Lecture #4: IoT Botnet Measurements

Cristian Hesselman, Elmer Lastdrager, Ramin Yazdani, and Etienne Khan

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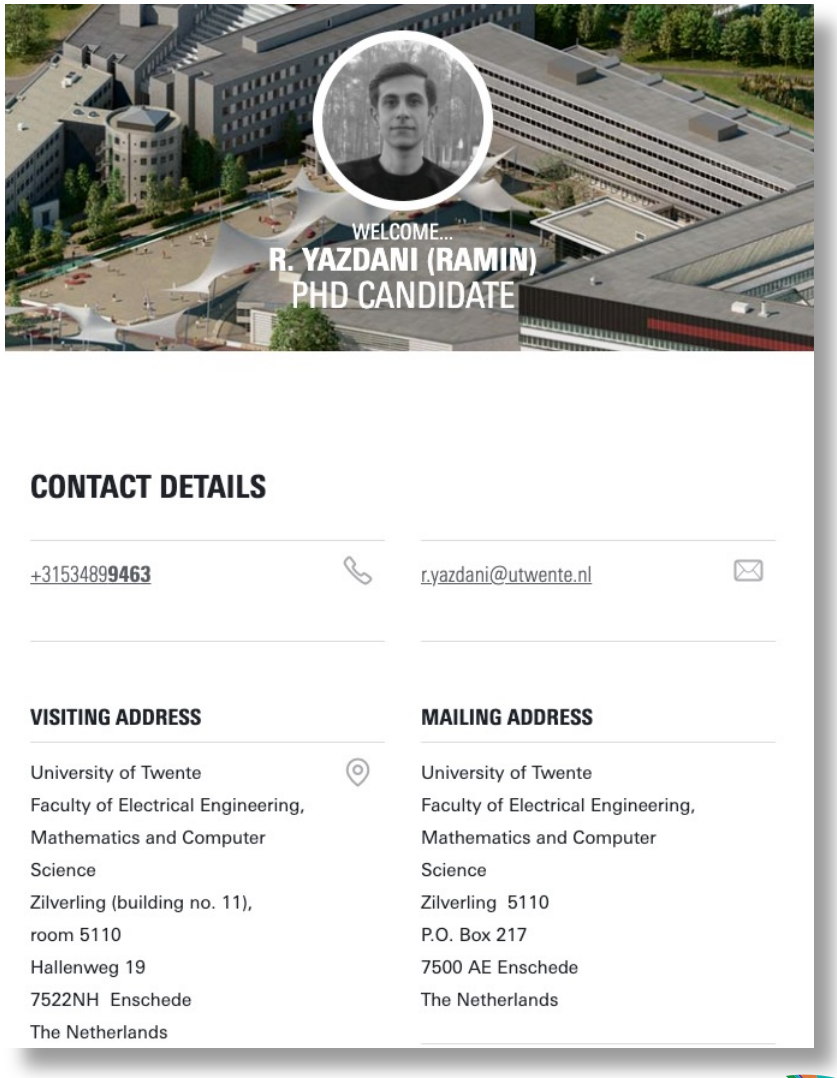
Devices for lab assignment

- Pick them up at Ramin's office
  - IoT device if you don't have any at home
  - Optional SPIN device

- Please contact Ramin beforehand!



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Interactive lectures

- Objective: enable you to learn from each other and further increase your understanding of the papers, contributes to preparing yourself for the oral exam

- Interactive format
  - Teachers summarize two papers per lecture
  - Multiple-choice questions (not graded) and discussion
  - We ask at least one of you to share their thoughts on each paper (pros, cons, surprises)
  - Enables you to learn from each other, so mandatory to participate

- A 7th “re-sit” lecture in case you miss a lecture (optional for everybody else), same format

Today's objective

- Discussing two botnets: after the lecture, you will be able to discuss how IoT botnets are organized and spread their infections.

- [Mirai] is the infamous botnet that alerted many of the risks of IoT devices.

- [Hajime] is a more advanced IoT botnet, compared to Mirai, when it comes to bot management and usage of exploits.

