Lecture #5: IoT malware analysis

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University of Twente | May 25, 2022

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ITS NOT MALWARE
WH
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ITS ALTERNATIVE SOFTWARE
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Today's agenda

- Admin
- Introduction to today's lecture
- Paper on RIoTMAN
- Break
- Paper Open for Hire
- Feedback

Admin

Interactive lectures

- Overall 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 and open questions (not graded) and discussion
  - 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

Paper summaries

- You must have handed in your two summaries **before 7AM on the day of the lecture**
- Each summary can be at most 250 words, at most 1 single-sided A4 page
- You can add figures, and graphs from the paper or add your own if you like (e.g., concept maps)
- You can use the summaries during the oral exam
- Submit through CANVAS
- You **cannot** complete SSI without submitting 12 paper summaries!

Schedule

No.	Date	Contents
1	Apr 26	Course introduction Guest lecture #1: IoT and SPIN
2	May 11	Lecture: IoT security risks and challenges
3	May 18	Lecture: IoT Botnet Measurements
4	May 24	Guest lecture #2: Intro to cyber-physical systems (Jeroen Gaiser, Rijkswaterstaat)
5	May 25	Lecture: IoT Malware Analysis
6	Jun 1	Lecture: IoT Edge Security Systems
7	Jun 7	Lecture: IoT Device Security
8	Jun 14	Guest lecture #3: Strengthening the IoT Ecosystem: Privacy Preserving IoT Security Management (Dr Anna Maria Mandalari, Imperial College London)
9	Jun 15	Lecture: IoT in Non-Carpeted Areas
10	Jun 22	Lecture: IoT Honeypots (re-sit)

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Important dates

- Two summaries per lecture: before the lecture (07:00 CEST) in which the papers will be discussed
- Lab report (PDF) and required files: **Sun June 26, 2022, 23:59 CEST**
- All to be submitted through CANVAS

Introduction to today's lecture

Motivation: mitigation of IoT botnets

- Requires tools and services to understand **different** IoT botnets in a timely way and means to detect and eradicate them

- Challenging because of wide variety of IoT devices and their increasing number and distribution across multiple network operators

- Examples: post-mortem analysis [Mirai, Hajime], IoT honeypots [IoTPot, Honware], automated malware analysis [RIoTMAN], firewalls and IDS [DBolt, ARA]

Today's papers

[RIoTMAN] A. Darki, and M. Faloutsos, "RIoTMAN: a systematic analysis of IoT malware behavior", CoNEXT '20: Proceedings of the 16th International Conference on emerging Networking EXperiments and Technologies, November 2020

[OpenForHire] S. Srinivasa, J.M. Pedersen, E. Vasilomanolakis, "Open for hire: Attack trends and misconfiguration pitfalls of IoT devices", 21st ACM Internet Measurement Conference (IMC 2021), November 2021

Today's learning objective

- After the lecture, you will be able to discuss different ways of analyzing IoT malware at scale, so across different IoT botnets (the pervious lecture focused on individual botnets)

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

“RIoTMAN: a systematic analysis of IoT malware behavior”

16th International Conference on emerging Networking EXperiments and Technologies (CoNEXT), November 2020

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Wooclap quizzes (max 3 per paper)

Multiple-choice questions: 30 seconds
Open questions: 1.5 minutes

Problem and approach

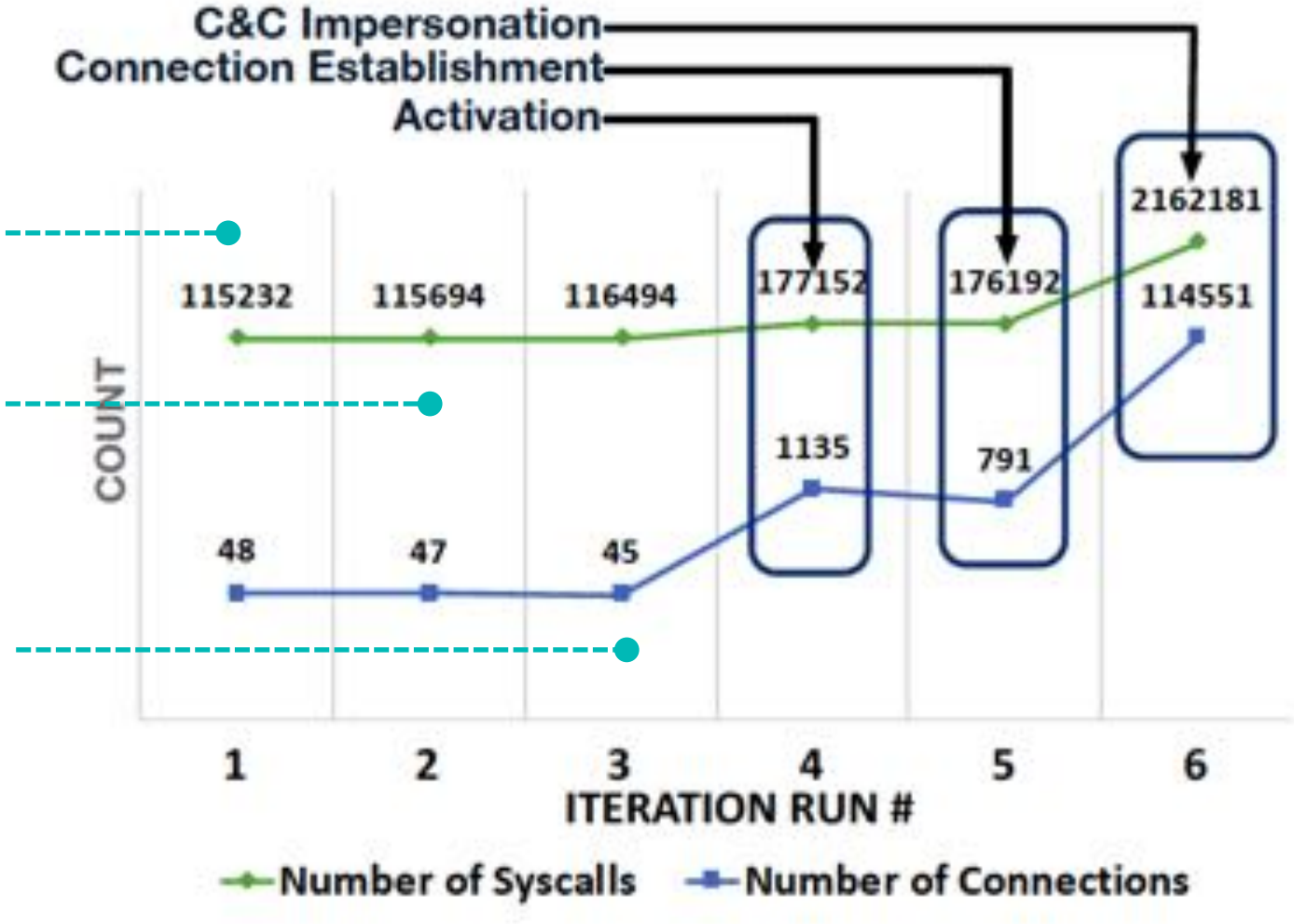
- Profiling the behavior of IoT malware based on binaries => understand, detect, mitigate
- Labor intensive because of wide variety of a IoT devices and their growing number
- RIoTMAN dynamically analyzes botnets: adaptive sandboxing and communications exploration
- Goal: profile the behavior of IoT malware binaries
- Activated malware: infection complete and establishes comms with outside world
- Engaged malware: instructions result in new traffic/system behavior and connection stays up

