Lecture #10: IoT Honeypots

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University of Twente | 14 June 2023

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Oral exams

- June 21st, 22nd, 26th, 28th, 30th, July 4th
- 45 minutes
- Details: https://courses.sidnlabs.nl/ssi-2023/#oral-exam

Schedule

No.	Date	Contents
1	Apr 26	Course introduction
2	May 3	Lecture: IoT and Internet Core Protocols
3	May 10	Lecture: IoT Botnet Measurements 1
4	May 17	Lecture: IoT Edge Security Systems
5	May 24	Lecture: IoT Device Security
6	May 31	Lecture: IoT Botnet Measurements 2
7	Jun 1	Guest lecture #1: Naval Systems, Dr. Sorin Iacob, Thales
8	Jun 5	Lecture: IoT Security in Non-Carpeted Areas
9	Jun 12	Guest lecture #2: Product Security for Bosch (IoT) products, Stephan van Tienen, Bosch Security Systems
10	Jun 14	Lecture: IoT Honeypots (re-sit)

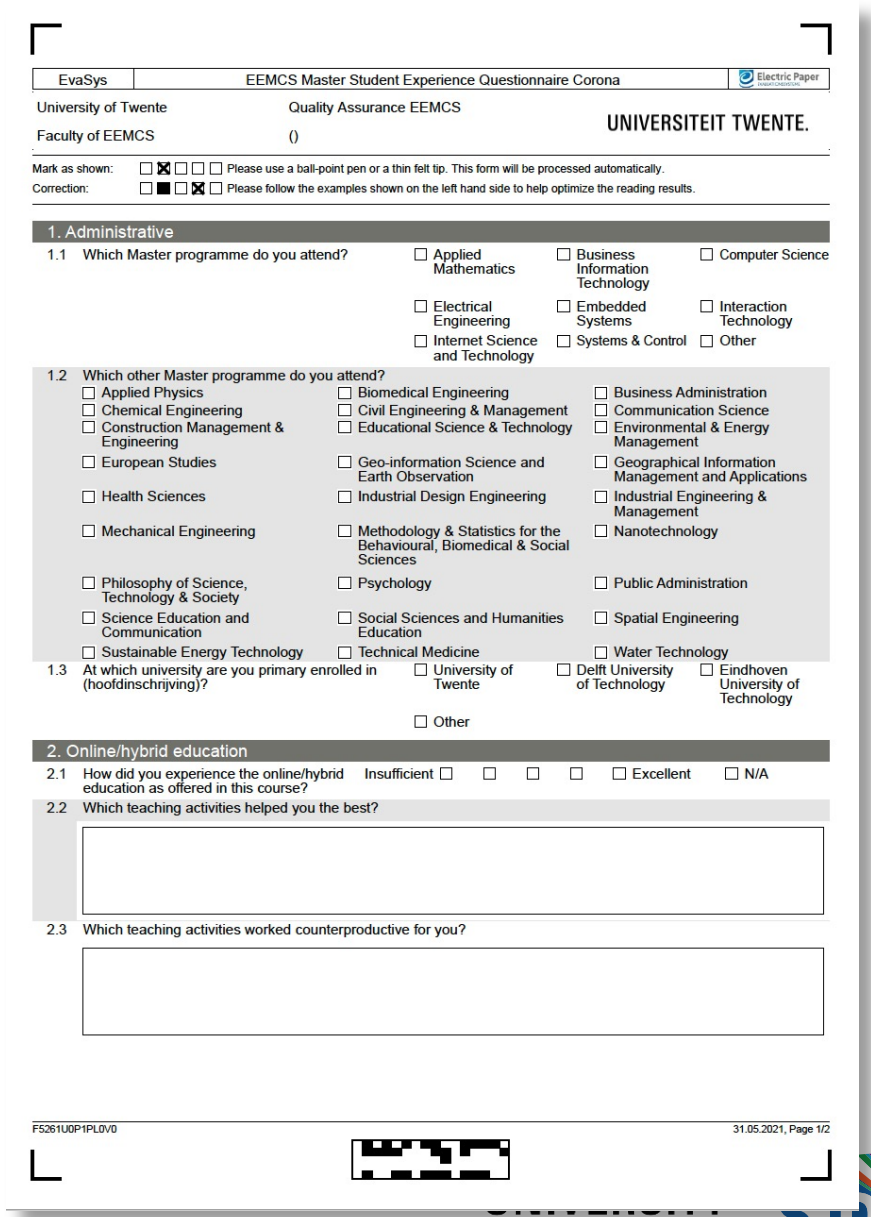
Important dates

- Lab report (PDF) and required files: **Sun June 23, 2023, 23:59 CEST**

- All to be submitted through CANVAS

Official feedback forms

- Survey by EEMCS Quality Assurance folks
- Will be sent out on in the week of July 3rd
- Please fill it out, your feedback is **crucial** for us to further improve the course!
- Next year's students will thank you for it ;-)
- We'll let you know how we handled your feedback



EvaSys | EEMCS Master Student Experience Questionnaire Corona | Electric Paper

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Mark as shown: ☐ ☒ ☐ ☐ ☐ Please use a ball-point pen or a thin felt tip. This form will be processed automatically.

Correction: ☐ ■ ☐ ☒ ☐ Please follow the examples shown on the left hand side to help optimize the reading results.

1. Administrative

1.1 Which Master programme do you attend?

☐ Applied Mathematics ☐ Business Information Technology ☐ Computer Science
☐ Electrical Engineering ☐ Embedded Systems ☐ Interaction Technology
☐ Internet Science and Technology ☐ Systems & Control ☐ Other

1.2 Which other Master programme do you attend?

☐ Applied Physics ☐ Biomedical Engineering ☐ Business Administration
☐ Chemical Engineering ☐ Civil Engineering & Management ☐ Communication Science
☐ Construction Management & Engineering ☐ Educational Science & Technology ☐ Environmental & Energy Management
☐ European Studies ☐ Geo-information Science and Earth Observation ☐ Geographical Information Management and Applications
☐ Health Sciences ☐ Industrial Design Engineering ☐ Industrial Engineering & Management
☐ Mechanical Engineering ☐ Methodology & Statistics for the Behavioural, Biomedical & Social Sciences ☐ Nanotechnology
☐ Philosophy of Science, Technology & Society ☐ Psychology ☐ Public Administration
☐ Science Education and Communication ☐ Social Sciences and Humanities Education ☐ Spatial Engineering
☐ Sustainable Energy Technology ☐ Technical Medicine ☐ Water Technology

1.3 At which university are you primary enrolled in (hoofdinschrijving)?

☐ University of Twente ☐ Delft University of Technology ☐ Eindhoven University of Technology
☐ Other

2. Online/hybrid education

2.1 How did you experience the online/hybrid education as offered in this course? Insufficient ☐ ☐ ☐ ☐ ☐ Excellent ☐ N/A

2.2 Which teaching activities helped you the best?

2.3 Which teaching activities worked counterproductive for you?

F5261U0P1PL0V0 31.05.2021, Page 1/2

Introduction to today's lecture

Today's objective

- After this lecture, you will be able to explain what is the purpose of using IoT honeypots
- You will be able to discuss different kinds of implementations for IoT honeypots and argue why they are designed in that way.
- 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

- **[IoTPOT]** Yin Minn Pa Pa, Shogo Suzuki, Katsunari Yoshioka, Tsutomu Matsumoto, Takahiro Kasama, Christian Rossow. "IoTPOT: Analysing the Rise of IoT Compromises". 9th USENIX Workshop on Offensive Technologies (co-located with USENIX Sec '15), WOOT '15, Washington, DC, https://christian-rossow.de/publications/iotpot-woot2015.pdf

