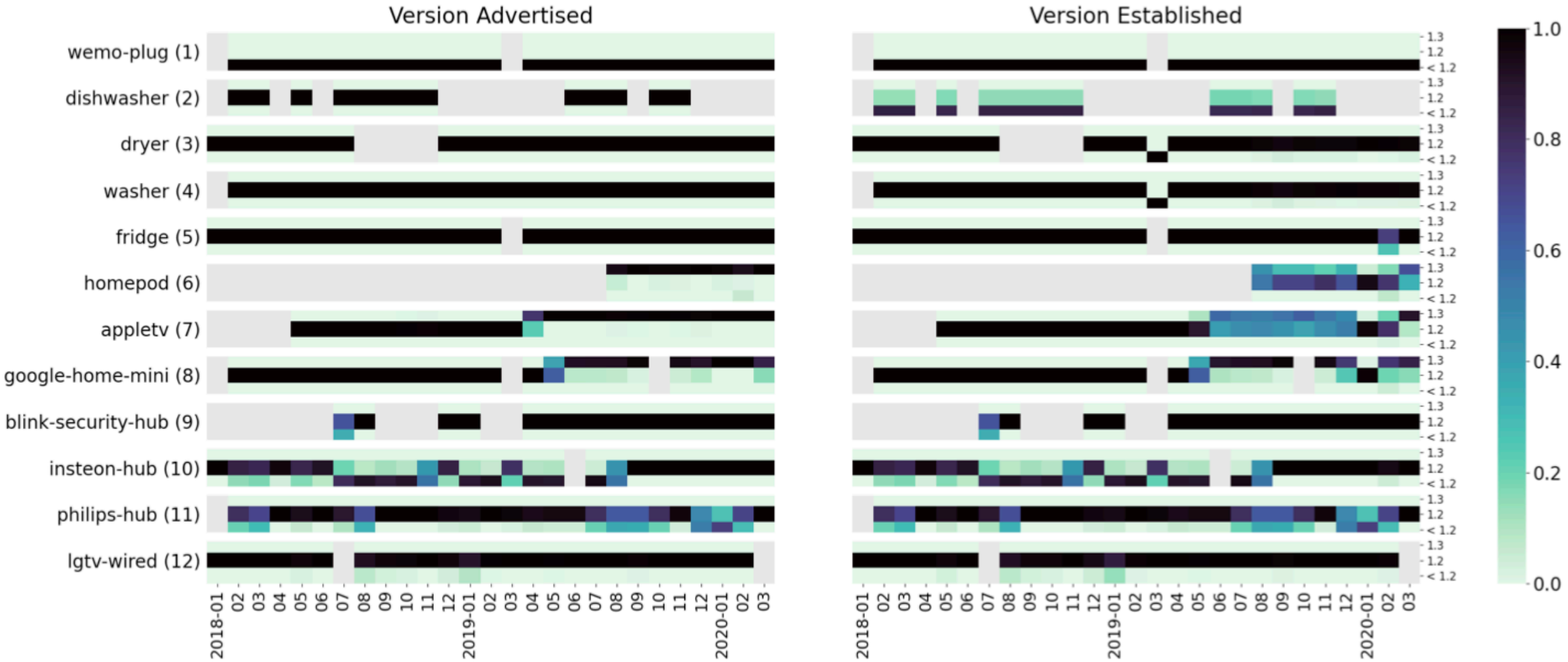

TLS version supported in IoT devices.

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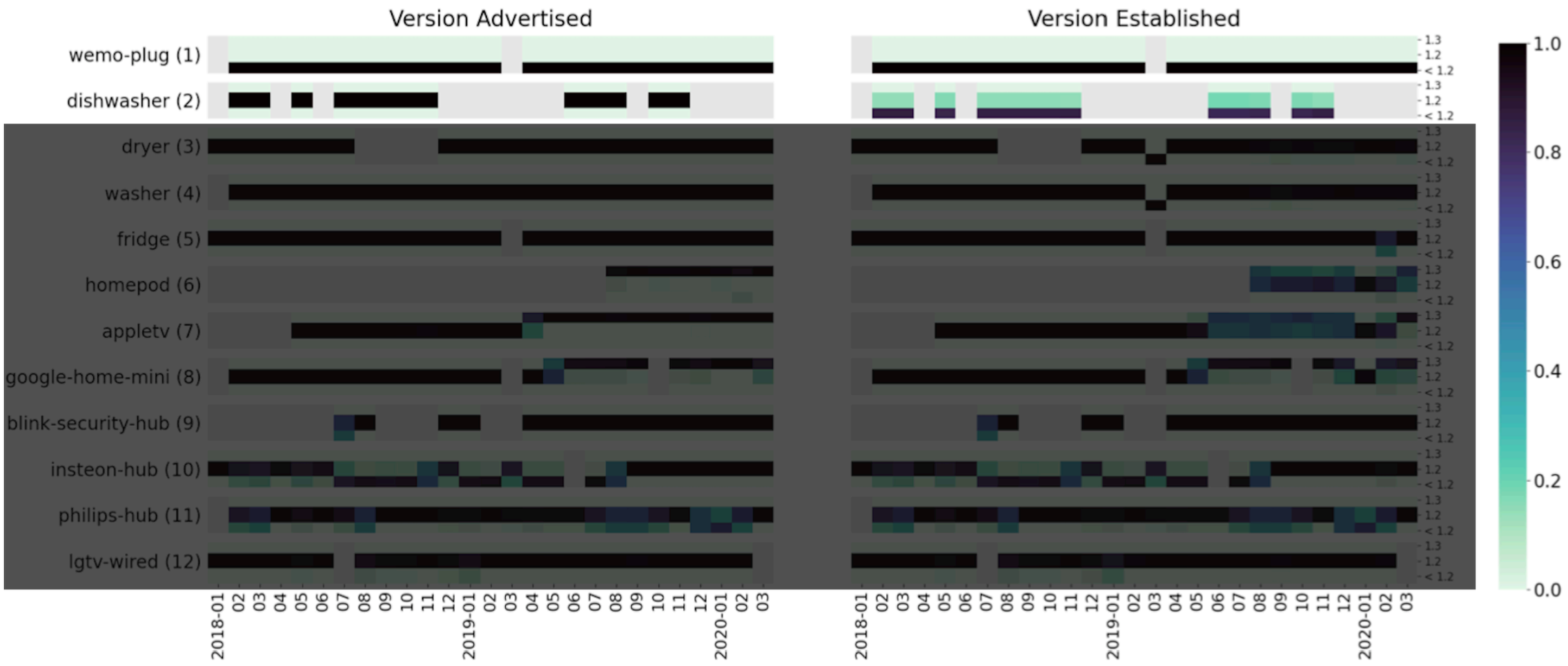