- Contributes to SSI learning goal #1: "Understand IoT concepts and applications, security threats, technical solutions, and a few relevant standardization efforts in the IETF"

Today's papers

Are about measuring IoT botnets

- [**Mirai**] M. Antonakakis, T. April, M. Bailey, M. Bernhard, E. Bursztein, J. Cochran, Z. Durumeric, J. A. Halderman, L. Invernizzi, M. Kallitsis, D. Kumar, C. Lever, Z. Ma, J. Mason, D. Menscher, C. Seaman, N. Sullivan, K. Thomas, and Y. Zhou, "Understanding the Mirai Botnet", in: 26th USENIX Security Symposium, 2017

- [**Hajime**] S. Herwig, K. Harvey, G. Hughey, R. Roberts, and D. Levin, "Measurement and Analysis of Hajime, a Peer-to-peer IoT Botnet", Network and Distributed Systems Security (NDSS) Symposium 2019, San Diego, CA, USA, February 2019

“Understanding the Mirai Botnet”
26th USENIX Security Symposium, 2017

Antonakakis, April, Bailey, Bernhard, Bursztein, Cochran, Durumeric, Halderman, Invernizzi, Kallitsis,Kumar, Lever, Ma, Mason, Menscher, Seaman, Sullivan, Thomas, and Zhou

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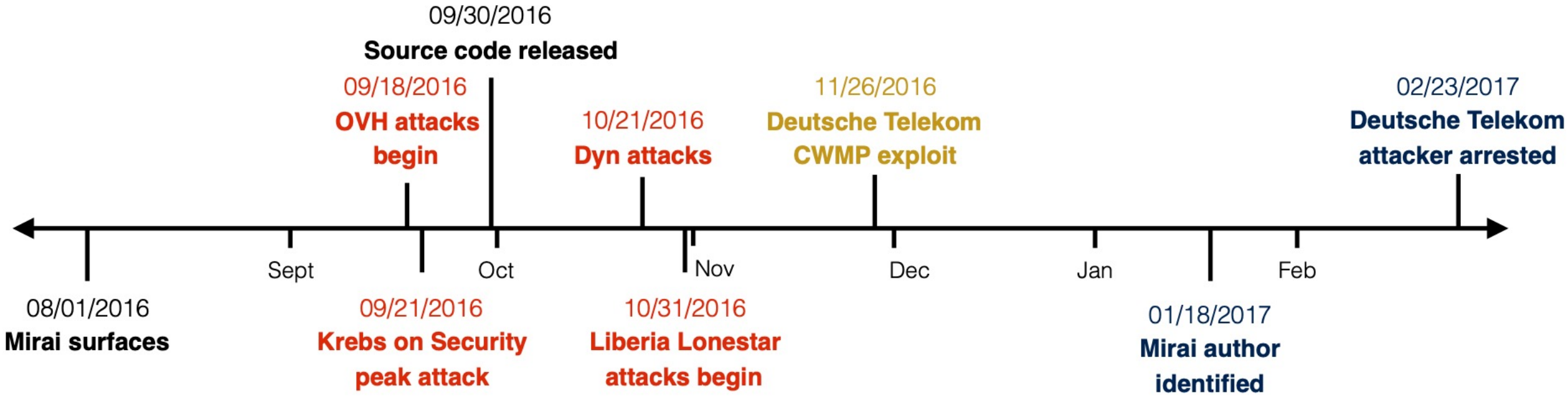
Mirai post-mortem

- Impressive cooperation between = different vantage points:
  - Akamai Technologies, Cloudflare, Google, Merit Network
  - Georgia Institute of Technology, University of Illinois Urbana-Champaign, University of Michigan



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Quiz

Botnets can be used for purposes other than launching DDoS attacks.

For what other activity was the Mirai botnet used?