- [**Honware**] Vetterl, Alexander, and Richard Clayton. "Honware: A virtual honeypot framework for capturing CPE and IoT zero days." Symposium on Electronic Crime Research (eCrime). IEEE. 2019. https://www.cl.cam.ac.uk/~amv42/papers/vetterl-clayton-honware-virtual-honeypot-framework-ecrime-19.pdf

“IoTPOT: Analysing the Rise of IoT Compromises”, 9th USENIX Workshop on Offensive Technologies (WOOT), 2015

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Darknet monitoring

270.000 IP's

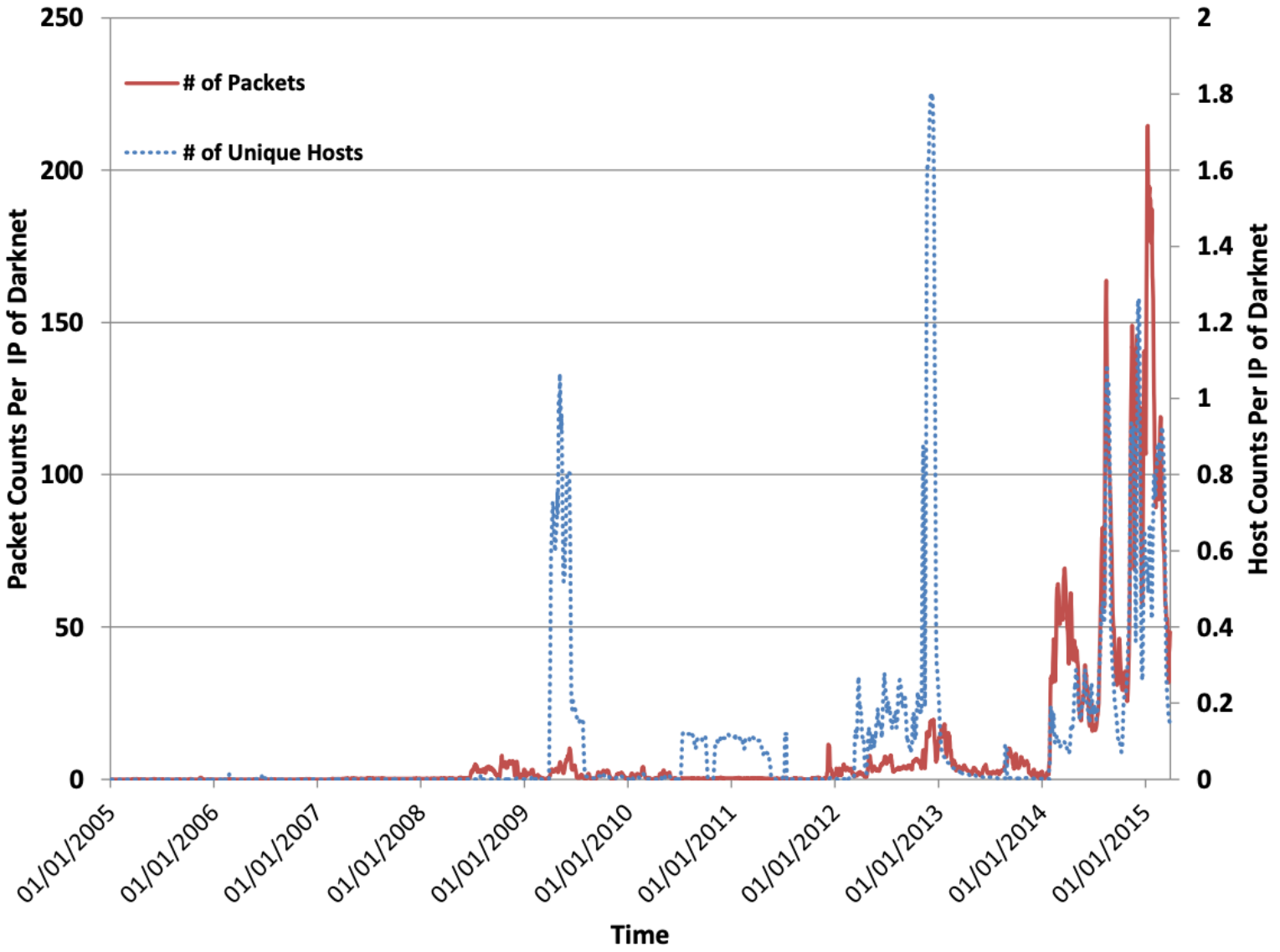
Connect back 23/80 TCP

& collect banners.

Table 1 - Scanning hosts and device models

Device Type	Host Count	Device Model Count
DVR	1,509	19
IP Camera	523	16
Wireless Router	118	45
Customer Premises Equipment	65	1
Industrial Video Server	22	1
TV Receiver	19	2
Heat Pump	10	1
EMU System	9	1
Digital Video Scalar	5	2
Router	4	3

Darknet monitoring (2)