Example: Linux.Tsunami

uClibc and libnvram libs missing

Malware fails to access NVRAM memory

Missing source configuration information (a device name in this case) from the simulated NVRAM.



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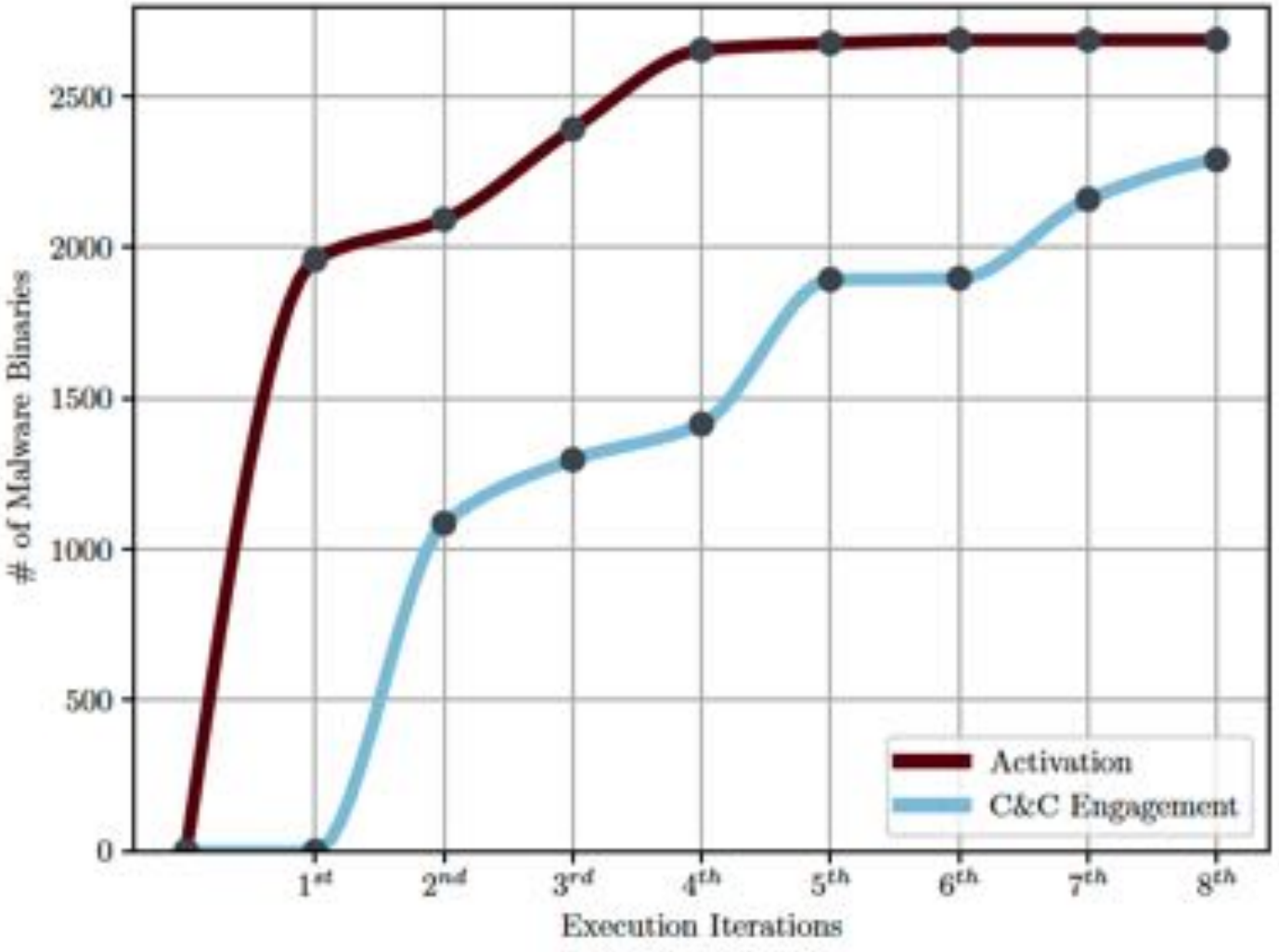
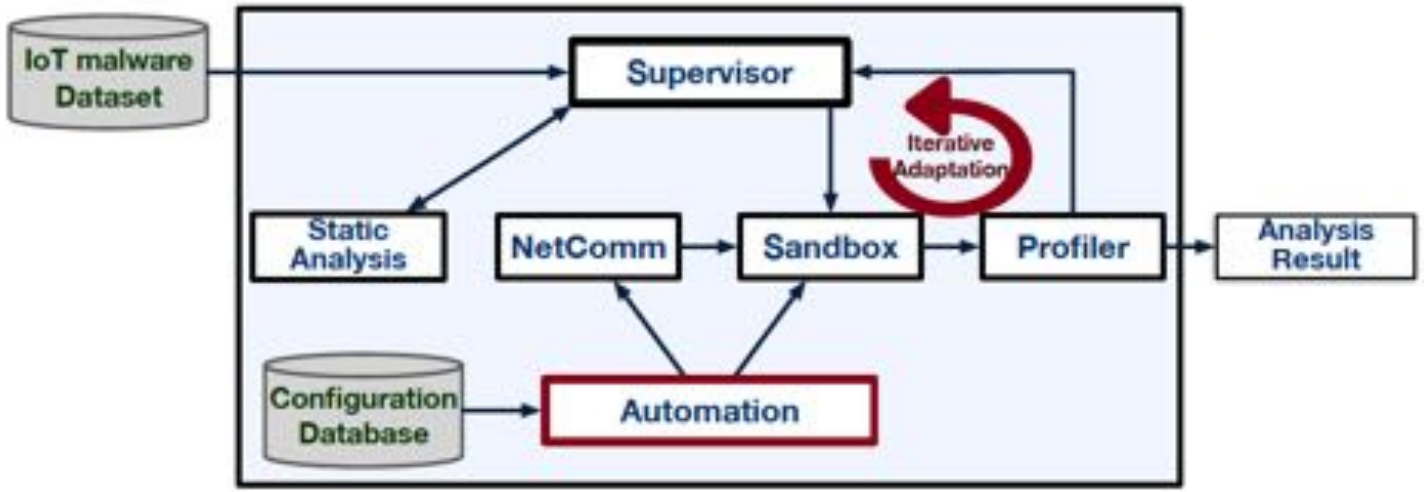
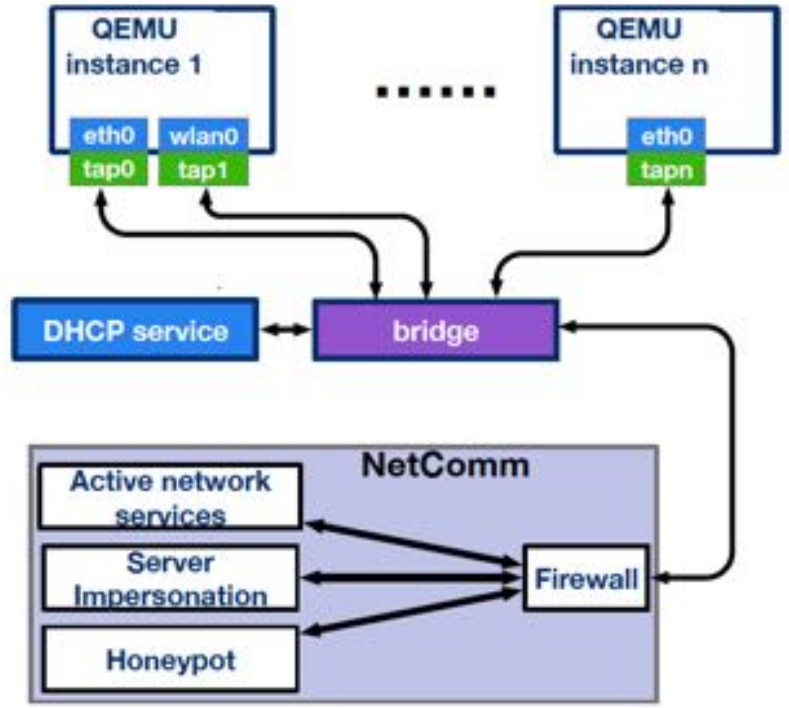
Key measurement result – what are we looking at?



RIoTMAN measurement architecture





What are the responsibilities of the components?
Discuss!

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Measurement results

Total binaries	2885	
Activated	2688	93%
Engaged	2291	79%

Command Type	**Malware**	
Configuration or Report	1750	61%
Attack	2031	70%
Scanning	1842	64%
Termination	1684	58%

IoT malware behaviors discovered

IP address	Single	2261
	Multiple	62
Domain	Fixed	257
	DGA	5

Family from Virustotal	Impersona-tion Success	Gafgyt C&C		Tsunami C&C		Aidra C&C	Mirai C&C
		Prometheus	QBot	Remaiten	Capsaicin	Lightaidra	Mirai
Gafgyt (>6 sub-families)	94%	148	1296	-	2	-	5
Tsunami (>2 sub-families)	98%	4	26	43	25	-	-
Aidra (>2 sub-families)	87%	1	5	-	-	2	-
Mirai (>2 sub-families)	86%	-	-	-	-	-	402
IRCBot	76%	-	-	-	13	-	3
IoTReaper	50%	-	-	-	-	-	2
Other (>14 families)	71%	13	120	5	6	1	45
Unclassified	70%	1	76	9	15	1	22
Total (weighted)	79%						

Malware Procedure	**Most common techniques**					
	Bin.	**Technique 1**	Bin.	**Technique 2**	Bin.	**Technique 3**
Infection	1676	Brute-force login	166	Exploit public facing apps	-	None observed
Persistence	375	Add routine in rc script	333	Add a job to cronjob	15	Specific to IoT device
Defense evasion	1494	Process masquerading	648	Malware binary removal	128	Software packing
Identifying device	1445	Use network config	843	Use config files	286	List processes in device
Impact on host	414	Block OS level access	413	Stop remote services	6	Bitcoin mining