A Bitcoin mining

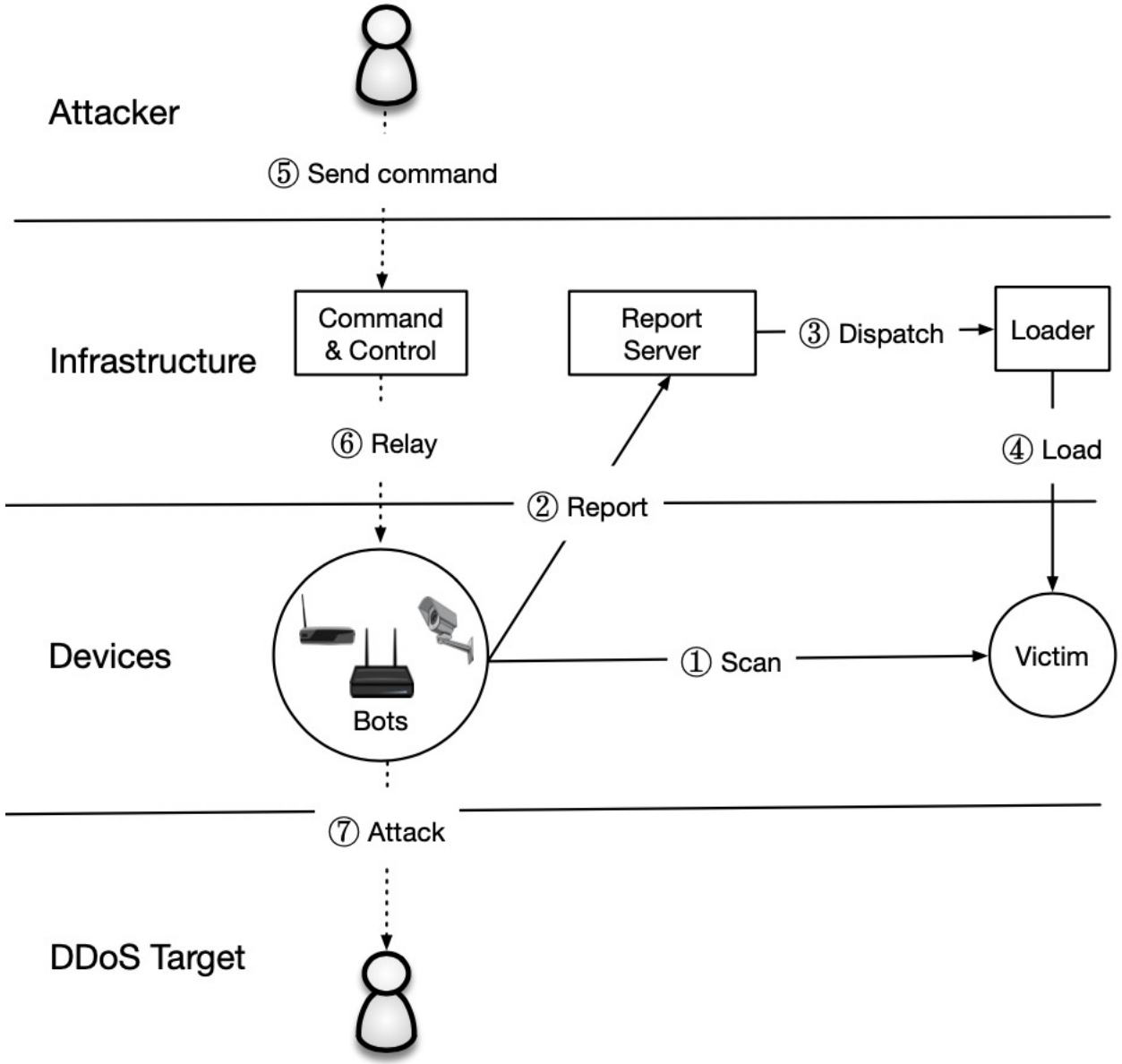
B Sending spam

C Sharing videos

D Click fraud

Mirai inner working

- Rapid stateless scanning: 23 and 2323 TCP SYN (seq num)
- On connection: start brute force login (10 attempts)
- Report successful login to hard-coded report server
- (Async) infect with loader program.
- Close ports and perform AV cleanup
- C2 await commands