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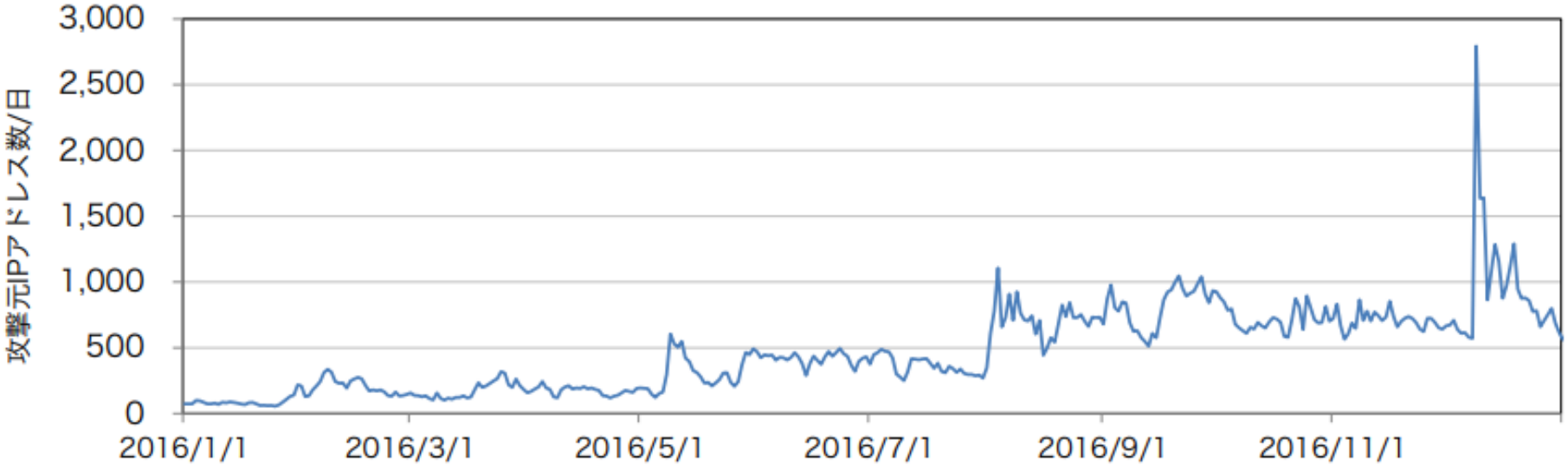
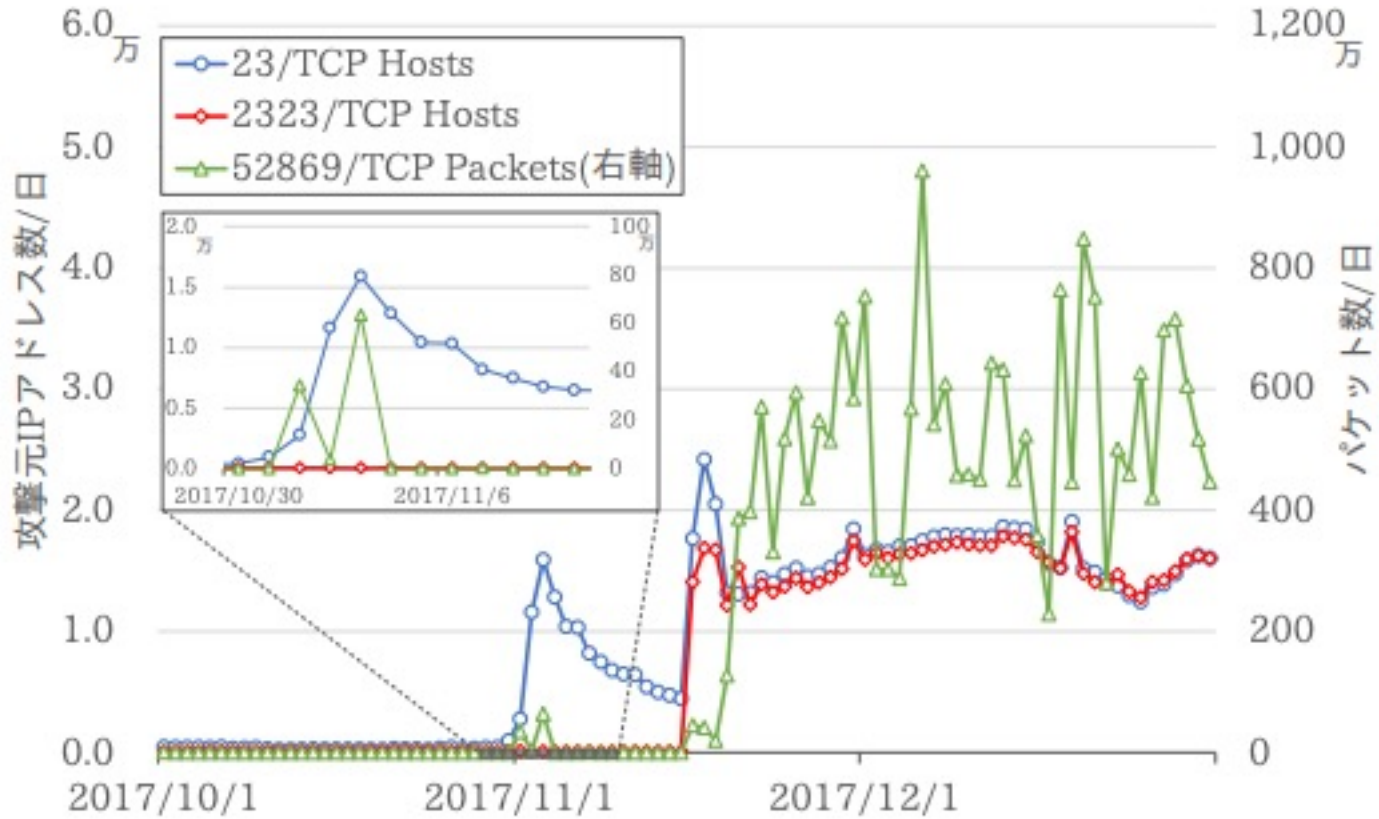


図5: 23/TCP に対する日本国内からの攻撃



Quiz

Why is a **darknet** useful for IoT malware research?

A: Malware runs better, because it's from the dark side

B: No legitimate traffic

C: No legal problems because a darknet is not managed by any company

D: It has residual trust from previous use

IoT POT

Running on 165 IP addresses

5 weeks running time

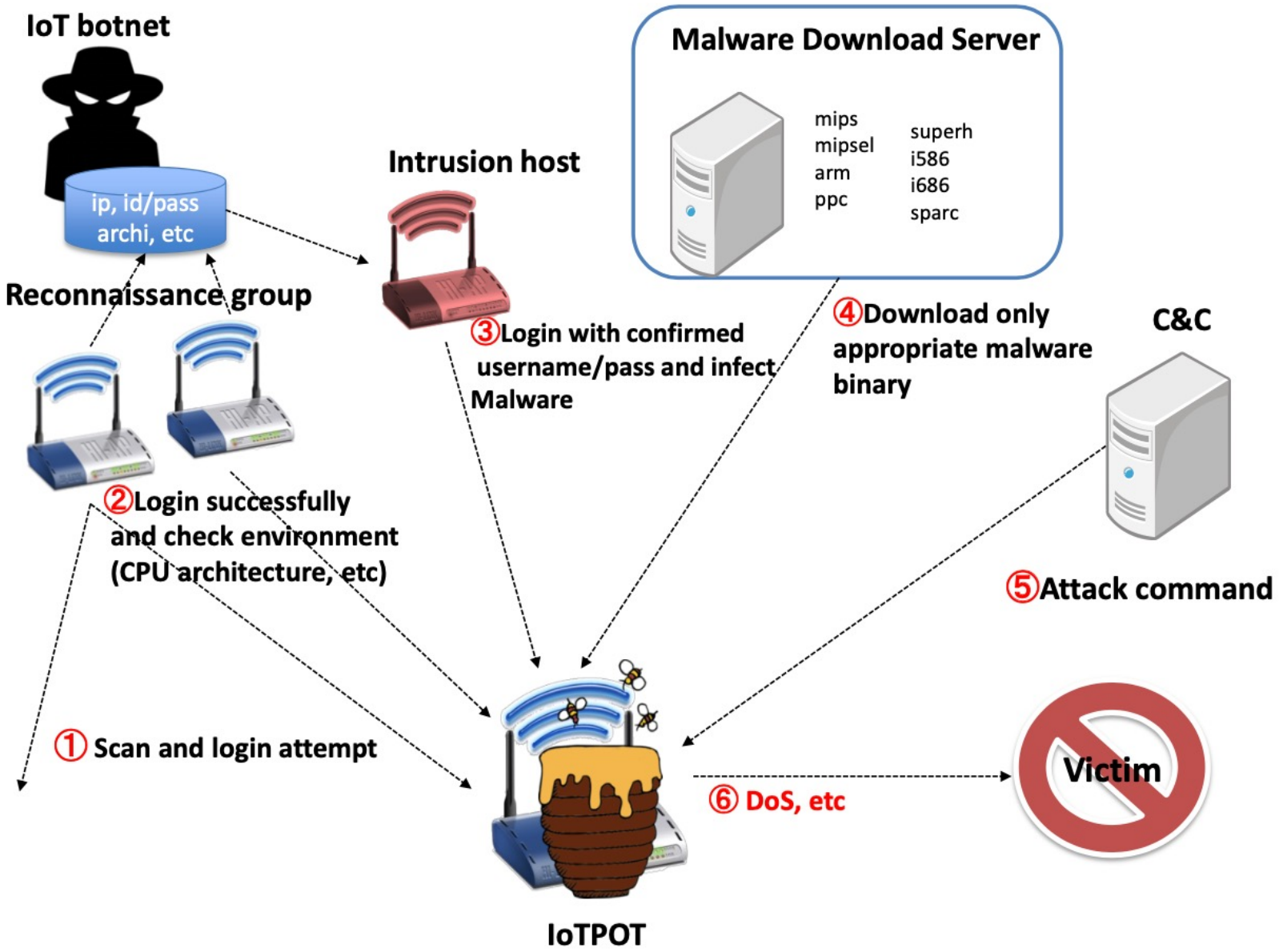
Telnet attack stages:

(1) Intrusion; (2) Infection; (3) Monetization. *Remember Mirai?*

Credentials in Fixed/Random order (1)

6 patterns of commands (2) distinguished

‘Coordinated intrusion’



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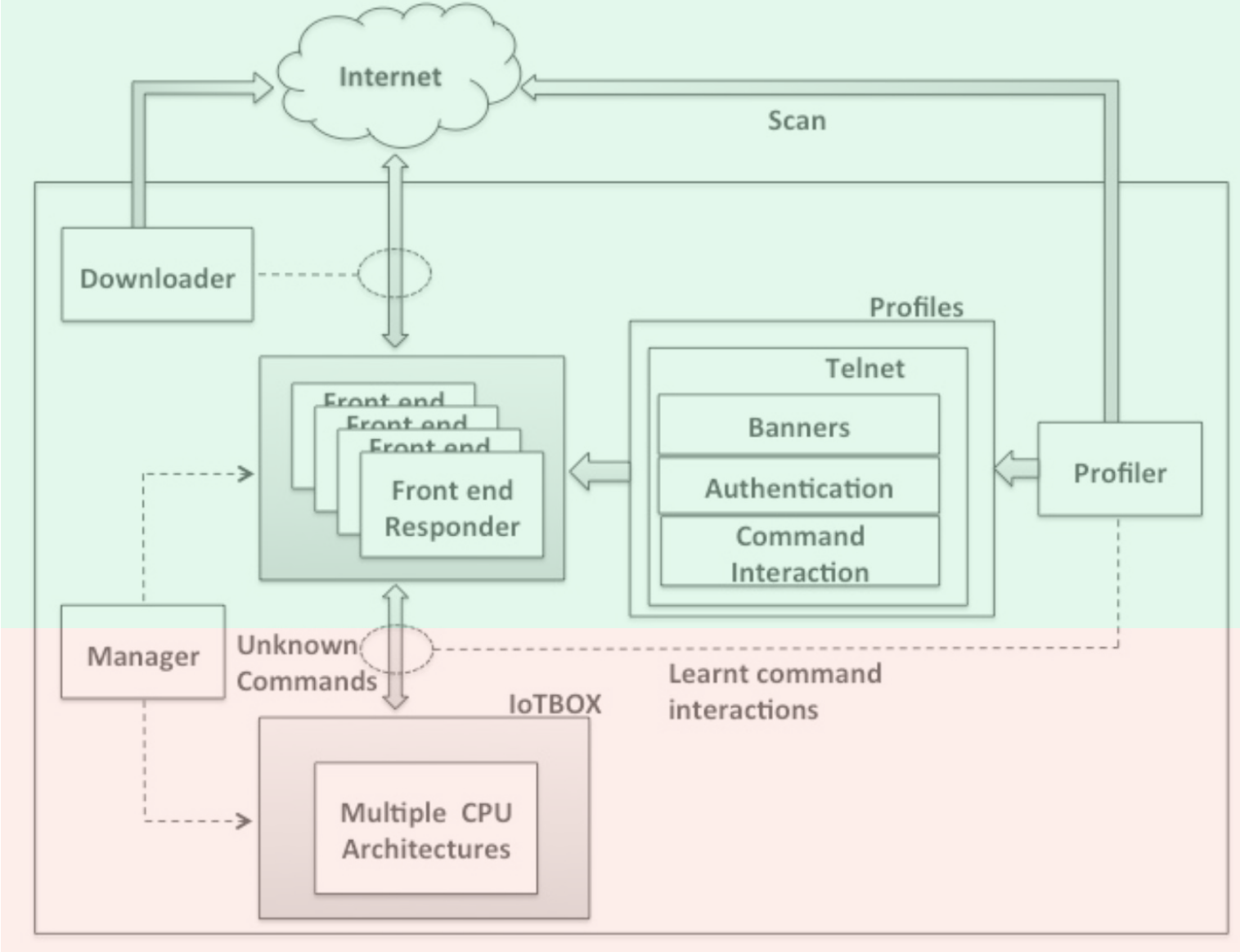
IoTPOT & IoTBOX



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Quiz

What would an operator of an IoTPOT honeypot need to do to support Hajime?

A: Add support for MIPS CPU architecture

B: Track DHT (P2P) communications

C: Expose many vulnerabilities

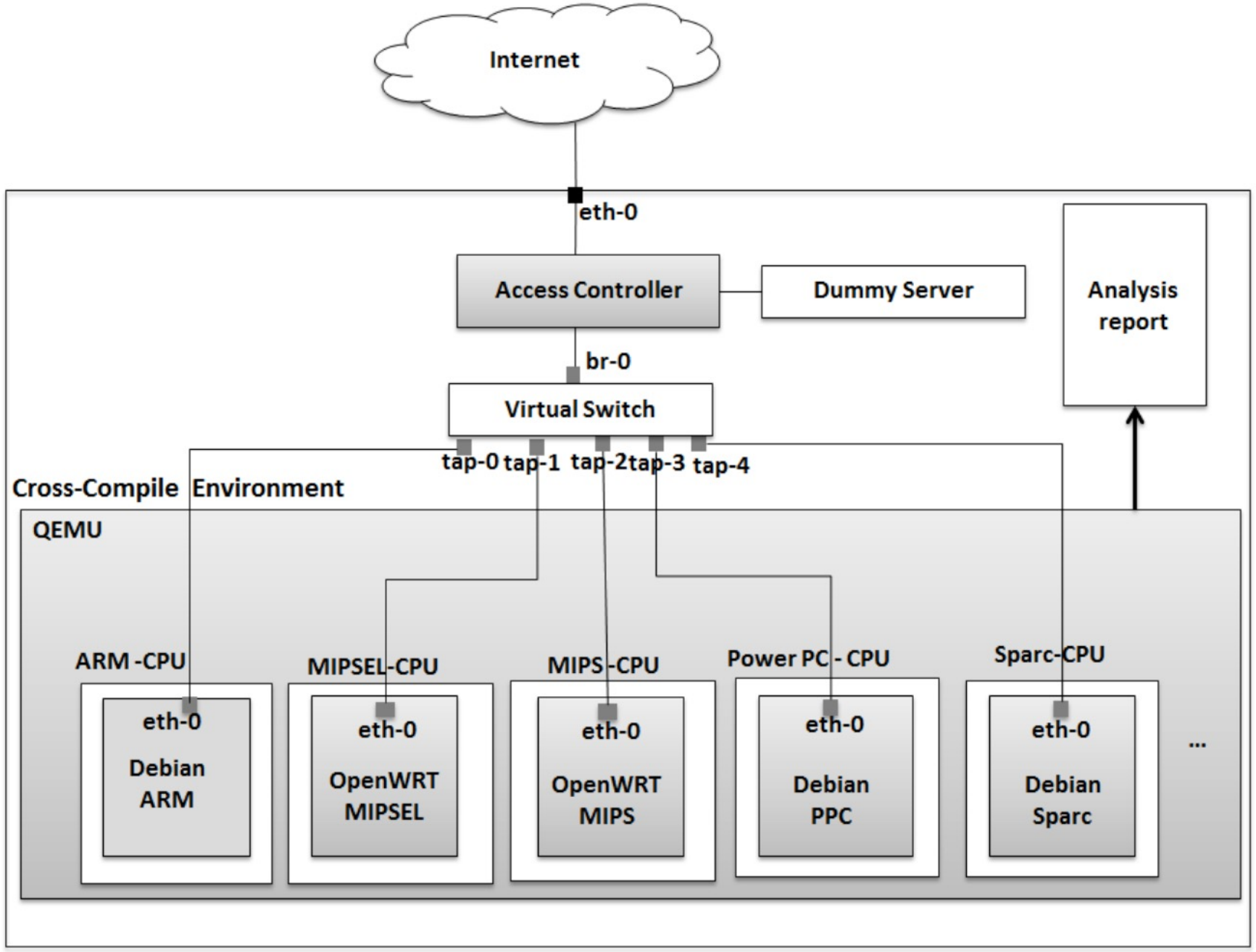
D: Run the honeypot in different subnets