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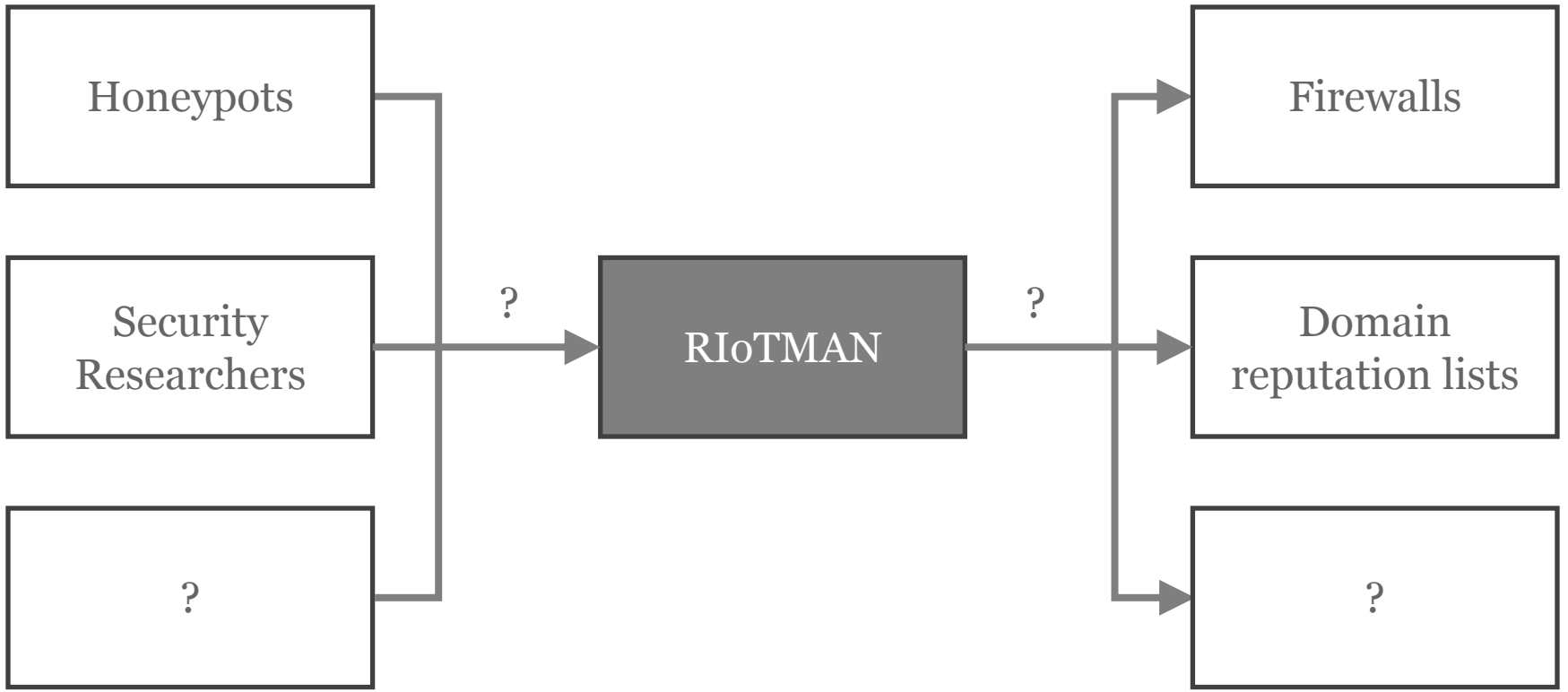
RIoTMAN and its ecosystem



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Limitations

- Linux-based IoT devices only

- They exclude botnets that use encryption, P2P botnets, and IPv6 communications

Further discussion

Key takeaways

- Dynamic analysis of IoT malware, limited manual effort
- Important to understand, detect, and mitigate IoT botnets at scale
- One piece of the “IoT botnet mitigation puzzle”
- Significant amount of work in terms of engineering, finding datasets, and analysis
- Next challenge: how will RIoTMAN-like systems work in practice (higher TRLs)?

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Coffee break

“Open for hire: Attack trends and misconfiguration pitfalls of IoT devices” Internet Measurement Conference 2021

S. Srinivasa, J.M. Pedersen, E. Vasilomanolakis

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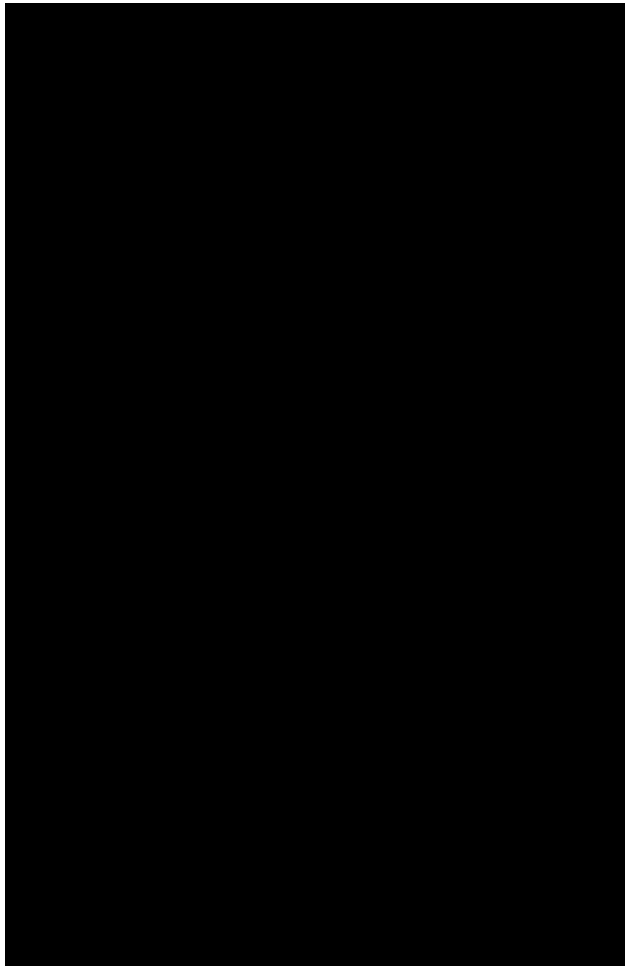
Question: what is this paper about? (And the methodology)?