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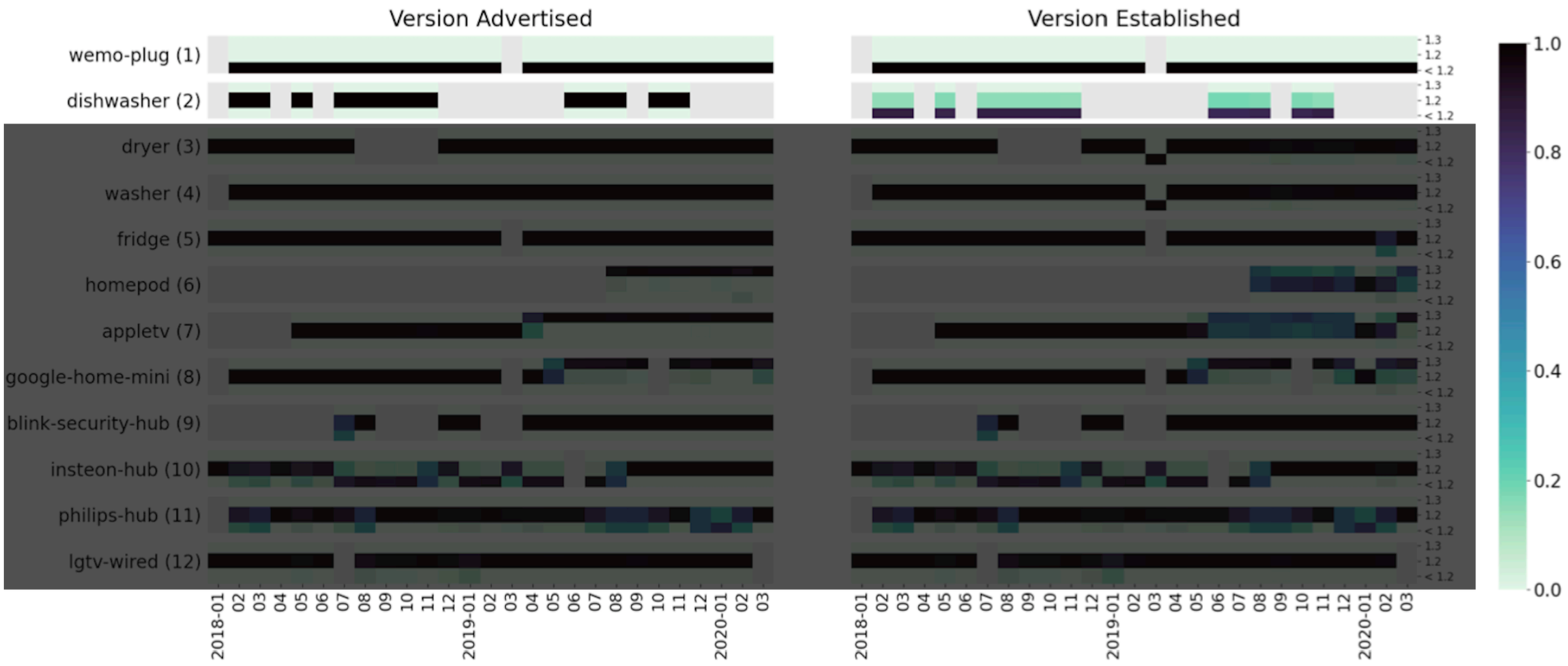

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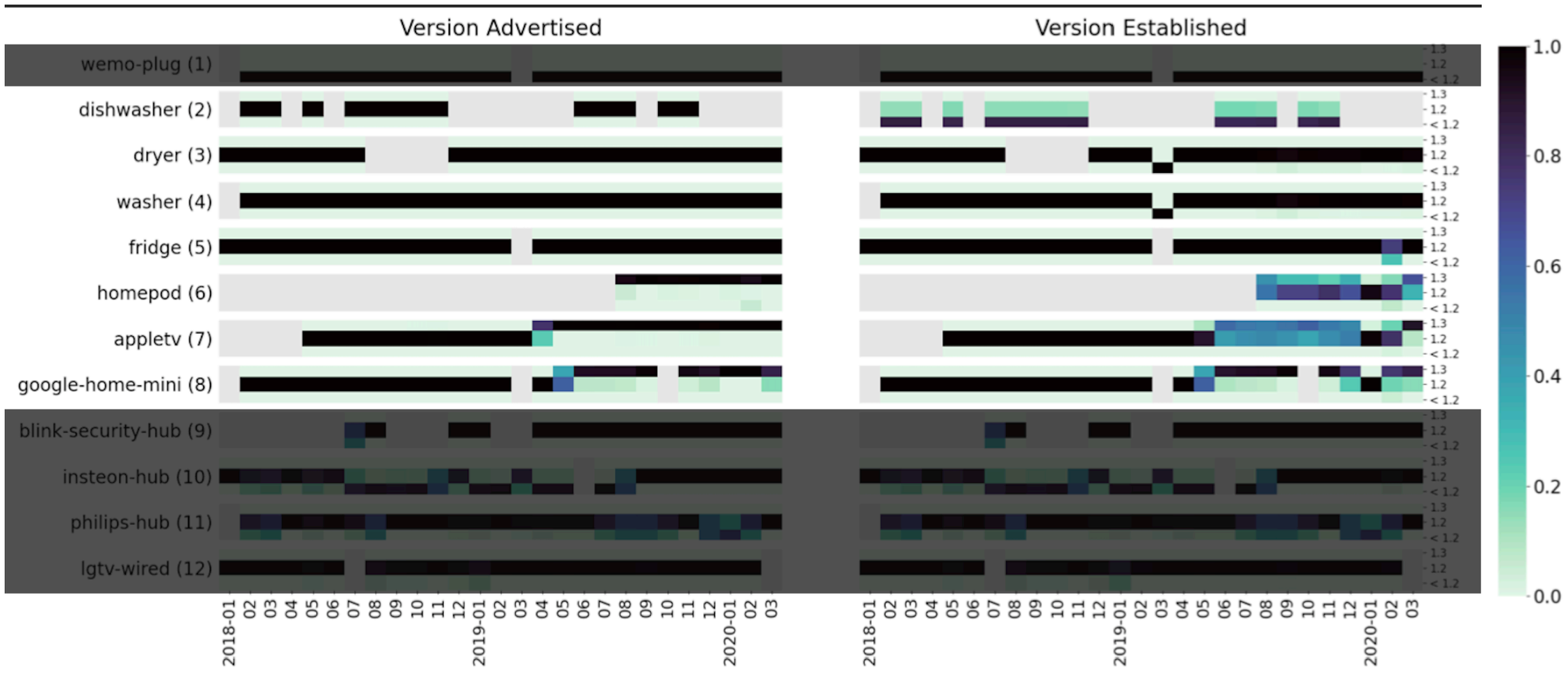

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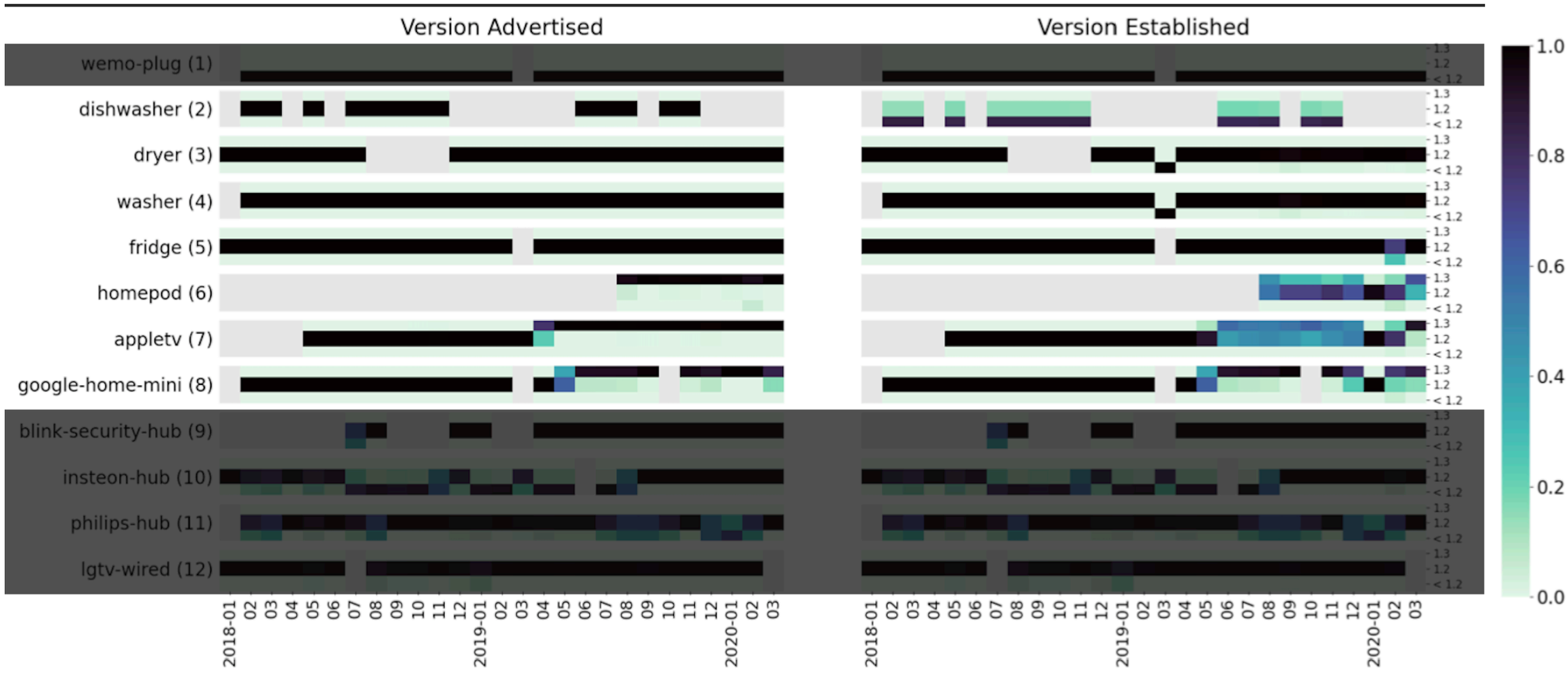