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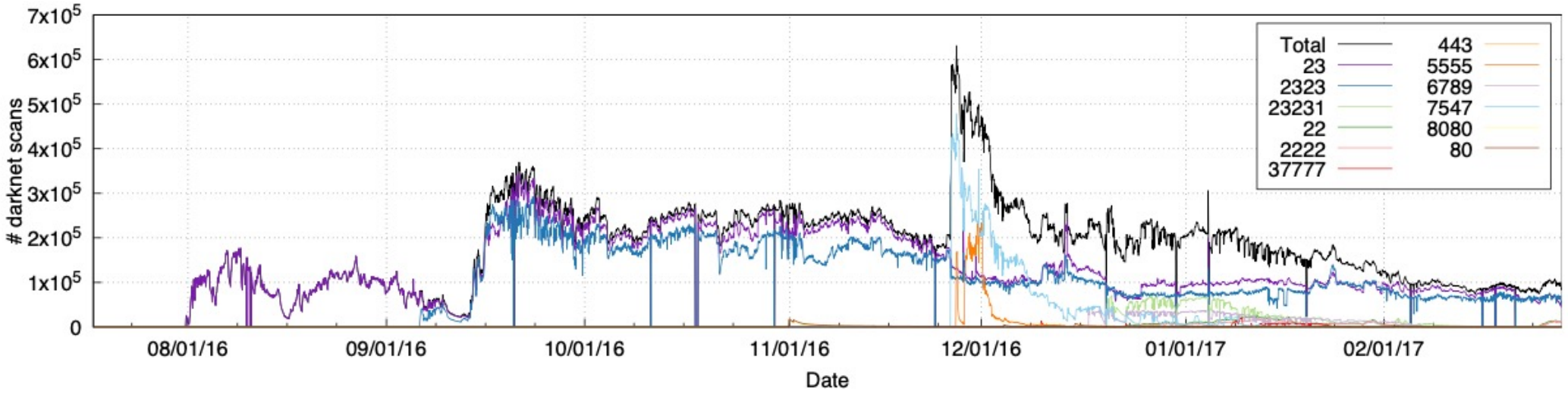
Mirai from a network perspective

- Active scanning: (Censys)
- IoT Honeypot: 1028 unique samples and 67 C2 domains
- Passive and Active DNS to find more C2 servers
- C2 milker: 15.000 attacks



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Quiz

How many hosts show Mirai-like SYN-scans in 2019?

