Chair of Network Architectures and Services
Department of Informatics
Technical University of Munich

Security Implications of Publicly Reachable Building Automation Systems

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Outline

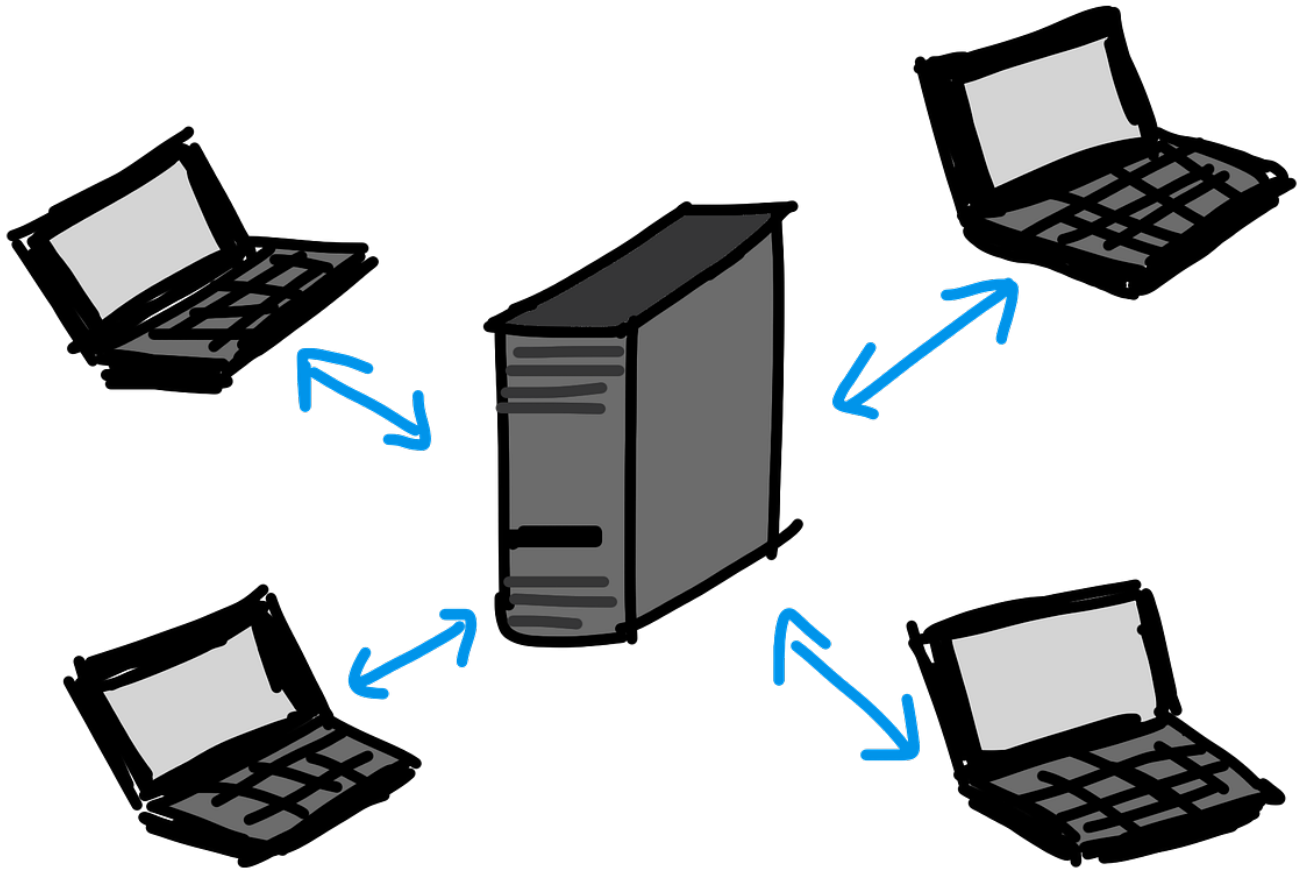
Motivation

Building Automation Protocol

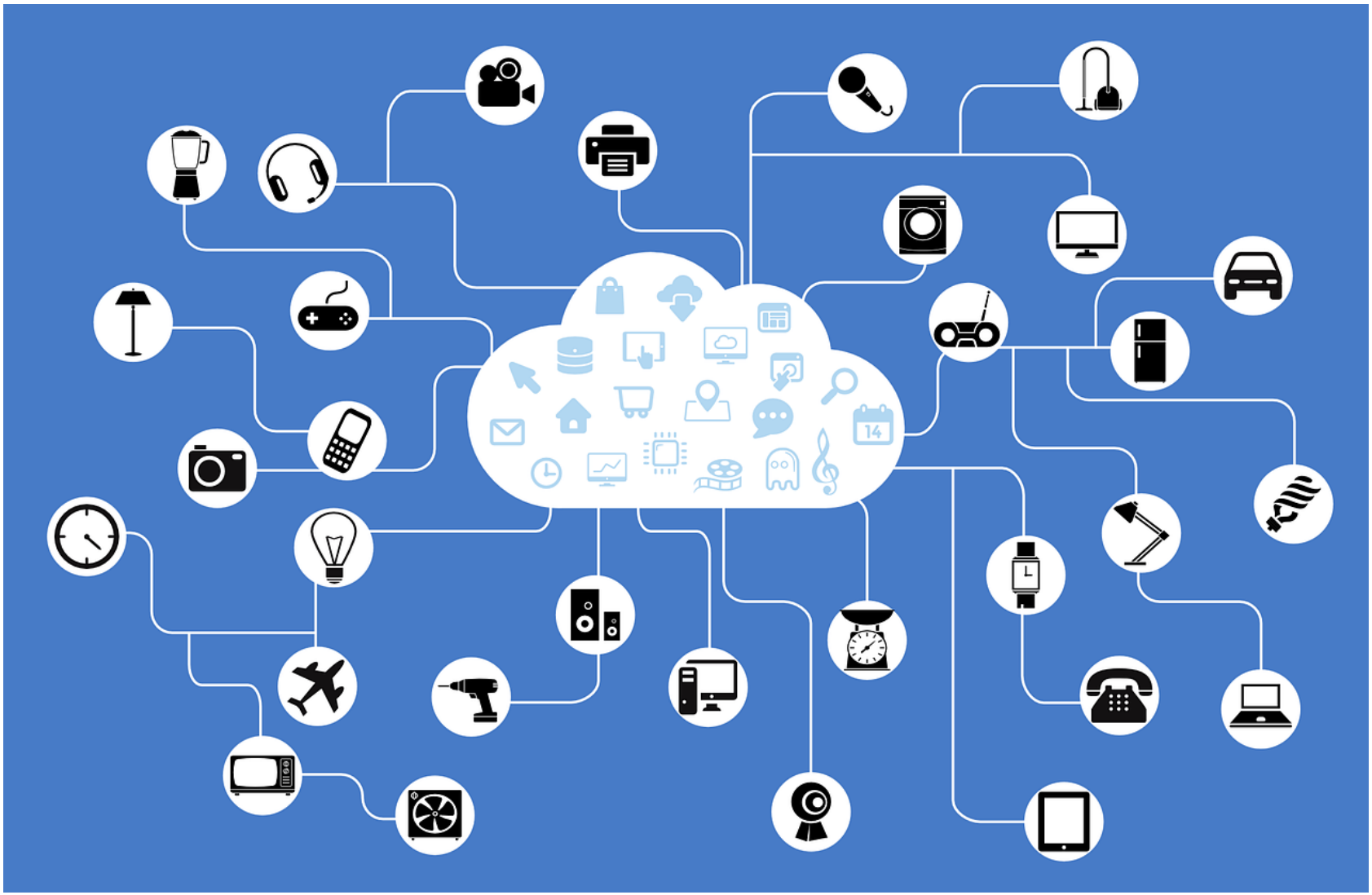
Finding Building Automation Devices

Security Implications

The Internet?