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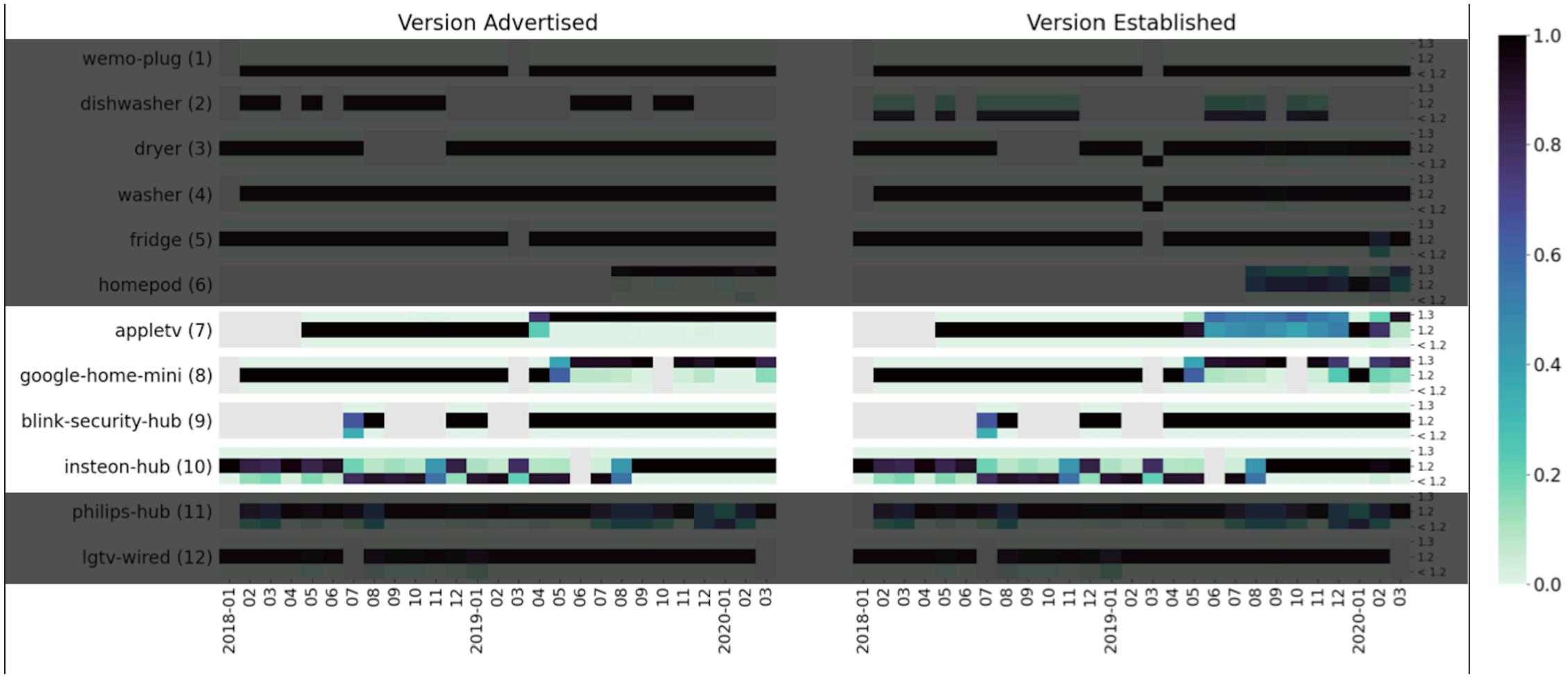

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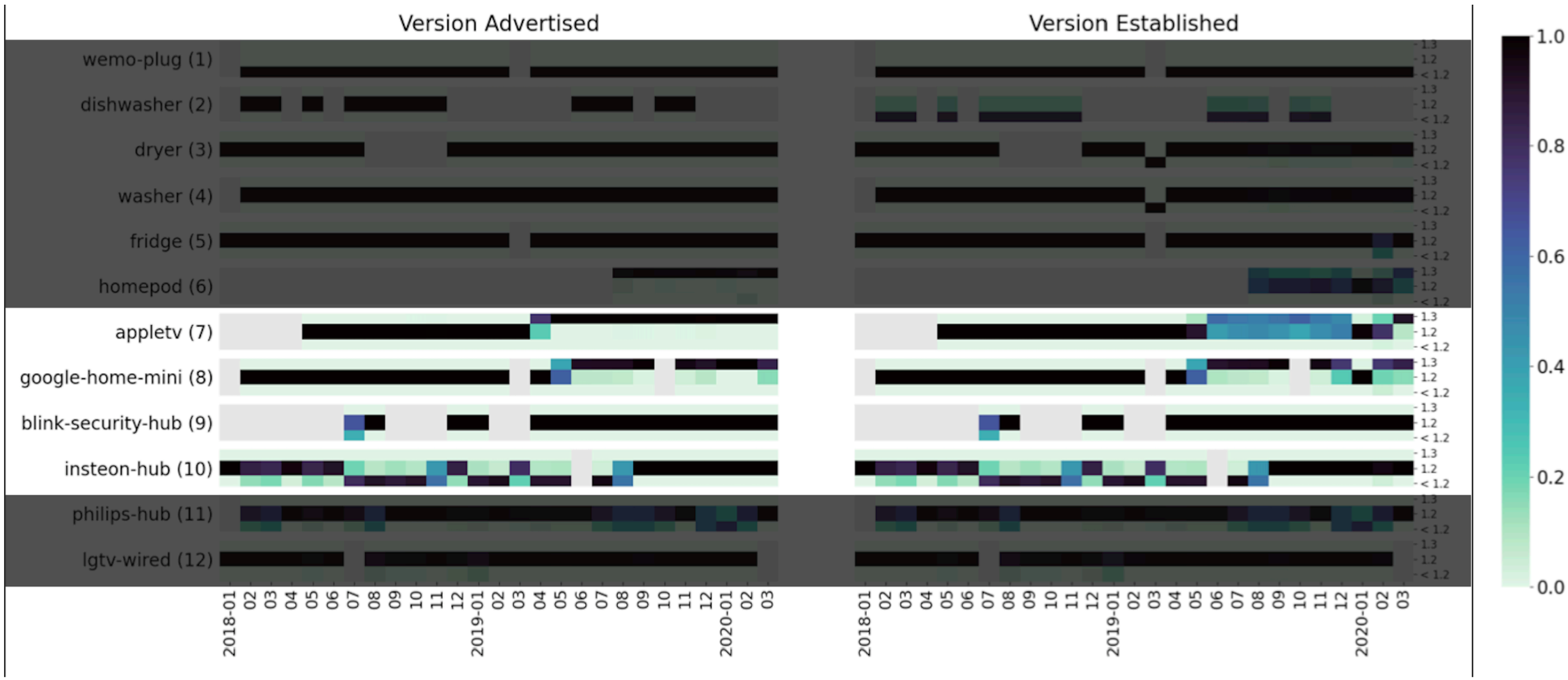

TLS version supported in IoT devices.