A 1k

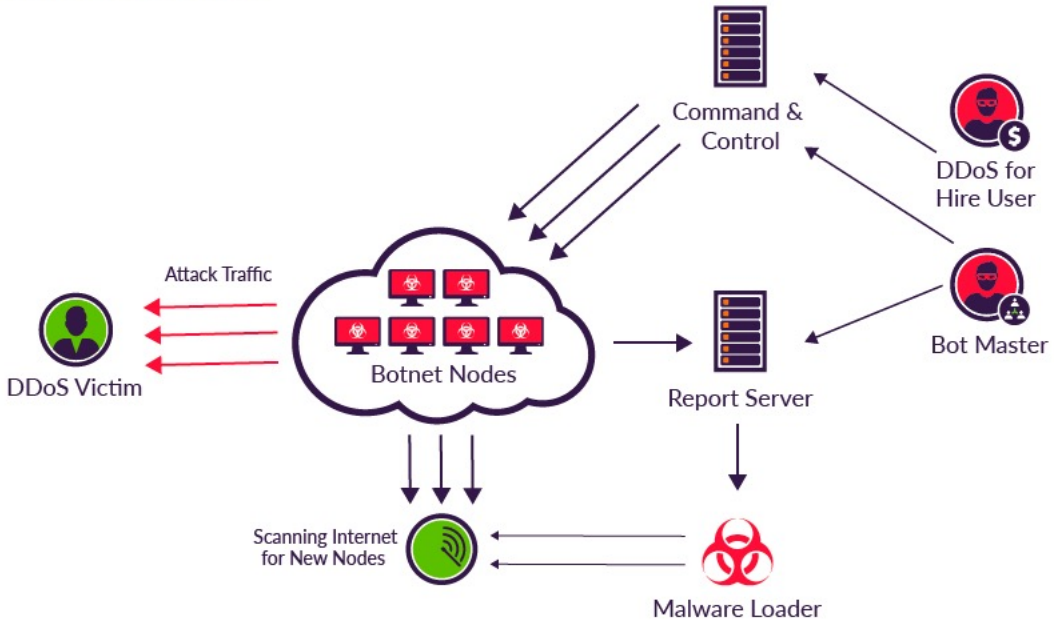
B 5k

C 20k

D 50k

Mirai DDoS attacks

- Volumetric, TCP State Exhaustion, Application-level attacks.
- Most targets in USA (50%), France, UK.
- Games
- Mirai C2 servers
- High-profile targets: Krebs on Security, Lonestar Cell (Liberia), Dyn.



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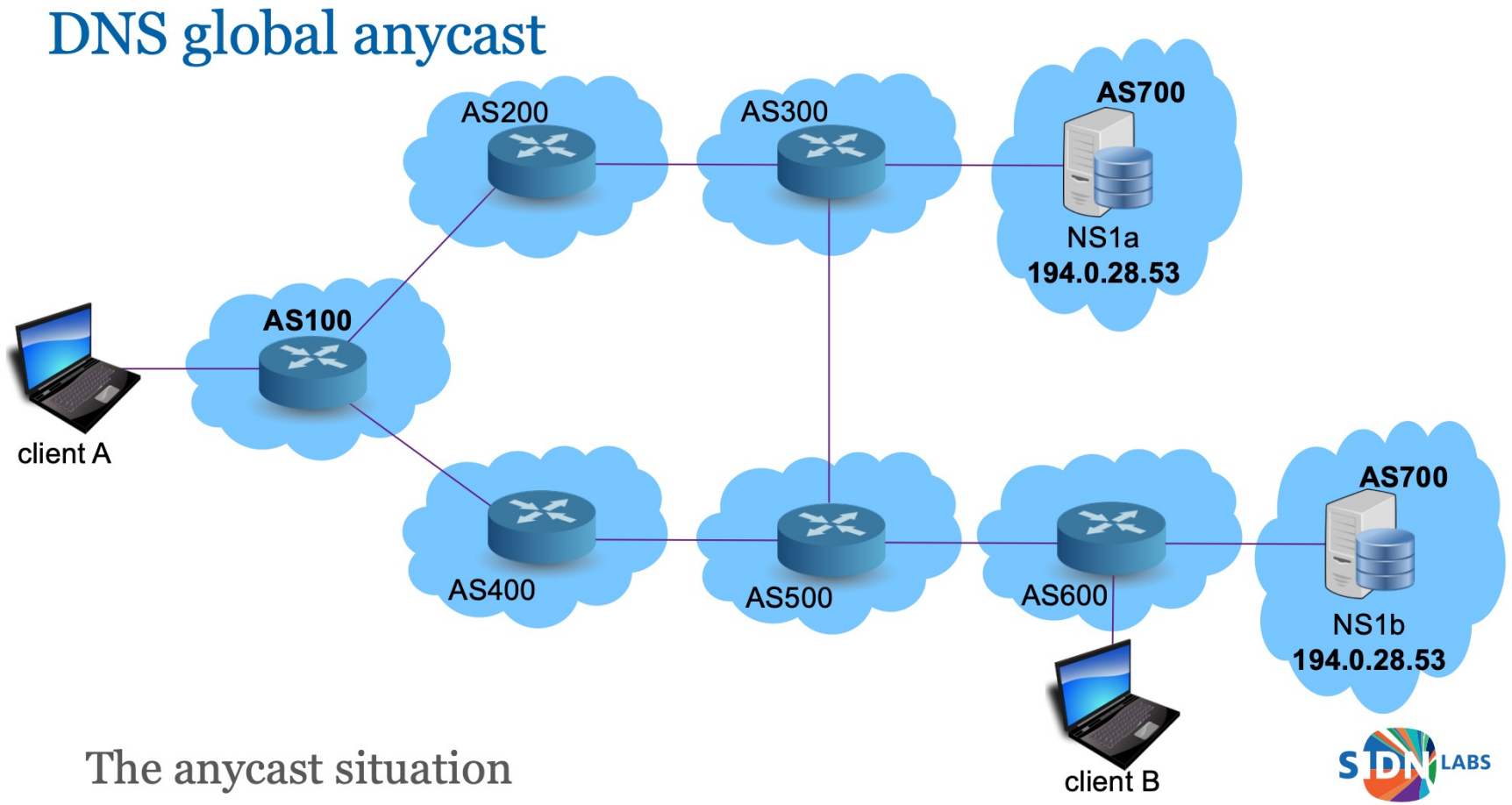
Mitigation of DDoS attacks