The Internet



Internet of Things

- More and more embedded systems and devices
- Implications of network connectivity unclear to most users
- Security risk
  - Data theft
  - Privacy
  - Manipulating operation of devices
  - Misuse for attacks (*e.g.*, Mirai botnet)

Our goal

- Find publicly accessible building automation systems
- Evaluate deployment
- Analyze security implications

BACnet

History:

- 1995: Building Automation and Control Networks
- 1999: BACnet/IP
- 2016: BACnet/IPv6

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Use cases:

- Heating
- Ventilation
- Air conditioning
- Security systems

BACnet protocol

- Request-response protocol
- Various services, *e.g., ReadProperty*
- UDP-based

Finding BACnet devices

BACnet scanning:

- Scan for 16 BACnet ports
- ZMap with custom UDP payload
- IPv4 and IPv6 scans

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Minimizing scan intrusiveness:

- Non-modification of BACnet devices
- Blacklist from previous scans
- Limited packet rate
- Dedicated measurement network
- Website explaining measurements

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→ No abuse emails ✓

What did we find?

No one would attach a BACnet device to the Internet, right?

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Significant clustering

- Top 5 ASes $\approx$ 30 % of total 1439 ASes
- 60 % in US, 20 % in Canada
- Top 3 vendors $\approx$ 50 % of total 97 vendors

Security implications

What are the security implications of publicly reachable BACnet devices?

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- Unauthorized data access
- Privacy (*e.g.*, presence detection)
- Manipulation of devices (*e.g.*, disable heating)
- Misuse for attacks

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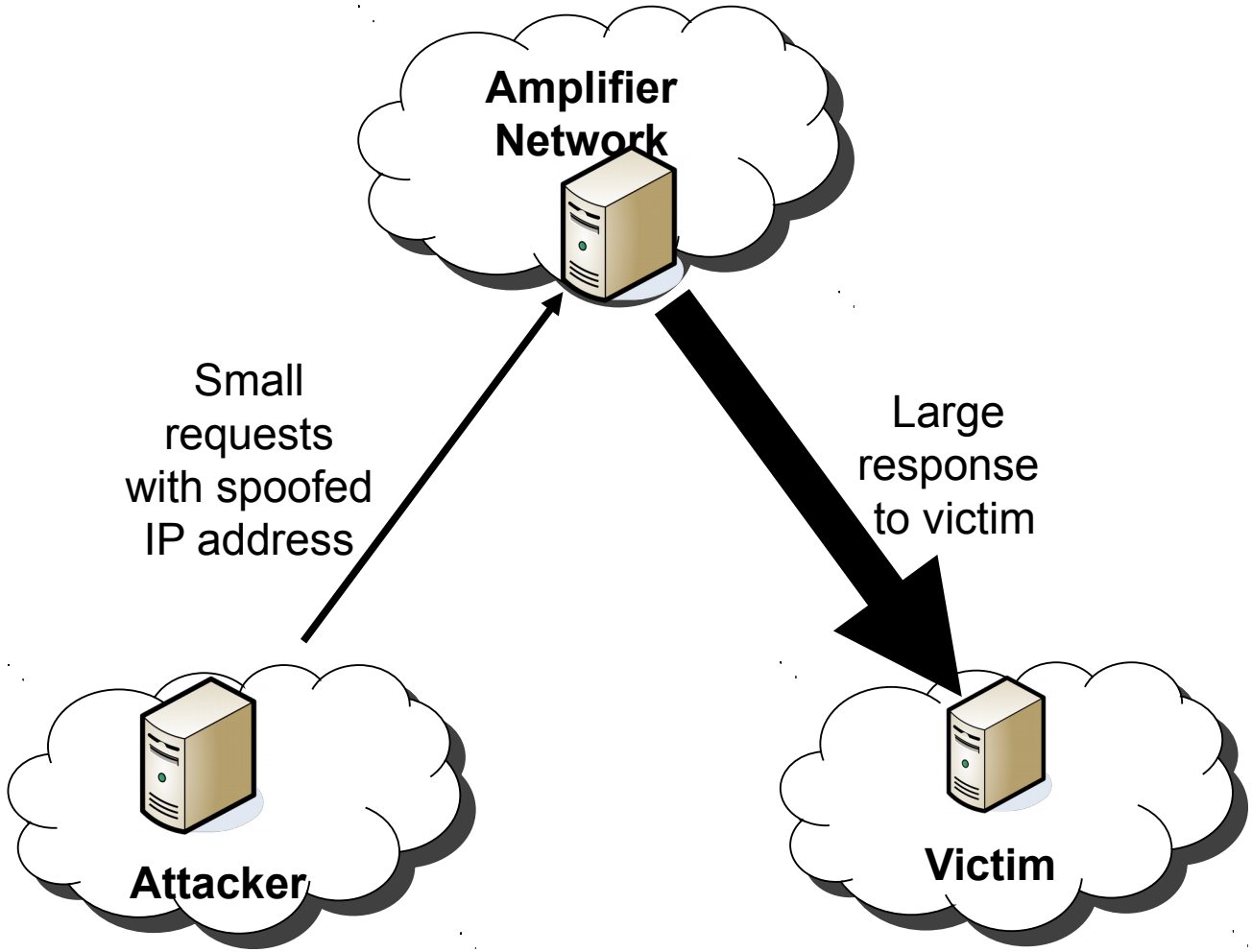
- Privacy (*e.g.*, presence detection)
- Manipulation of devices (*e.g.*, disable heating)
- **Misuse for attacks**