RQ1: TLS Connection Security (Active)

Device	TLS 1.0 Available?	TLS 1.1 Available?
Zmodo Doorbell	✓	✓
Wink Hub 2	✓	✓
Yi Camera	✓	✓
Philips Hub	✓	✓
Smarter Brewer	✓	✓
TP-Link Bulb	✓	✓
Roku TV	✓	✓
Meross Dooropener	✓	✓
LG TV	✓	✓
Google Home Mini	✓	✓
Amazon Fire TV	✓	✓
Amazon Echo Spot	✓	✓
Amazon Echo Plus	✓	✓
Amazon Echo Dot	✓	✓
Amcrest Camera	✓	✓
Samsung Fridge	✗	✓
Samsung Dryer	✗	✓
Wemo Plug	✓	✗

Device	Failed Handshake	Incomplete Handshake	Behavior	Downgraded / Total Destinations
Amazon Echo Dot	✗	✓	Falls back to using SSL 3.0	7 / 9
Amazon Echo Plus	✗	✓	Falls back to using SSL 3.0	6 / 7
Amazon Echo Spot	✗	✓	Falls back to using SSL 3.0	11 / 15
Amazon Fire TV	✗	✓	Falls back to using SSL 3.0	13 / 21
Apple Homepod	✗	✓	Falls back to using TLS 1.0	7 / 9
Google Home Mini	✗	✓	Falls back to supporting a weaker ciphersuite and signature algorithm (TLS_RSA_WITH_3DES_EDE_CBC_SHA and RSA_PKCS1_SHA1)	5 / 5
Roku TV	✓	✓	Falls back from offering 73 ciphersuites to just 1 (TLS_RSA_WITH_RC4_128_SHA)	8 / 15

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LG TV	✓	✓
Google Home Mini	✓	✓
Amazon Fire TV	✓	✓
Amazon Echo Spot	✓	✓
Amazon Echo Plus	✓	✓
Amazon Echo Dot	✓	✓
Amcrest Camera	✓	✓
Samsung Fridge	✗	✓
Samsung Dryer	✗	✓
Wemo Plug	✓	✗

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7 IoT devices that downgrade security upon connection failures.

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Amazon Echo Spot	✓	✓
Amazon Echo Plus	✓	✓
Amazon Echo Dot	✓	✓
Amcrest Camera	✓	✓
Samsung Fridge	✗	✓
Samsung Dryer	✗	✓
Wemo Plug	✓	✗

18 IoT devices that support older TLS versions.

Device	Failed Handshake	Incomplete Handshake	Behavior	Downgraded / Total Destinations
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7 IoT devices that downgrade security upon connection failures.

RQ2: TLS Certificate Validation

Device	No-Validation	InvalidBasic-Constraints	Wrong-Hostname	Vulnerable/Total Destinations
Zmodo Doorbell	✓	✓	✓	6 / 6
Amcrest Camera	✓	✓	✓	2 / 2
Smarter Brewer	✓	✓	✓	1 / 1
Yi Camera	✓	✓	✓	1 / 1
Wink Hub 2	✓	✓	✓	1 / 2
LG TV	✓	✓	✓	1 / 2
Smartthings Hub	✓	✓	✓	1 / 3
Amazon Echo Plus	✗	✗	✓	1 / 8
Amazon Echo Dot	✗	✗	✓	1 / 9
Amazon Echo Spot	✗	✗	✓	1 / 17
Amazon Fire TV	✗	✗	✓	1 / 21

RQ2: TLS Certificate Validation

- 11 devices are vulnerable to TLS interception attacks.

Device	No-Validation	InvalidBasic-Constraints	Wrong-Hostname	Vulnerable/Total Destinations
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Smarter Brewer	✓	✓	✓	1 / 1
Yi Camera	✓	✓	✓	1 / 1
Wink Hub 2	✓	✓	✓	1 / 2
LG TV	✓	✓	✓	1 / 2
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Amazon Echo Dot	✗	✗	✓	1 / 9
Amazon Echo Spot	✗	✗	✓	1 / 17
Amazon Fire TV	✗	✗	✓	1 / 21

RQ2: TLS Certificate Validation

- 11 devices are vulnerable to TLS interception attacks.
- 7 vulnerable devices contained sensitive data that can be exposed to attackers.

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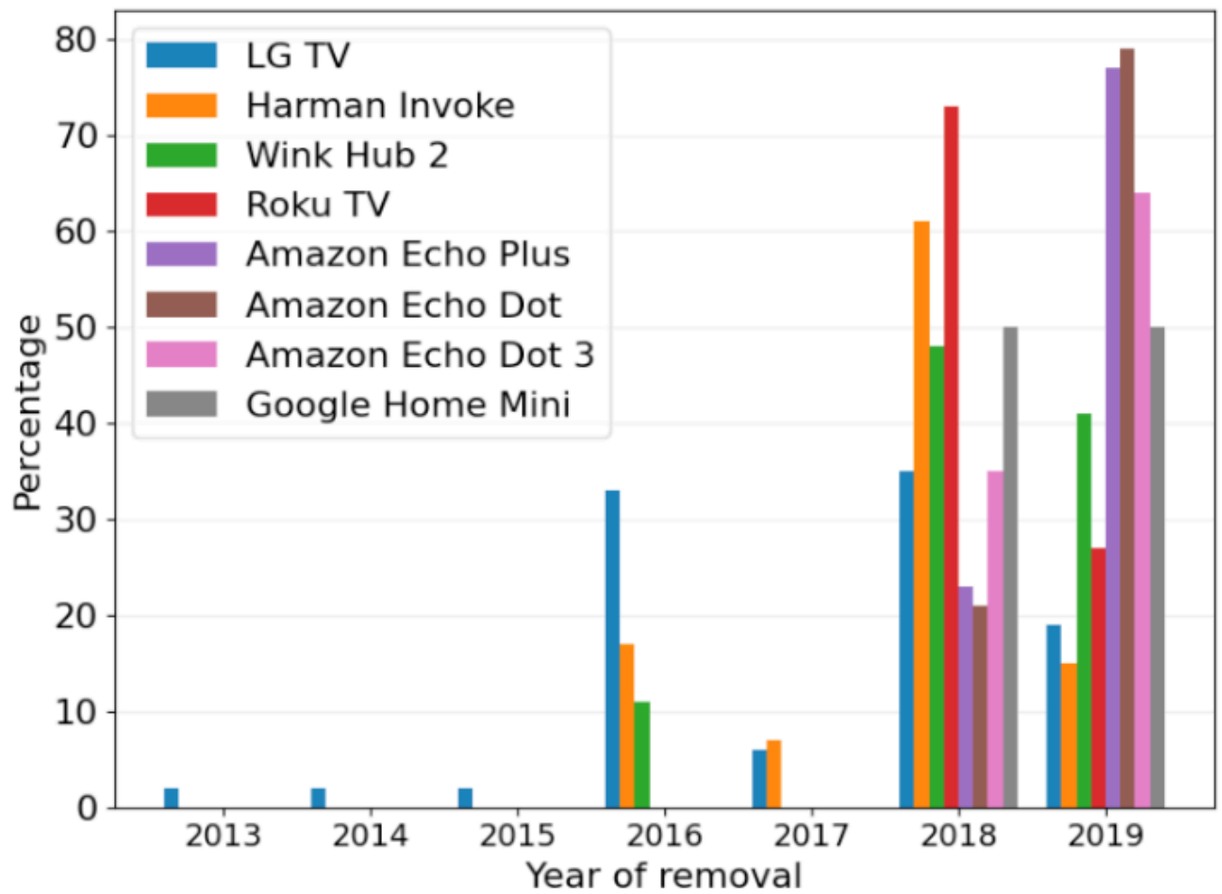
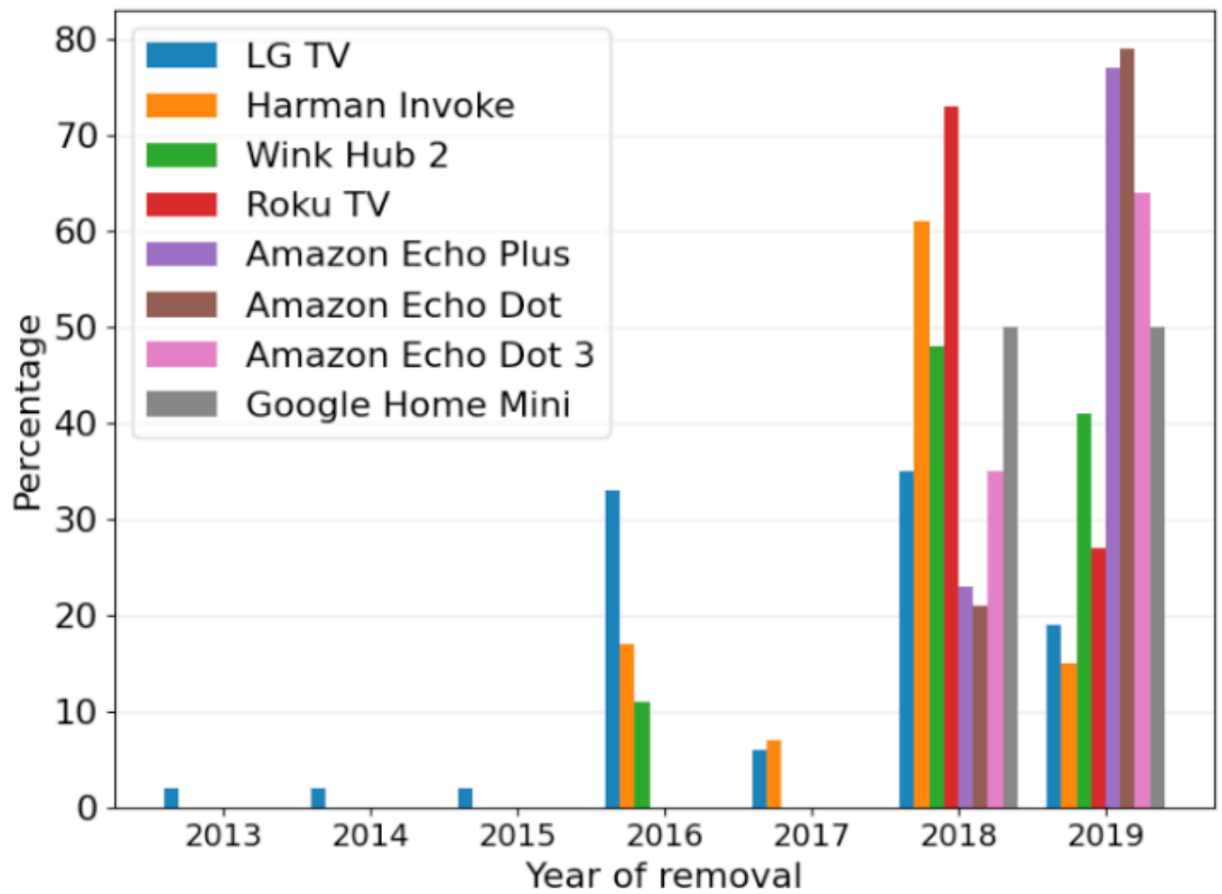