DDoS scrubbing service

DNS (Dyn): anycast



The anycast situation

Lessons learned

Simple attack, lots of damage

Automatic updates

Device identification on network

IoT end-of-life devices (externality)

Connecting datasets gives a lot of information!

Question

What was the biggest ‘contribution’ of Mirai in your opinion?

A Using IoT devices

B Stateless scanning

C Release code as Open Source

D Taking down Dyn

Volg ons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Discussion

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Measurement and Analysis of Hajime, a Peer-to-peer IoT Botnet

S. Herwig, K. Harvey, G. Hughey, R. Roberts, and D. Levin, “Measurement and Analysis of Hajime, a Peer-to-peer IoT Botnet”, Network and Distributed Systems Security (NDSS) Symposium 2019, San Diego, CA, USA, February 2019

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Focus

- The important differences between Mirai and Hajime
- Backscatter data from a root DNS server
- Discussions

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The 3 big differences

- Peer-to-Peer instead of centralized command & control
- More exploits based on the Vault7 leak
- Custom protocol to spread the malware

- No malicious activity had been recorded. Does this count as difference?

Architecture	Port	Service	Method
mipseb	23, 5358	Telnet	credentials
	7547	TR-064	CVE-2016-10372
	many	HTTP	Chimay-Red
	80	HTTP	CVE-2018-10561,-10562
mipsel	23, 5358	Telnet	credentials
	7547	TR-064	CVE-2016-10372
arm7	23, 5358	Telnet	credentials
	81	HTTP	GoAhead-Webs credentials
	81	HTTP	Cross Web Server RCE
arm6	23,5358	Telnet	credentials
arm5	23, 5358	Telnet	credentials
	9000	MCTP	CVE-2015-4464

TABLE I: Hajime's architecture-specific access methods and the corresponding ports scanned

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P2P Mechanisms

- DHT (Kademlia) based.
  - Known from e.g. BitTorrent
  - Traditional BitTorrent connections relied on trackers to exchange seeder/leecher information
- Basically, a distributed Key-Value storage
  - Key is filename concatenated with current day' timestamp
  - Values are IPs which are infected with Hajime and allow for payload downloads

Question

- Since the key is computed based on the current day's timestamp, and bots may have incorrectly synchronized clocks, we look up keys for a five-day range
(two days in the past through two days in the future).

- Do you think that this range will catch all devices?

Malicious activity(?)

- On infection, Hajime closes at least the following ports: 23 (Telnet), 5358 (WSDAPI), 5555 (Oracle Web Center Content/Freeciv), and 7547(CWMP)

- Do you remember which port/service was used by Mirai to infect devices?

- Small discussion: What do you think of the motive of the Hajime-bot author?