IoTBOX

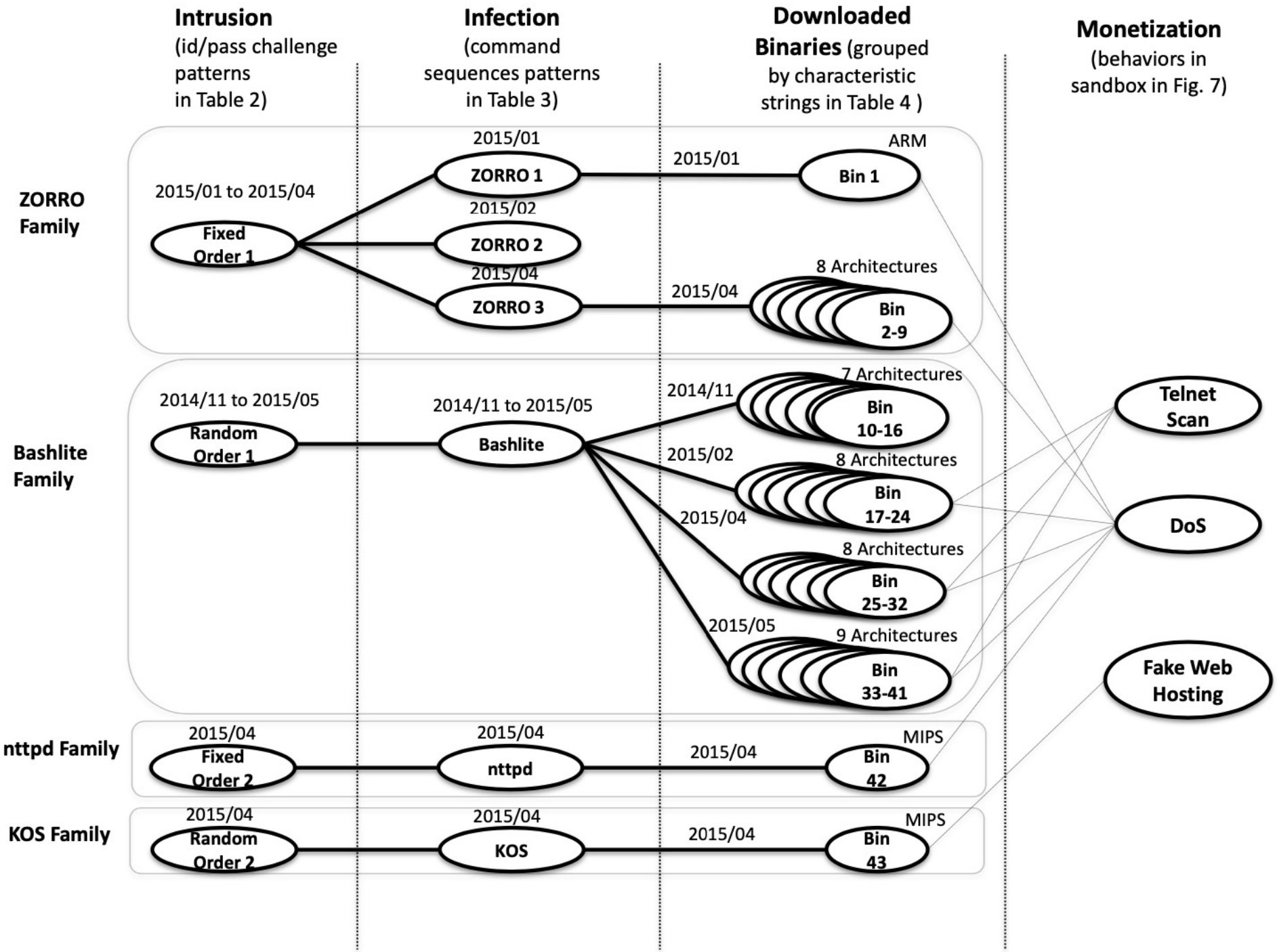
Sandbox with 8 CPU architectures

Limit outgoing to DNS/HTTP 5ppm

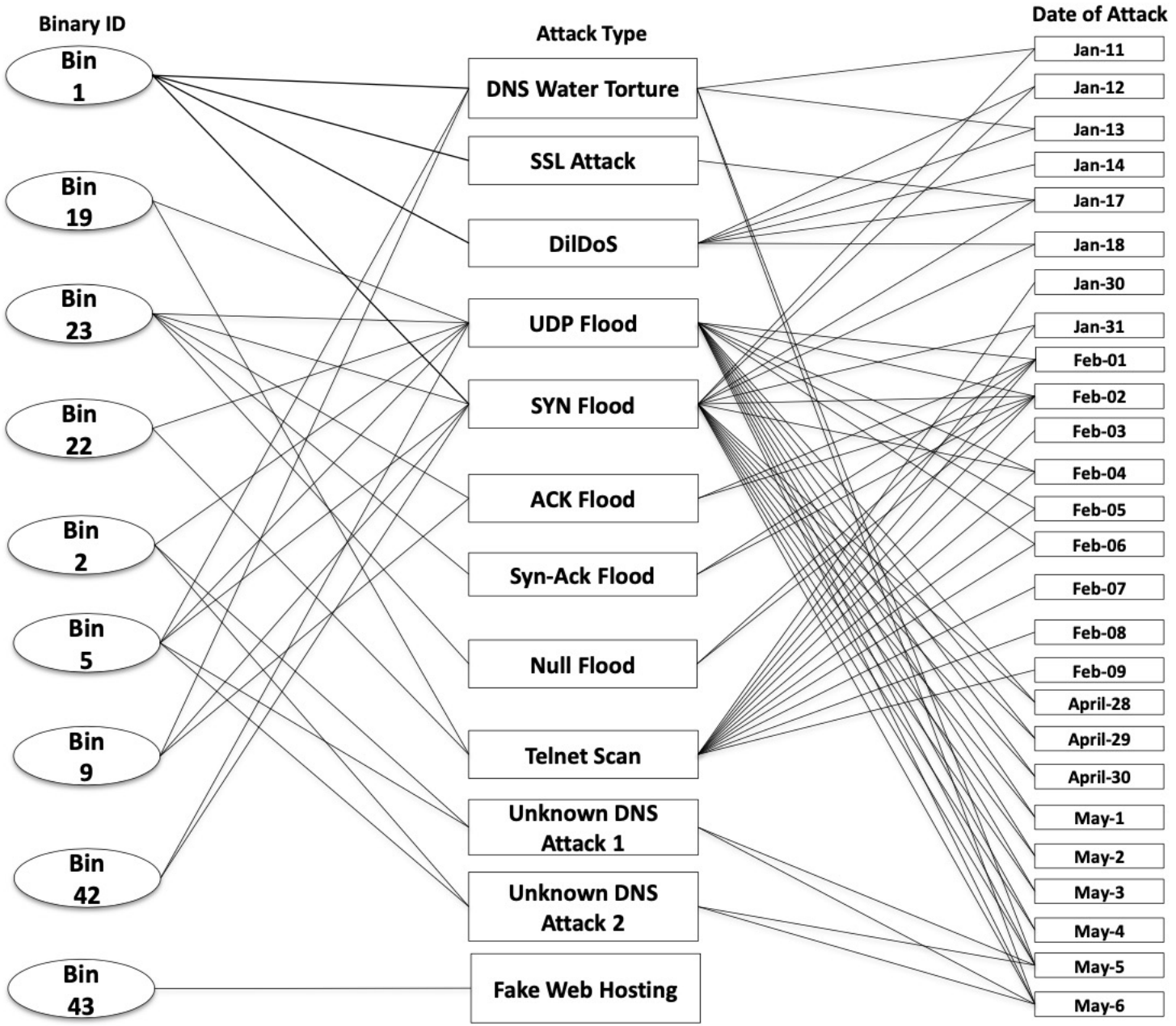
Telnet to Dummy server



Results


Intrusion
(id/pass challenge patterns in Table 2)
Infection
(command sequences patterns in Table 3)
Downloaded Binaries (grouped by characteristic strings in Table 4)
Monetization
(behaviors in sandbox in Fig. 7)
ZORRO Family
2015/01 to 2015/04
Fixed Order 1
2015/01
ZORRO 1
2015/02
ZORRO 2
2015/04
ZORRO 3
2015/01
ARM
Bin 1
2015/04
8 Architectures
Bin 2-9
Bashlite Family
2014/11 to 2015/05
Random Order 1
2014/11 to 2015/05
Bashlite
2014/11
7 Architectures
Bin 10-16
2015/02
8 Architectures
Bin 17-24
2015/04
8 Architectures
Bin 25-32
2015/05
9 Architectures
Bin 33-41
nttpd Family
2015/04
Fixed Order 2
2015/04
nttpd
2015/04
MIPS
Bin 42
KOS Family
2015/04
Random Order 2
2015/04
KOS
2015/04
MIPS
Bin 43
Telnet Scan
DoS
Fake Web Hosting

Results



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Question

What is –in your opinion- the most important next-step?

A: More CPU architectures

B: Passthrough and monitor C&C traffic

C: Standardized botnet profiles for sharing between organizations

D: Running on real (IoT) hardware

Key takeaways

IoT world heterogeneous => honeypots more complex

High-interaction needed to get useful results

Require many (!) IP addresses to catch scans

Discussion

⇒ What is IoT about IoTPOT?

⇒ Ethical considerations in running a honeypot?

⇒ How would you improve IoTPOT?

⇒ Other means to achieve the same?

Honware: A Virtual Honeypot Framework for Capturing CPE and IoT Zero Days