RQ2: TLS Certificate Validation

- All 8 devices trust at-least-one CA certificate that is ***explicitly distrusted*** by one of the major platforms (i.e., Chrome, Firefox, Ubuntu, Microsoft).



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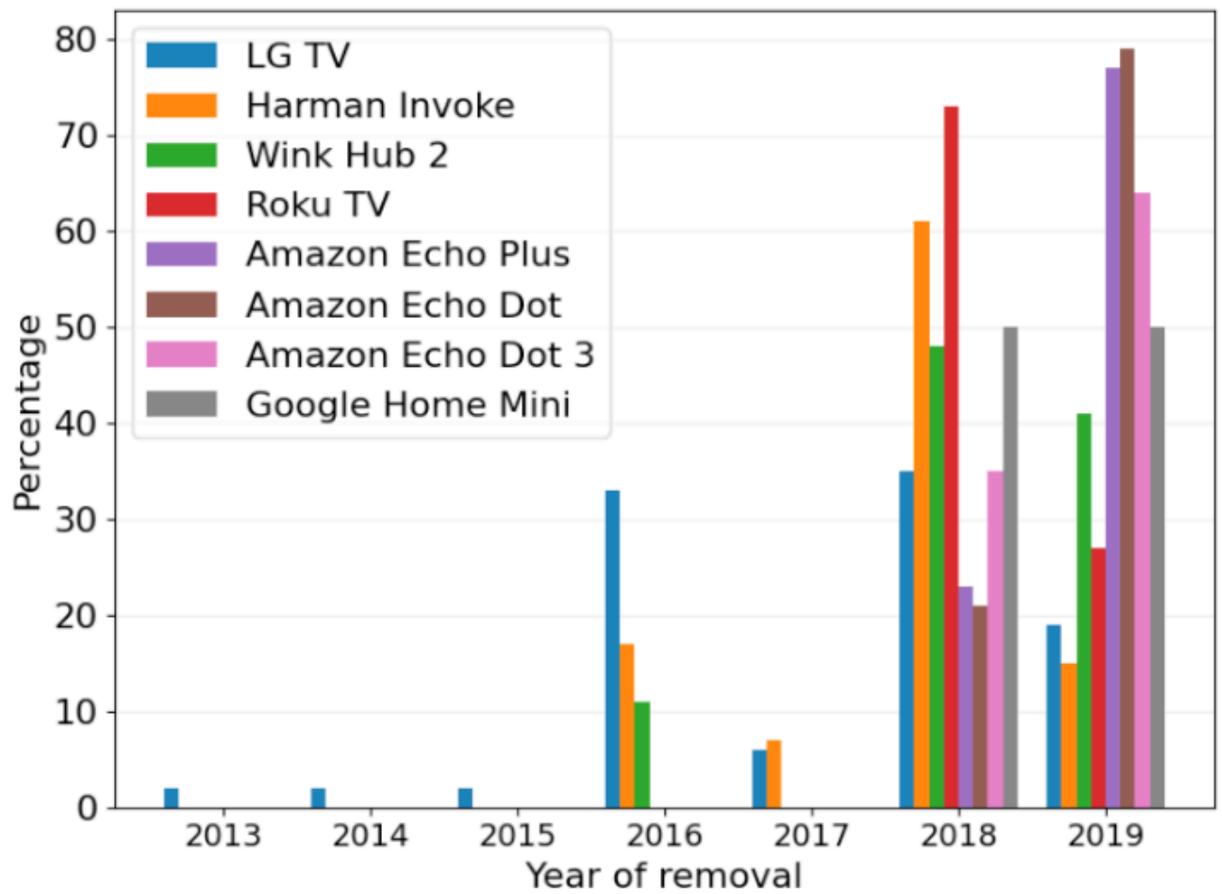
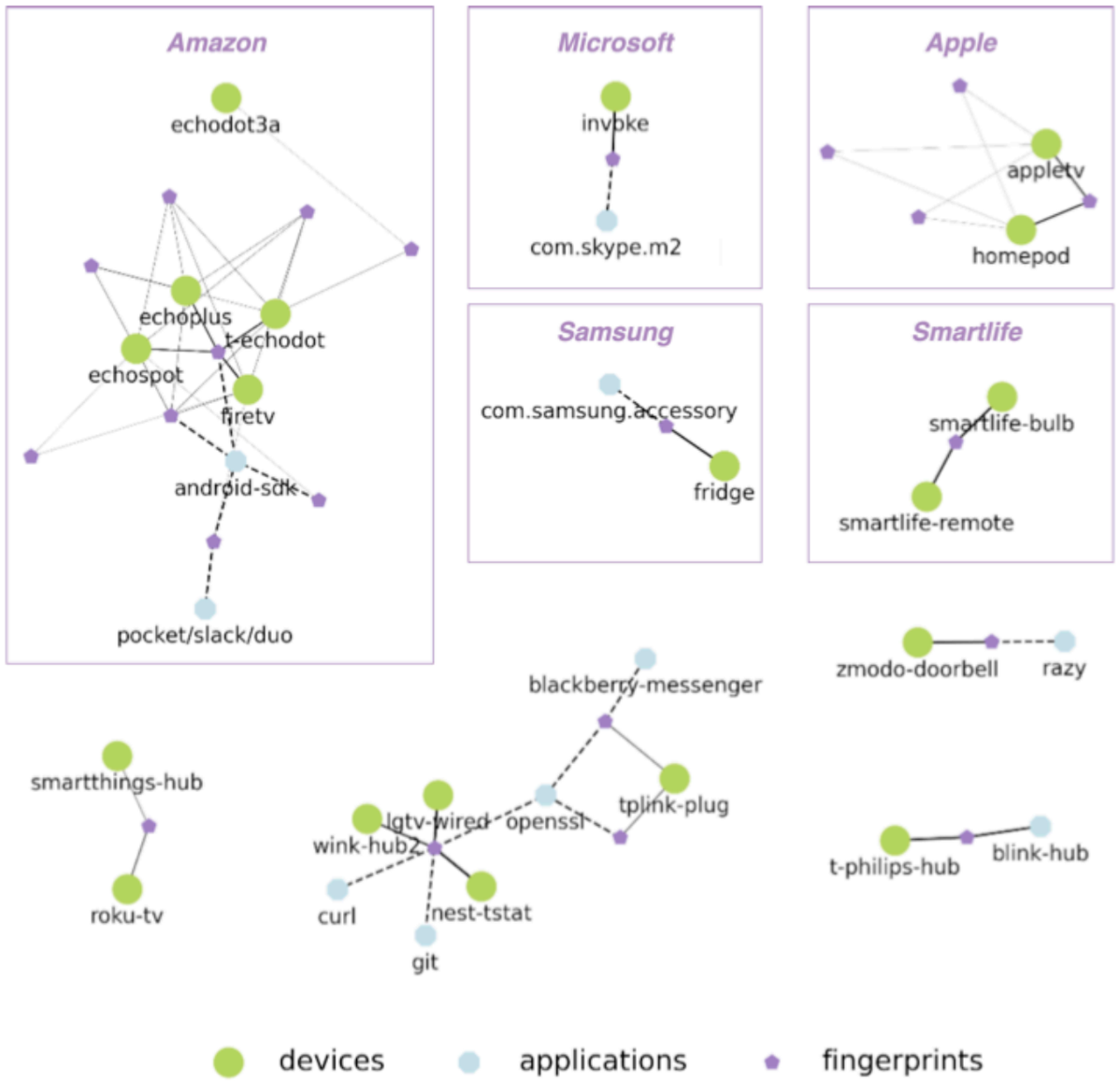
- Some devices trust CA certificates as old as 2013.