Custom uTorrent Transport Protocol

- Mirai was enumerable/detectable due to its custom TCP sequence field
- Hajime uses unique cryptographic public keys to allow for a count of infected hosts

- Some churn expected due to recreation of the public key, during updates to the .i module
- Still a stronger identifier, compared to weak identifiers such as IPs (ie. due to carrier grade NAT)

DNS backscatter data

- Based on trying to inject shell-commands into a NTP configuration file
- Vulnerable devices won't sanitize the input and then execute the commands, infecting the device.
- Remember how DNS lookups work? Invalid queries will be sent to the root DNS servers
    - Conveniently the researchers of the paper operate one of the root DNS servers

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Question

- Do you think that Hajime is still active?
  A. Yes
  B. No

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Demo

1. UTC timestamp
2. payload name
3. date used as input for computing the payload's DHT hash ID
4. payload DHT ID (the hash we lookup or announce on the DHT)
5. "seeder" or "leecher" (are we collecting seeders or leechers, respectively)
6. IPv4 address of seeder/leecher bot
7. port number of seeder/leecher bot

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Demo (Backup)

```
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 98.43.129.55 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 109.148.173.191 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 79.161.52.82 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 24.88.23.242 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 69.112.168.236 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 108.173.178.204 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 71.210.33.221 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 24.115.107.208 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 176.14.243.44 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 71.190.197.164 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 70.119.82.44 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 184.83.113.35 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 137.25.255.15 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 185.108.162.49 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 176.110.136.21 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 62.46.102.115 62289
1620769710 atk.mipseb.1506215619 2021-05-09 1173332a85f47e1a40b15f3d77a550ff342442c2 seeder 67.251.129.160 62289
1620769711 1173332a85f47e1a40b15f3d77a550ff342442c2 5.139.3.14:49978 117710404a4f6e018508fce5f2855ef7b4b63620 115.
#1620769711 1173332a85f47e1a40b15f3d77a550ff342442c2 117710404a4f6e018508fce5f2855ef7b4b63620 5.139.3.14:49978 Tot
1620769711 1173332a85f47e1a40b15f3d77a550ff342442c2 144.91.111.37:9613 1173332a85f47e1a40b15f3d77a550fa00c24bc9 18
1620769711 1173332a85f47e1a40b15f3d77a550ff342442c2 144.91.111.37:9613 1173332a85f47e1a40b15f3d77a550fa00c24bc9 47
```