Amplification attacks



Amplification attack characteristics

- Connectionless:

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BACnet amplification factor

Amplification attack: small request and large response

BACnet:

- Request size: Header overhead + ID of requested property
- Response size: Depends on requested property

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Amplification attack: small request and large response

BACnet:

- Request size: Header overhead + ID of requested property
- Response size: Depends on requested property

Example:

- Request: *What is your location?*
- Response: *Fairmont Hotel, San Jose, California, USA.*

Maximizing the amplification factor

Requesting one property is nice, but. . .

- Header overhead rather large
- Not all devices might have the requested property

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Requesting one property is nice, but...

- Header overhead rather large
- Not all devices might have the requested property

ReadPropertyMultiple request

- Send a list of requested property IDs
- Reduce header overhead
- Higher chance that device has some of requested properties

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Maximizing the maximized amplification factor

It can’t get any worse, right?

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Maximizing the maximized amplification factor

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- Request: *Location? Location? Location?*
- Response: *Fairmont Hotel, San Jose, California, USA. Fairmont Hotel, San Jose, California, USA. Fairmont Hotel, San Jose, California, USA.*

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Maximizing the maximized amplification factor

~~It can't get any worse, right?~~ **Wrong**

- Request: *Location? Location? Location?*
- Response: *Fairmont Hotel, San Jose, California, USA. Fairmont Hotel, San Jose, California, USA. Fairmont Hotel, San Jose, California, USA.*

Request **the same property** multiple times within one request

- Choose property with highest amplification factor
- Reduce header overhead even more
- Maximized amplification factor, similar to DNS Open Resolvers

Amplification attacks using BACnet

- Connectionless: BACnet $\rightarrow$ UDP-based ✓
- No authentication: BACnet $\rightarrow$ No handshake necessary ✓
- Amplification:

Amplification attacks using BACnet

- Connectionless: BACnet $\rightarrow$ UDP-based ✓
- No authentication: BACnet $\rightarrow$ No handshake necessary ✓
- Amplification: BACnet $\rightarrow$ Freely choose requested property ✓

Amplification attack mitigation

- Ingress filtering against IP address spoofing
- Throttling BACnet traffic
- Standardizing that each property can be requested only once
- BACnet devices should not be reachable from the public Internet
  - Notification campaign in cooperation with DFN-CERT

BACnet: Real-world location response

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Hwy 57; Located in the silver box on the electrical pole in front of Grove Primary Care Clinic. Pole 123