Vetterl, A., & Clayton, R. (2019, November). Honware: A virtual honeypot framework for capturing CPE and IoT zero days. In *Symposium on Electronic Crime Research (eCrime). IEEE.*

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A Virtual Honeypot Framework for Capturing CPE and IoT Zero Days

- We've seen IoTPOT as a generic example, can we improve on that model?
  - Specialized honeypots can be built for known malware (leaked Mirai sourcecode)
  - But this might not capture attack traffic of unknown derivates (e.g. Yowai/Hakai)
- Malware engineers can easily scan the whole IPv4 Internet to look for vulnerable devices and quickly infect them.
- This means defenders need to scale fast too
  - IoTPOT → Hardcoded answers (and limited sandbox), Firmadyne → Not setup for network traffic, SIPHON→ physical devices
- Using original firmware as a basis for honeypots

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A Virtual Honeypot Framework for Capturing CPE and IoT Zero Days

- Using original firmware as a honeypot basis
  - Automated firmware extraction with Binwalk
  - Customizing the kernel to allow logging & emulating proprietary hardware
  - Signal interception (signals are a form of inter-process communication (IPC))
  - Module loading disabled
  - NVRAM is not available and thus has to be emulated
  - Network configuration (adding interfaces)
  - Emulation self-check (am I reachable via ping?)

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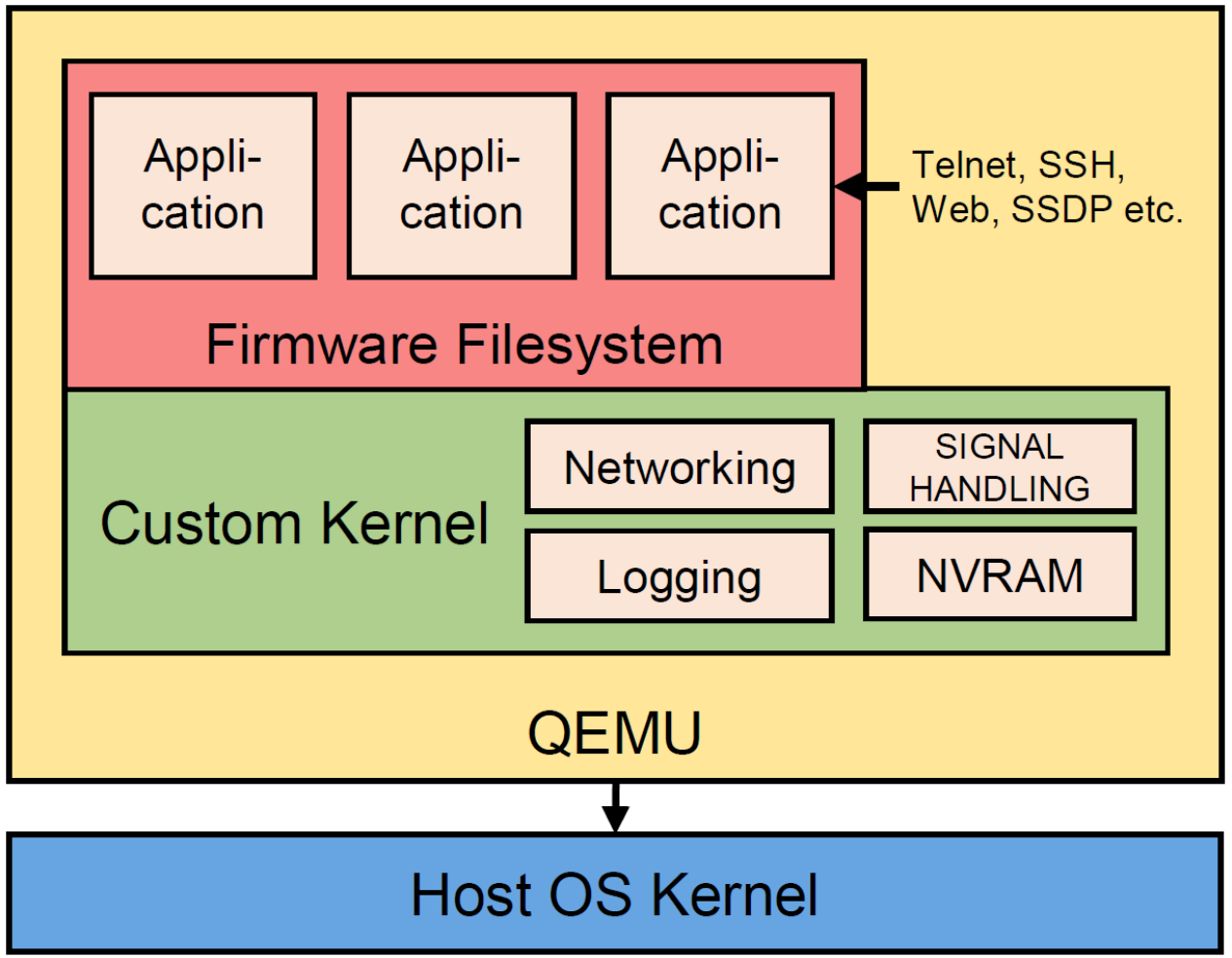
A Virtual Honeypot Framework for Capturing CPE and IoT Zero Days