Three-part methodology



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Scanning IPv4 or IPv6?

Scanning IPv4: Misconfigurations

Protocol	Vulnerability	#Devices found
CoAP	No auth, admin access	427
AMQP	No auth	2,731
Telnet	No auth	4,013
XMPP	No encryption	5,421
CoAP	No auth	9,067
Telnet	No auth, root access	22,887
MQTT	No auth	102,891
XMPP	Anonymous login	143,986
CoAP	Reflection-attack resource	543,341
UPnP	Reflection-attack resource	998,129
Total		**1,832,893**

Table 5: Total misconfigured devices per protocol

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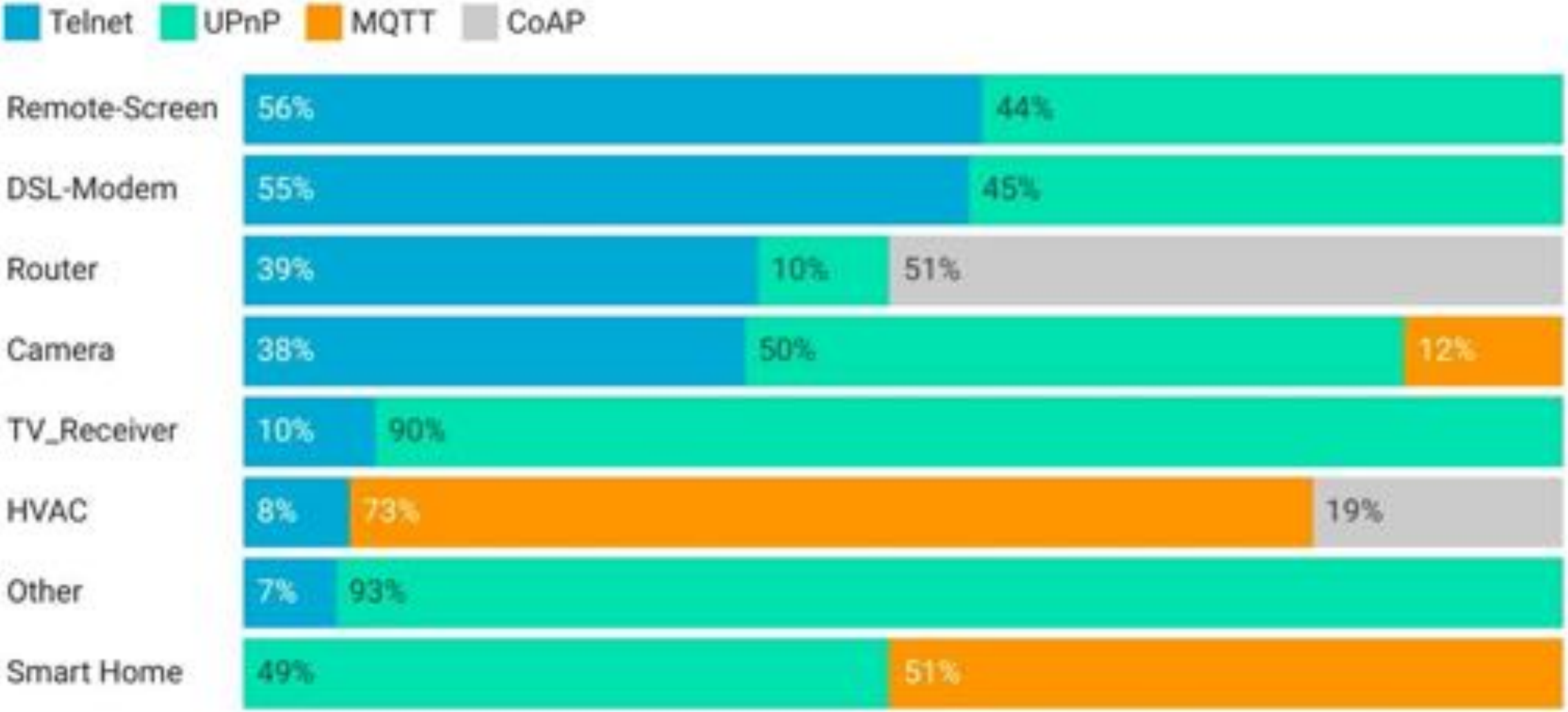
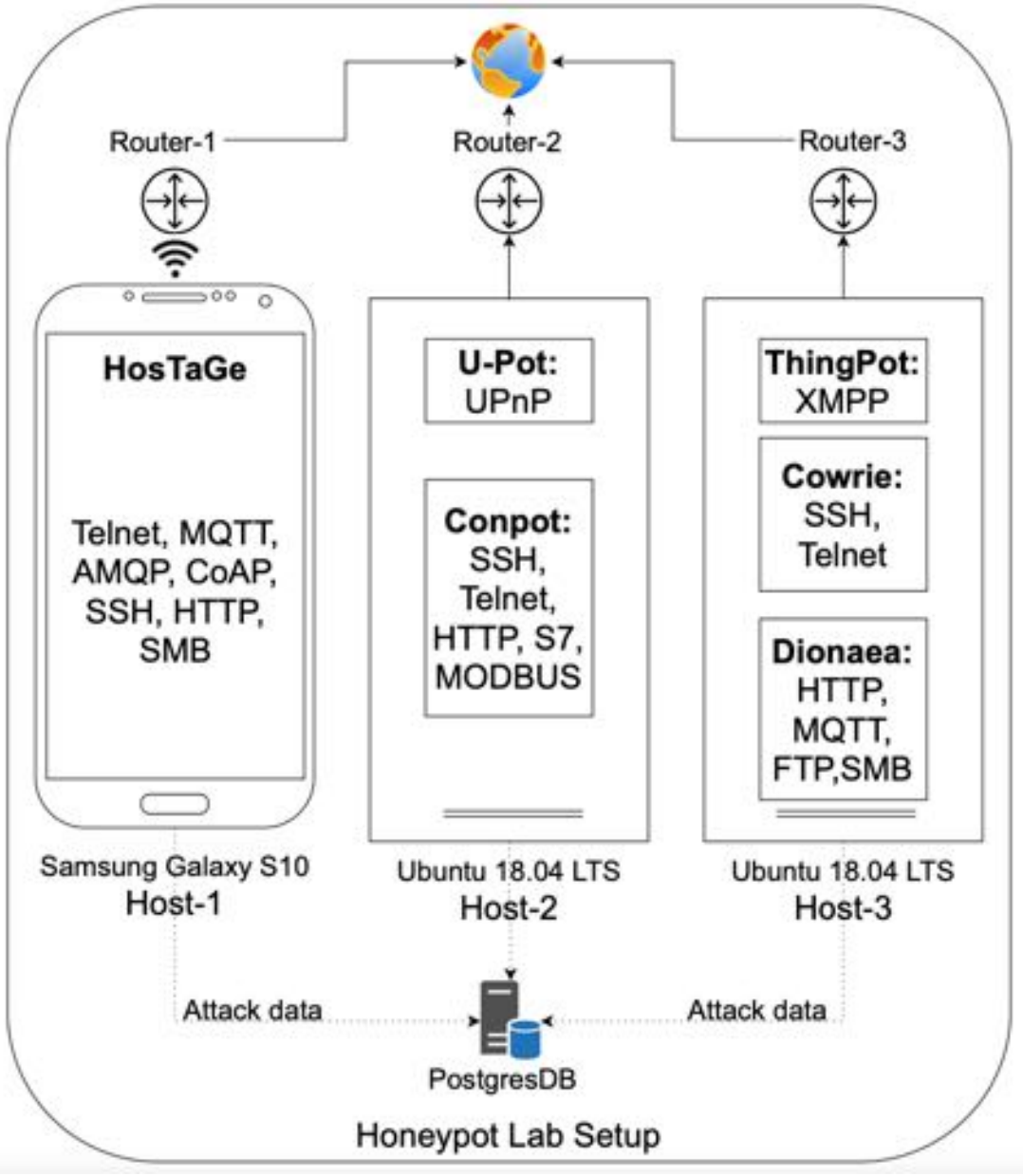
Scanning: discovered devices