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Demo (Backup)

```
1620769773 .i.armv6l.1509400182 2021-05-11 2f9f80b52e7df032562bfdc6174733006fb978e9 seeder 173.46.242.130 62289
1620769773 .i.armv6l.1509400182 2021-05-11 2f9f80b52e7df032562bfdc6174733006fb978e9 seeder 174.20.138.204 62289
1620769773 .i.armv6l.1509400182 2021-05-11 2f9f80b52e7df032562bfdc6174733006fb978e9 seeder 79.136.72.19 62289
1620769773 .i.armv6l.1509400182 2021-05-11 2f9f80b52e7df032562bfdc6174733006fb978e9 seeder 87.81.93.7 62289
1620769773 .i.armv6l.1509400182 2021-05-11 2f9f80b52e7df032562bfdc6174733006fb978e9 seeder 154.45.216.220 62289
1620769774 2f9f80b52e7df032562bfdc6174733006fb978e9 144.91.111.37:9613 2f9f80b52e7df032562bfdc6174733fa00c24bc9 173.46.242.130 62289
1620769774 2f9f80b52e7df032562bfdc6174733006fb978e9 144.91.111.37:9613 2f9f80b52e7df032562bfdc6174733fa00c24bc9 174.20.138.204 62289
1620769774 2f9f80b52e7df032562bfdc6174733006fb978e9 144.91.111.37:9613 2f9f80b52e7df032562bfdc6174733fa00c24bc9 79.136.72.19 62289
1620769774 2f9f80b52e7df032562bfdc6174733006fb978e9 144.91.111.37:9613 2f9f80b52e7df032562bfdc6174733fa00c24bc9 87.81.93.7 62289
1620769774 2f9f80b52e7df032562bfdc6174733006fb978e9 144.91.111.37:9613 2f9f80b52e7df032562bfdc6174733fa00c24bc9 154.45.216.220 62289
#1620769774 2f9f80b52e7df032562bfdc6174733006fb978e9 2f9f80b52e7df032562bfdc6174733fa00c24bc9 144.91.111.37:9613 Total seeders: 5 new_
1620769785 .i.mipseb.1524631409 2021-05-11 5b28b53bc218c21fdd3ec9b11e696c137a7420f8 seeder 174.17.14.156 62289
1620769785 .i.mipseb.1524631409 2021-05-11 5b28b53bc218c21fdd3ec9b11e696c137a7420f8 seeder 64.121.214.41 62289
1620769785 .i.mipseb.1524631409 2021-05-11 5b28b53bc218c21fdd3ec9b11e696c137a7420f8 seeder 79.136.72.19 62289
1620769785 .i.mipseb.1524631409 2021-05-11 5b28b53bc218c21fdd3ec9b11e696c137a7420f8 seeder 188.17.175.246 62289
1620769785 .i.mipseb.1524631409 2021-05-11 5b28b53bc218c21fdd3ec9b11e696c137a7420f8 seeder 81.217.115.184 62289
1620769786 5b28b53bc218c21fdd3ec9b11e696c137a7420f8 144.91.111.37:9613 5b28b53bc218c21fdd3ec9b11e696cfa00c24bc9 174.17.14.156 62289
1620769786 5b28b53bc218c21fdd3ec9b11e696c137a7420f8 144.91.111.37:9613 5b28b53bc218c21fdd3ec9b11e696cfa00c24bc9 64.121.214.41 62289
1620769786 5b28b53bc218c21fdd3ec9b11e696c137a7420f8 144.91.111.37:9613 5b28b53bc218c21fdd3ec9b11e696cfa00c24bc9 79.136.72.19 62289
1620769786 5b28b53bc218c21fdd3ec9b11e696c137a7420f8 144.91.111.37:9613 5b28b53bc218c21fdd3ec9b11e696cfa00c24bc9 188.17.175.246 62289
1620769786 5b28b53bc218c21fdd3ec9b11e696c137a7420f8 144.91.111.37:9613 5b28b53bc218c21fdd3ec9b11e696cfa00c24bc9 81.217.115.184 62289
#1620769786 5b28b53bc218c21fdd3ec9b11e696c137a7420f8 5b28b53bc218c21fdd3ec9b11e696cfa00c24bc9 144.91.111.37:9613 Total seeders: 5 new_
1620769787 .i.mipseb.1522574410 2021-05-12 09f5299a344afa50742c3f29ac7d9a163fc04b94 seeder 5.146.192.252 62289
1620769788 09f5299a344afa50742c3f29ac7d9a163fc04b94 144.91.111.37:9613 09f5299a344afa50742c3f29ac7d9afa00c24bc9 5.146.192.252 62289
#1620769788 09f5299a344afa50742c3f29ac7d9a163fc04b94 09f5299a344afa50742c3f29ac7d9afa00c24bc9 144.91.111.37:9613 Total seeders: 1 new_
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Lessons learned

1. Command-And-Control impossible to take down, without also affecting legitimate users
2. Multiple identifiers can help in mapping the extent of a botnet (uTP keys, backscatter data)
3. Abandoned botnets float through the Internet, like satellite debris around earth's orbit
4. (By proxy), manufacturers treat their security division poorly

Discussion: Botnet

- Why would the cleanup of IoT botnets take longer than for traditional bots?

Key takeaways

- Analyzing botnets properly requires many vantage points and datasets.
- Mirai ‘shook the world’ and showed potential of IoT botnets in terms of DDoS attacks.
- By leveraging an established decentralized communication protocol for command & control, Hajime circumvents traditional take-down measures for botnets.

Lecture feedback

1. To what extent do you think you'll be able to discuss the reasons behind the success of IoT botnets? (A = 🟢, B = 🟠, C = 🔴)

2. To what extent do you think you can explain what makes Hajime different from many other botnets? (A = 🟢, B = 🟠, C = 🔴)

3. Open question: what are your main lesson learned of the papers and this lecture?

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Discussion & feedback

Next lecture: **Tue May 18, 11:00-12:45**

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