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A Virtual Honeypot Framework for Capturing CPE and IoT Zero Days

- **Not required, but fun:**
- **Reverse engineering my router's firmware with binwalk**
- https://embeddedbits.org/reverse-engineering-router-firmware-with-binwalk/
- **Playing with signals**
- **http://www.it.uu.se/education/course/homepage/os/vt18/module-2/signals/**

A Virtual Honeypot Framework for Capturing CPE and IoT Zero Days

- How does this system compare to the alternative (Firmadyne)?
- Out of 8387 available firmwares, 4650 could be successfully extracted (55.4%)
    - Possibly due to having weaker constraints on the size of the extracted image
- From the 4650 extracted firmware images, 1903 responded to ICMP traffic (40.9%). Firmadyne only achieved this for 460 firmware images (15.8%)
    - Likely due to the kernel customizations, and handling of crashes

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A Virtual Honeypot Framework for Capturing CPE and IoT Zero Days

# Brand	Available (2019-03/2016-02/Δ)		Extracted (honw./firm./Δ)		Network reach. (honw./firm./Δ)	
1 Actiontec	0/14	14↓	–	–	–	–
2 Airlink101	0/15	15↓	–	–	–	–
3 Apple	0/9	9↓	–	–	–	–
4 Asus	1/3	2↓	1/1	←	1/0	1↑
5 AT&T	3/25	22↓	0/2	2↓	–	–
6 AVM	0/132	132↓	–	–	–	–
7 Belkin	123/140	17↓	49/49	←	9/0	9↑
8 Buffalo	97/143	46↓	6/7	1↓	2/1	1↑
9 CenturyLink	13/31	18↓	7/4	3↑	7/0	7↑
10 Cerowrt	0/14	14↓	–	–	–	–
11 Cisco	0/61	61↓	–	–	–	–
12 D-Link	1443/4688	3245↓	537/498	39↑	272/115	157↑
13 Forceware	0/2	2↓	–	–	–	–
14 Foscam	44/56	12↓	5/5	←	–	–
15 Haxorware	0/7	7↓	–	–	–	–
16 Huawei	13/29	16↓	0/3	3↓	–	–
17 Inmarsat	0/47	47↓	–	–	–	–
18 Iridium	0/17	17↓	–	–	–	–
19 Linksys	32/126	94↓	26/26	←	15/1	14↑
20 MikroTik	4/13	9↓	–	–	–	–
21 Netgear	1396/5280	3884↓	639/629	10↑	384/187	197↑
22 On Networks	0/28	28↓	–	–	–	–
23 Open Wir.	0/1	1↓	–	–	–	–
24 OpenWrt	756/1498	742↓	714/705	9↑	674/0	674↑
25 pfSense	214/256	42↓	–	–	–	–
26 Polycom	612/644	32↓	0/24	24↓	–	–
27 QNAP	8/464	456↓	–	–	–	–
28 RouterTech	0/12	12↓	–	–	–	–
29 Seiki	0/16	16↓	–	–	–	–
30 Supermicro	0/150	150↓	–	–	–	–
31 Synology	1977/2094	117↓	1866/239	1627↑	–	–
32 Tenda	6/244	238↓	4/3	1↑	2/0	2↑
33 Tenvis	9/49	40↓	6/6	←	6/4	2↑
34 Thuraya	0/18	18↓	–	–	–	–
35 Tomato	362/2942	2580↓	362/362	←	217/0	217↑
36 TP-Link	463/1072	609↓	171/171	←	147/95	52↑
37 TRENDnet	336/822	486↓	134/100	34↑	87/37	50↑
38 Ubiquiti	26/51	25↓	20/19	1↑	11/0	11↑
39 u-blox	0/16	16↓	–	–	–	–
40 Verizon	0/37	37↓	–	–	–	–
41 Western Dig.	0/1	1↓	–	–	–	–
42 ZyXEL	449/1768	1319↓	103/67	36↑	69/20	49↑
Total	8387/23035	14648↓	4650/2920	1730↑	1903/460	1443↑

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A Virtual Honeypot Framework for Capturing CPE and IoT Zero Days

TABLE II
COMPARING HONWARE AND FIRMADYNE: TOP 15 LISTENING SERVICES.

Prot.	Port/Service	Honware	Firmadyne	Δ
TCP	23/telnet	879	149	730↑
TCP	80/http	676	293	383↑
UDP	67/dhcp	316	160	156↑
UDP	1900/UPnP	239	128	111↑
UDP	53/various	239	174	65↑
TCP	3333/dec-notes	222	102	120↑
TCP	5555/freeciv	203	57	146↑
TCP	5431/UPnP	177	48	129↑
UDP	137/netbios	154	82	72↑
TCP	53/domain	139	73	66↑
TCP	443/https	107	105	2↑
UDP	5353/mdns	102	34	68↑
UDP	69/tftp	104	26	78↑
TCP	1900/UPnP	56	60	4↓
TCP	49152/UPnP	53	62	9↓

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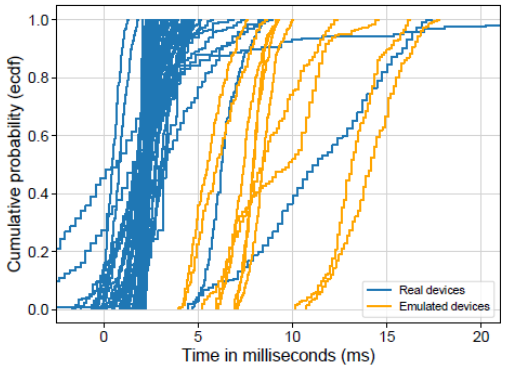
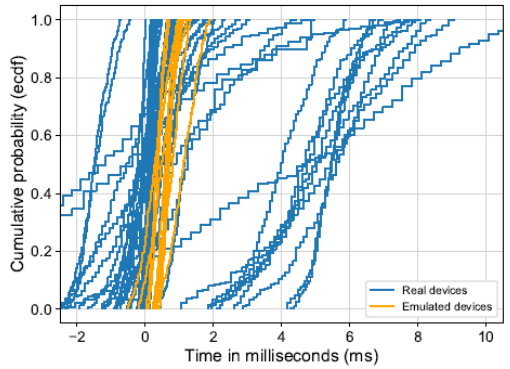
A Virtual Honeypot Framework for Capturing CPE and IoT Zero Days

- How does this system compare to the real deal (hardware in the wild)?
- Fingerprinting of honeypots is an ongoing concern

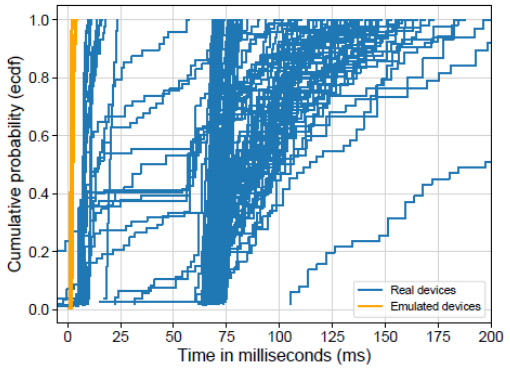
A Virtual Honeypot Framework for Capturing CPE and IoT Zero Days