Honeypots



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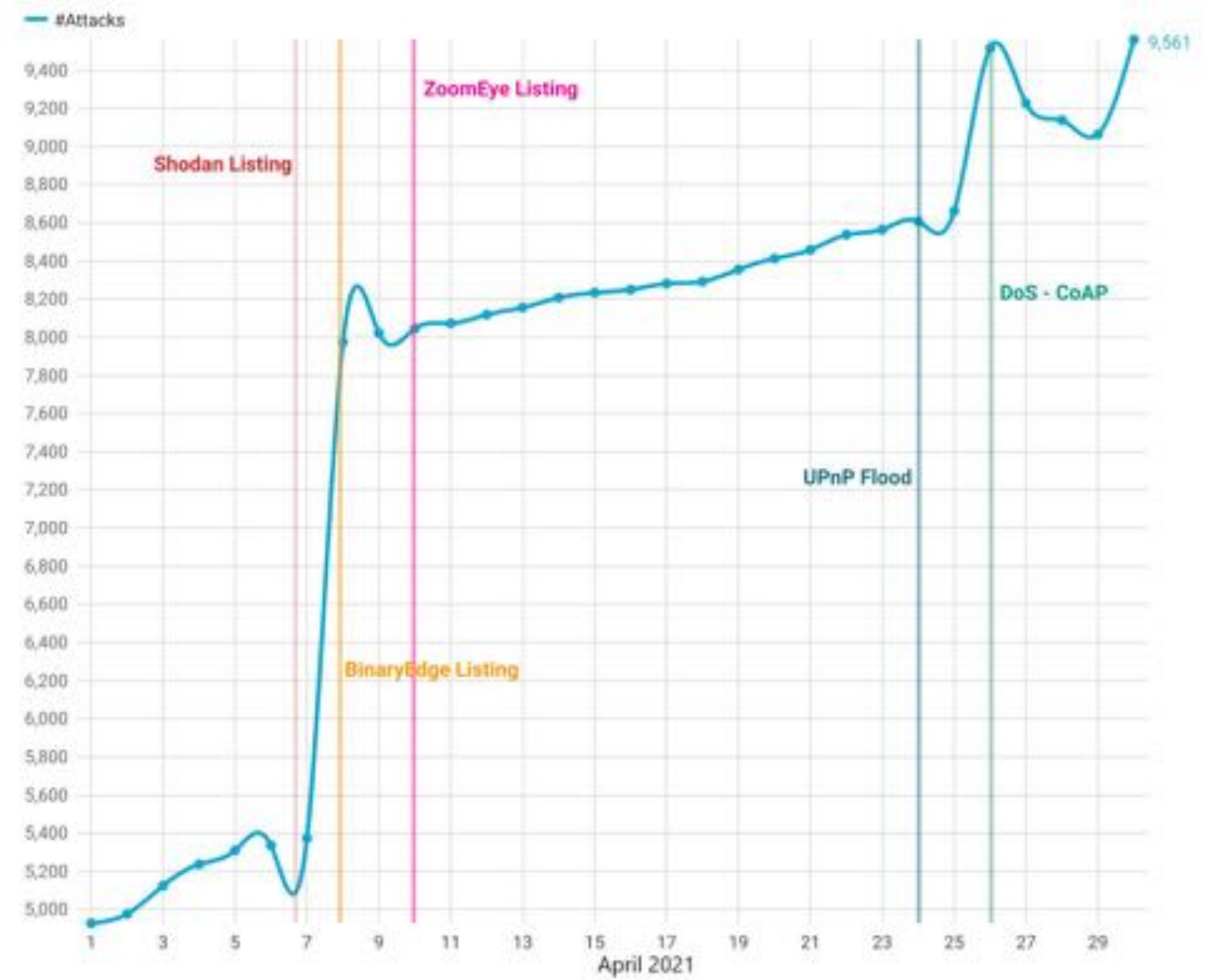
What do you conclude?