RQ3: Diversity of Behaviors



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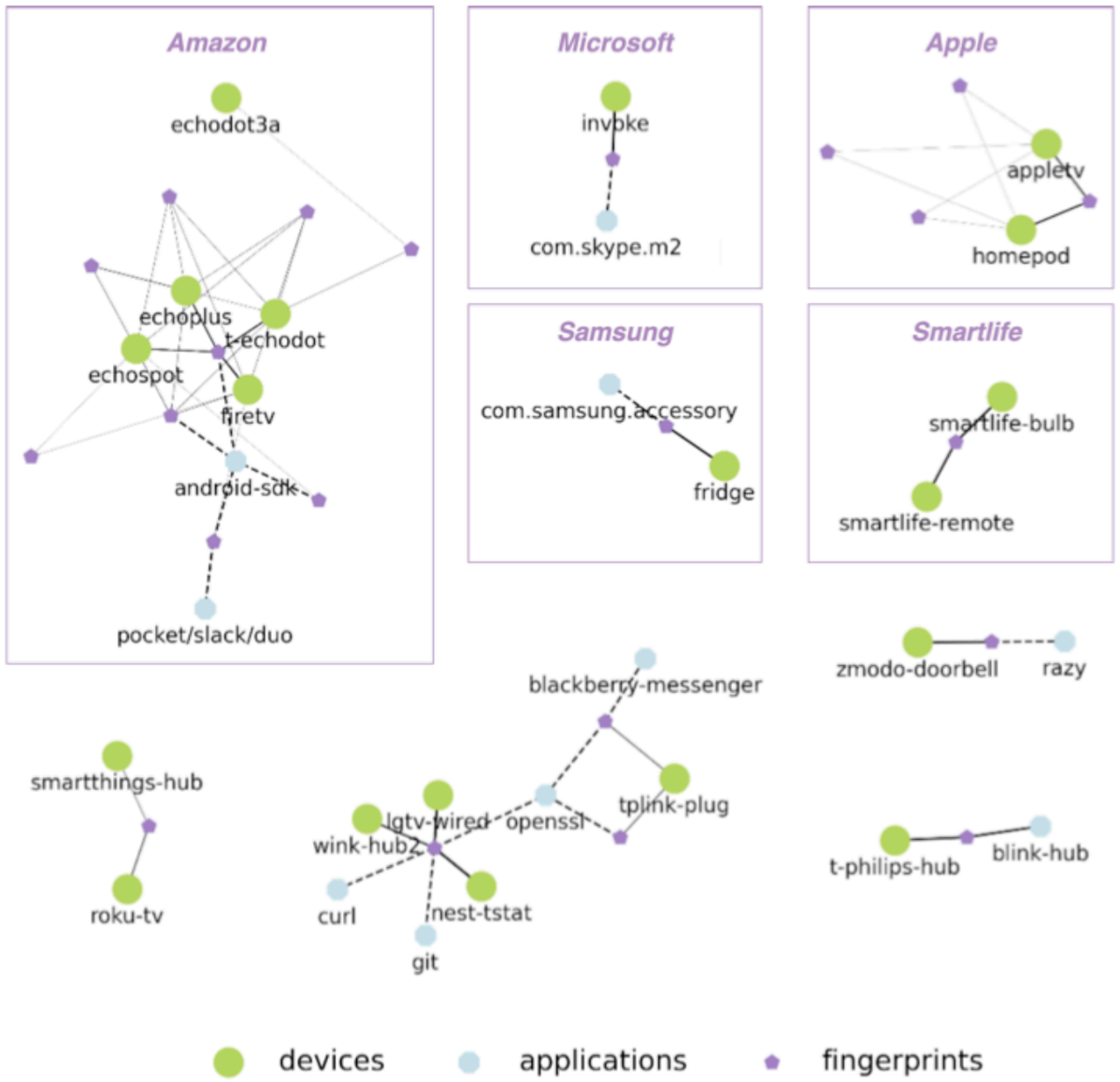

IoT devices that share TLS fingerprints with other devices and applications.

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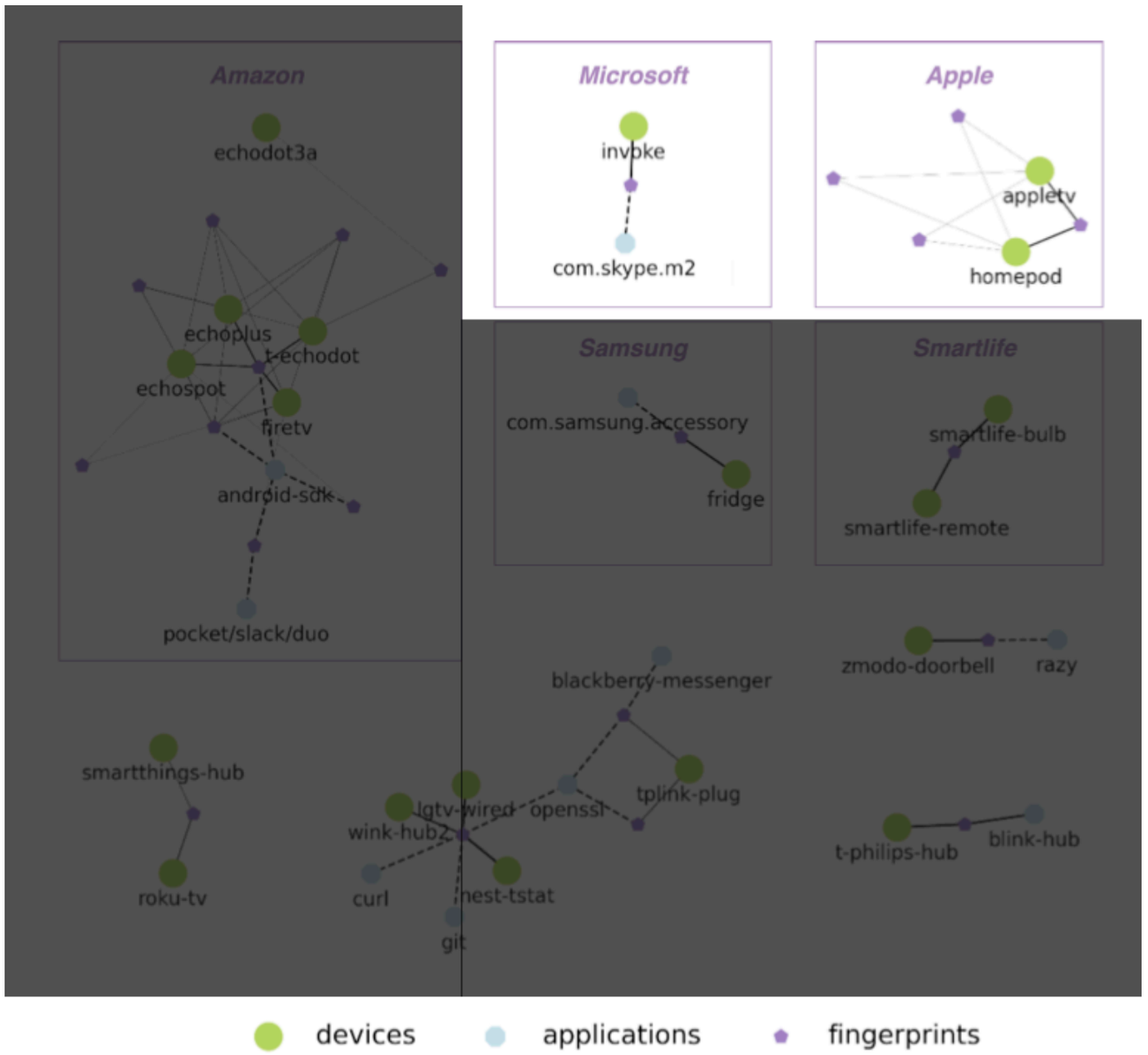