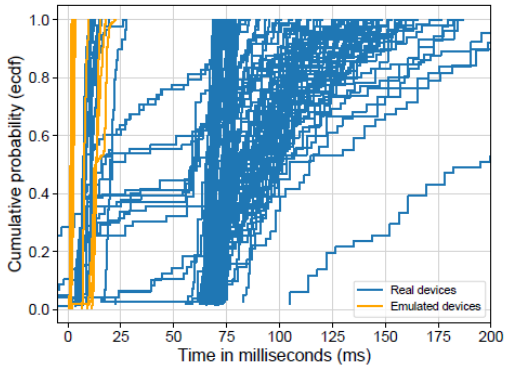
(a) ASUS RT-AC52U FTP server: Time to welcome message



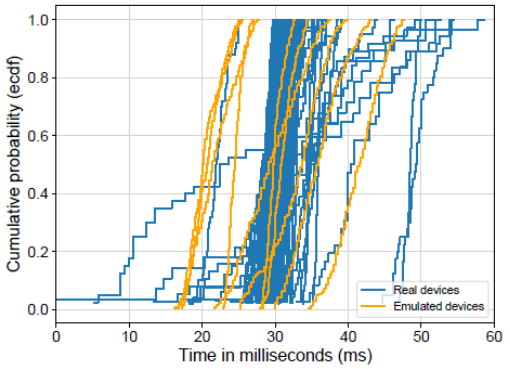
(b) ASUS RT-AC52U FTP server: Time between resource request (carriage return) and login message



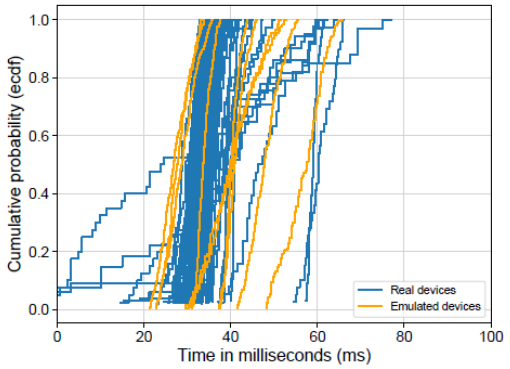
(c) Zyxel VMG1312-B10A Telnet server: Time to telnet negotiation characters



(d) Zyxel VMG1312-B10A Telnet server: Time to Login message



(e) D-Link DIR-825 HTTPS server: Time to complete the TLS handshake



(f) D-Link DIR-825 HTTPS server: Time between ClientHello and resource received (web page)

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Quiz 2

Hosting the honeypots in the cloud can aid attackers in the fingerprinting process

A. True
B. False

A Virtual Honeypot Framework for Capturing CPE and IoT Zero Days

- Real world results: fast

1. UPnPHunter took a research team 1 month to reverse engineer, Honware detected the complete attack within 24 hours
2. DNS hijack, a previously unknown attack
3. UPnPProxy
4. Mirai variants, target port 80 (HTTP) instead of 23 (Telnet)

- Detected malware samples were unknown to the wider community (Virustotal)

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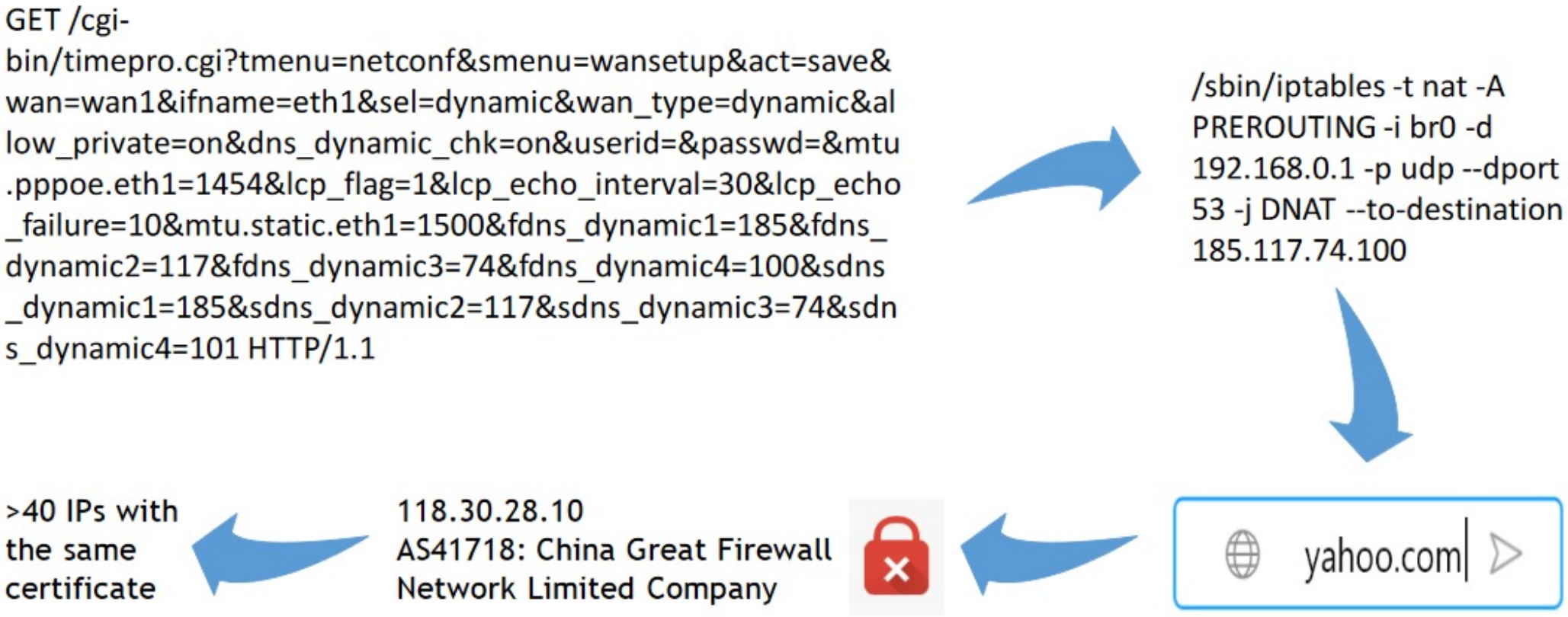
A Virtual Honeypot Framework for Capturing CPE and IoT Zero Days



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A Virtual Honeypot Framework for Capturing CPE and IoT Zero Days

- At the beginning we were not able to capture a valid sample as the honeypot needs to be able to simulate the above scenarios. We had to tweak and customize our honeypot quite a few times, then finally in Oct, we got it right and successfully tricked the botnet to send us the sample (we call it BCMUPnP_Hunter).
- https://blog.netlab.360.com/bcmpupnp_hunter-a-100k-botnet-turns-home-routers-to-email-spammers-en/
- Original slides by the authors of the paper:
- https://www.cl.cam.ac.uk/~amv42/papers/vetterl-clayton-honware-virtual-honeypot-framework-ecrime-19-slides.pdf

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Conclusion

- Honware uses real services/applications which are shipped with the device
  - In addition to that, the native configuration files are loaded
- Better than existing emulation strategies in all areas
  - Extraction, network reachability, listening services
- Capable of detecting vulnerabilities at scale
  - Rapid emulation cuts the attackers' ability to exploit vulnerabilities for considerable time

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Entire lecture: discussion of honeypot frameworks

1. What do you think of the proposed frameworks today? Would you change something and why?

2. Should governments only allow the sale of an IoT device, if they can run the firmware on a testbench?

3. Can you think of legal implications of running IoT honeypots?

Lecture feedback

To what extent do you think you can explain the purpose of IoT honeypots?

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Lecture feedback

To what extent do you think you can discuss IoT honeypot design choices?

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Discussion & feedback

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