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Attacks per service

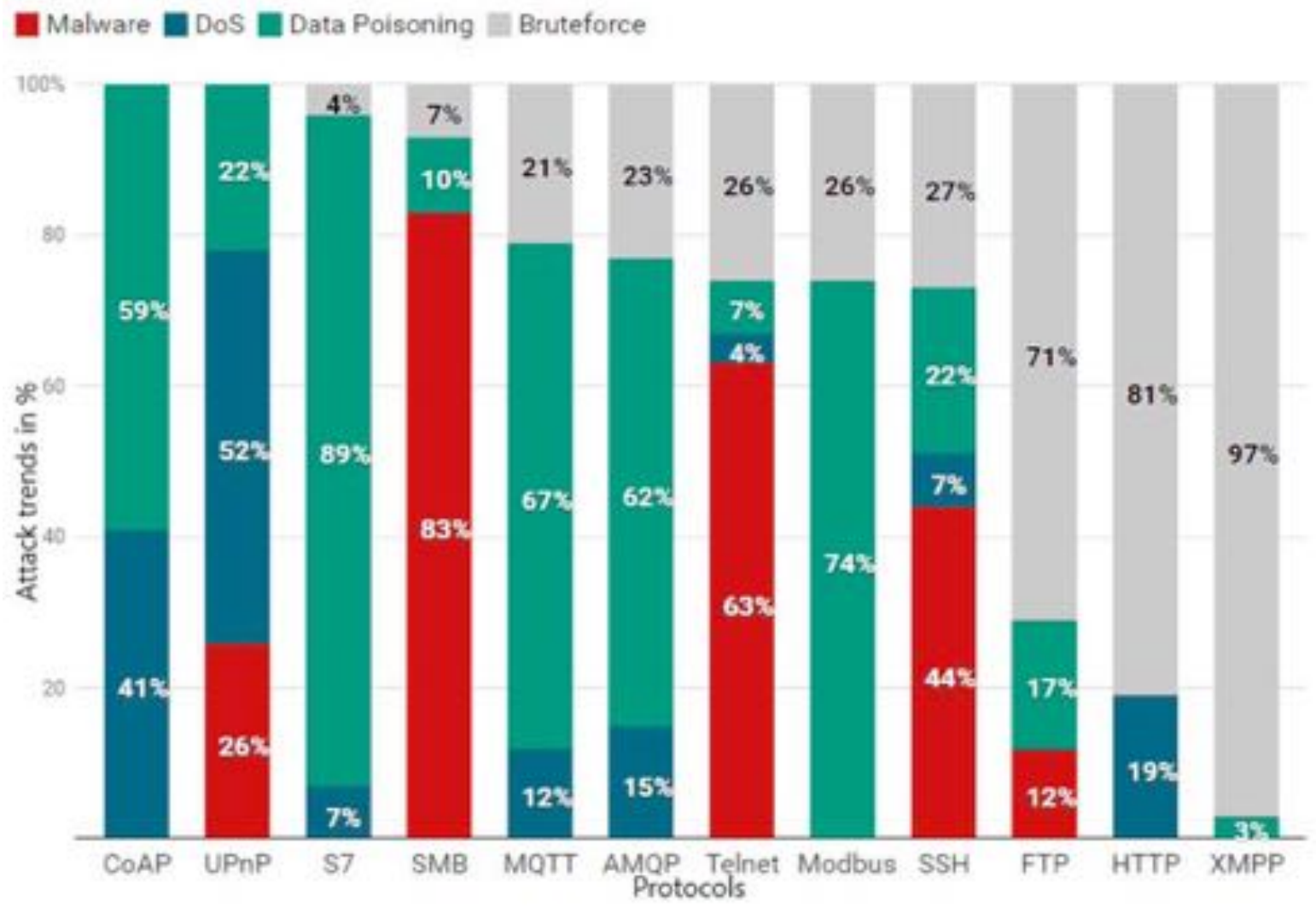

Figure 7: Attack trends by type (%) and protocol

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Attacks per honeypot software

Honeypot	Simulated Device Profile	Protocol	#Attack events	Scanning service*	Malicious*	Unknown/ Suspicious*
HosTaGe	Arduino Board with IoT Protocols	Telnet MQTT AMQP CoAP SSH HTTP SMB	19,733 2,511 2,780 11,543 19,174 16,192 1,830	2,866	21,189	2,347
U-Pot	Belkin Wemo smart switch	UPnP	17,101	1,121	7,814	1,786
Conpot	Siemens S7 PLC	SSH Telnet S7 HTTP	12,837 12,377 7,113 11,313	1,678	11,765	1,876
ThingPot	Philips Hue Bridge	XMPP	11,344	967	2,172	963
Cowrie	SSH Server with IoT banner	SSH Telnet	15,459 14,963	2,111	12,874	1,113
Dionaea	Arduino IoT device with frontend	HTTP MQTT FTP SMB	11,974 1,557 3,565 6,873	1,953	13,876	1,694
Total			**200,209**	**10,696**	**69,690**	**9,779**