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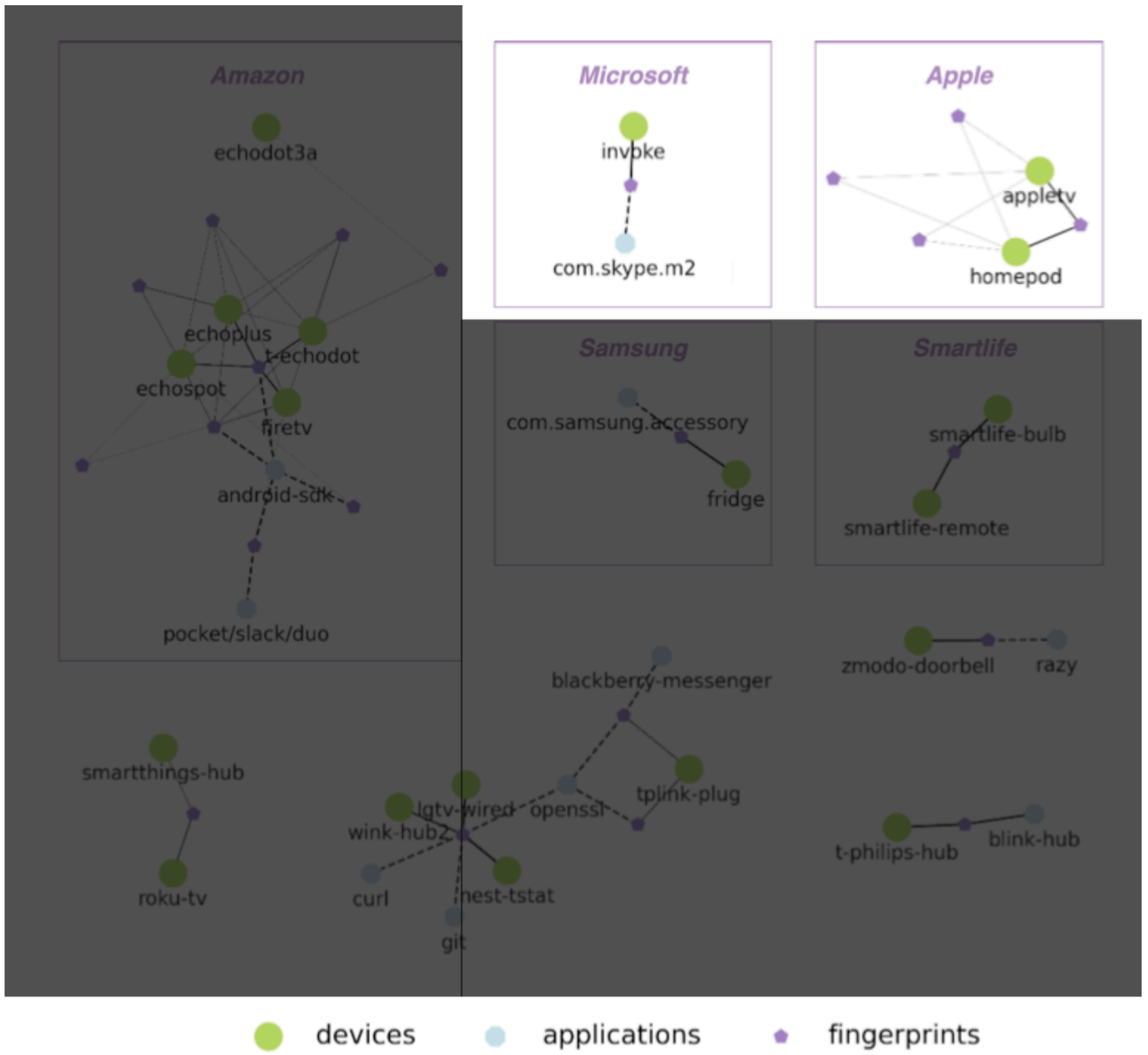

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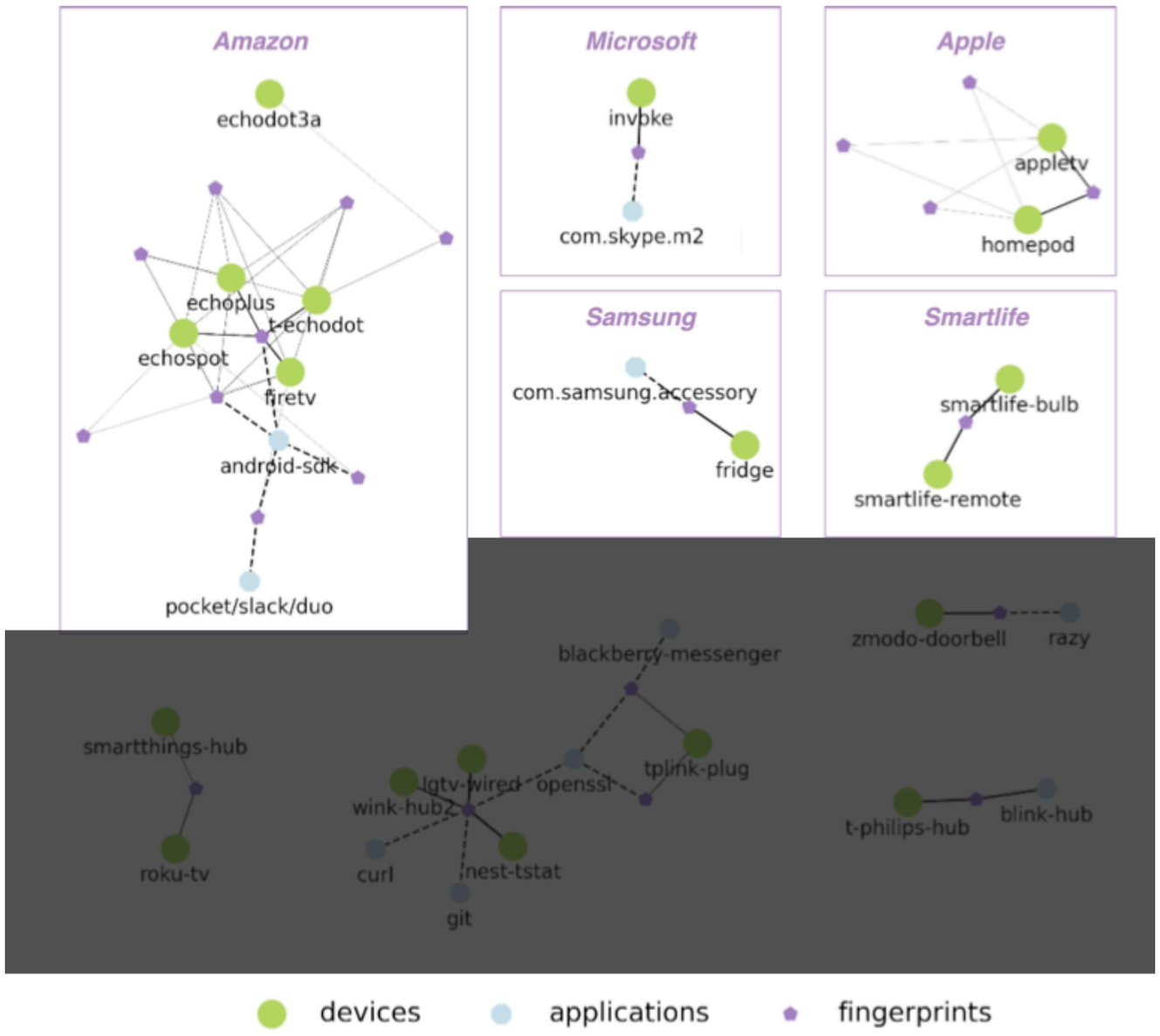