Table 7: Total attack events by type and protocol on honeypots (* unique source IPs)

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Telnet and SSH scans

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Multistage attacks

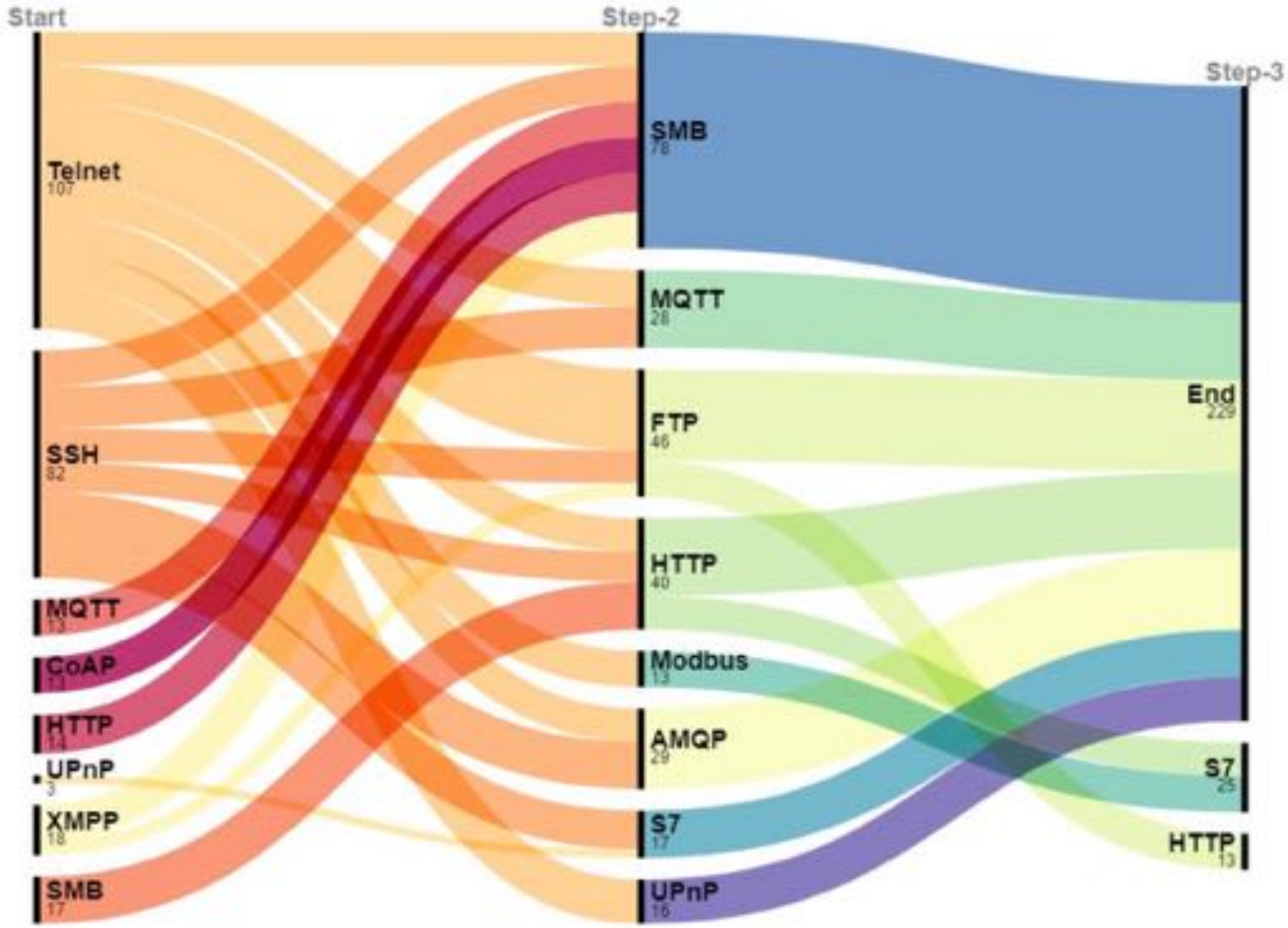

Figure 9: Multistage attacks detected on honeypots

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Darknet / Network telescope

Protocol	Daily Avg. Count	Unique IP	Scanning-service	Unknown/Suspicious
Telnet	2,554,585,920	85,615,200	4,142	85,611,058
UPnP	131,794,560	1,8633	2,279	16,354
CoAP	68,353,920	2,342	627	1,715
MQTT	17,072,640	5,572	1,248	4,324
AMQP	13,907,520	7,132	2,256	4,876
XMPP	6,429,600	4,255	1,973	2,282
Total	**2.7 Bil.**	**85.6 Mil.**	**12525**	**85.6 Mil.**

Table 8: Telescope suspicious traffic classification

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Ethics

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Linking datasets

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Discussion

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Key takeaways

- RIoTMan shows the next steps in analyzing botnets in an automated fashion.

- Combining datasets (just like in the Mirai paper) at scale is feasible (but still a lot of work ☺)

- Today's papers only provide a small piece of the puzzle of how conduct botnet analysis in the future.

Lecture feedback

https://www.wooclap.com/SSILECTURE5

1: wooclap

2: Open feedback

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You cannot vote anymore

To what extent will you be able to discuss different ways of analyzing IoT malwa...

1 Green (good) 75% 15

2 Orange (medium) 25% 5

3 Red (bad) 0% 0

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Discussion & feedback

Next lecture: **Wed Jun 1, 10:45-12:30 VR 583**

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