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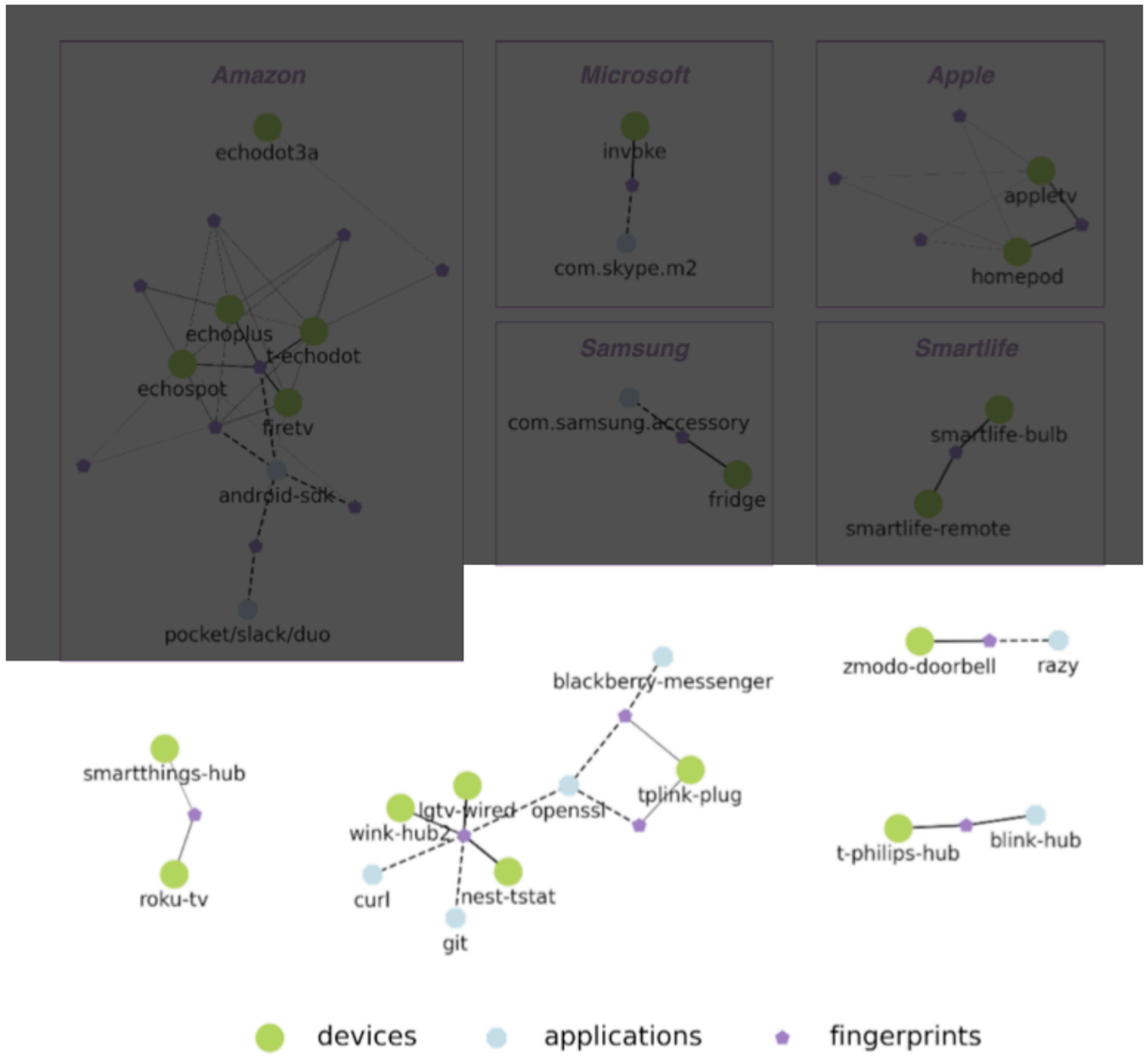

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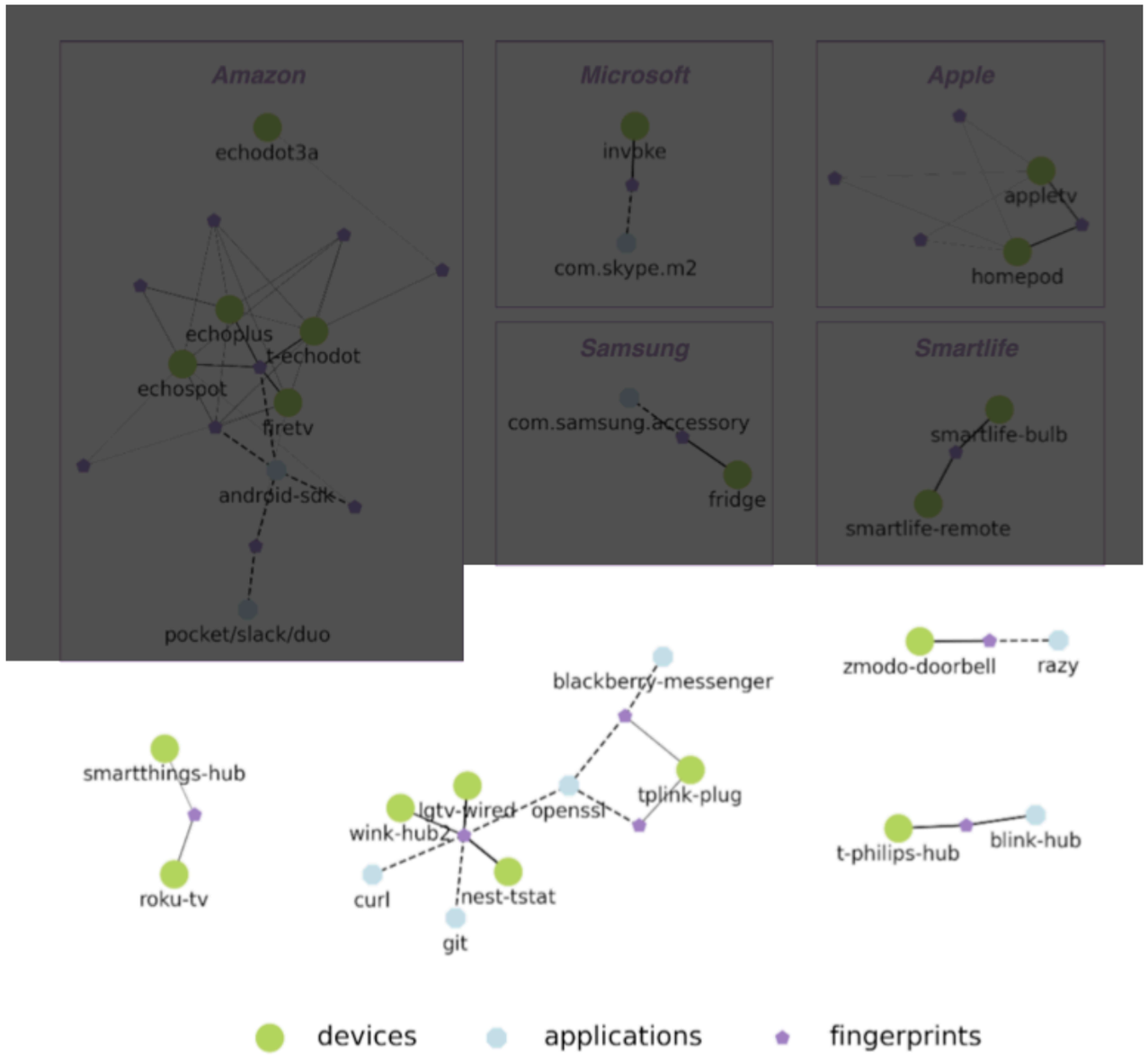

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