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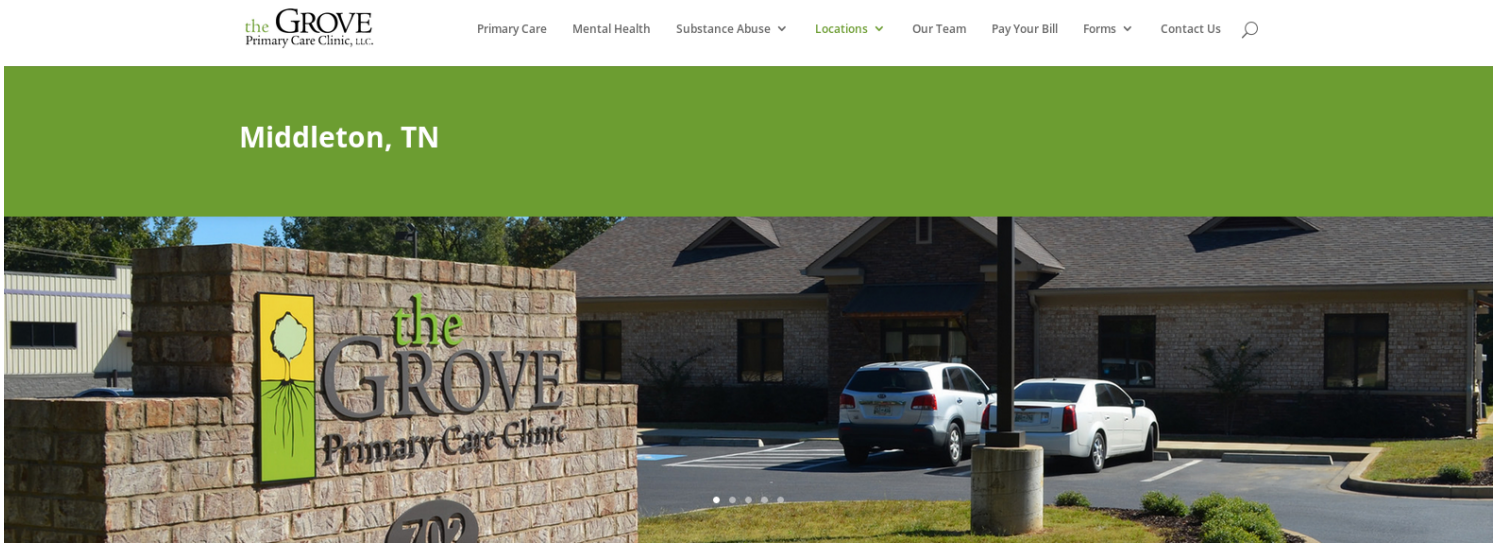

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Conclusion

- Largest Internet-wide BACnet scans to date
- Analysis of BACnet's amplification potential
- Notification campaign in cooperation with CERT
- Release of BACnet Python module as open-source

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https://www.net.in.tum.de/~gasser/

Amplification factors

- BACnet: $\approx$ 30x
- DNS: $\approx$ 40x

Table 1: Overview of all BACnet scans.

Type of scan	Ports	Rate	Duration	Targets	Resp.	BACnet
IPv4-wide	16	25 kpps	41 h	2.4 G	32 868	16 485
IPv6 hitlist	1	5 kpps	2 min	407 k	0	0
Amplification	16	100 pps	3 min	16 k	15 598	15 429

Table 2: Top 5 BACnet vendors in results.

Pos.	Vendor ID	Vendor Name	Count	%
1	35	Reliable Controls Corporation	3740	24.8
2	36	Tridium Inc.	2079	13.8
3	8	Delta Controls	2004	13.3
4	5	Johnson Controls Inc.	1328	8.8
5	24	Automated Logic Corporation	1051	7.0

Table 3: Top 5 ASes by count of BACnet devices.

Pos.	ASN	Organization	Count	%
1	7018	AT&T Services, Inc.	1510	9.2
2	7922	Comcast Cable Communications, Inc.	1450	8.8
3	22394	Cellco Partnership DBA Verizon Wireless	774	4.7
4	852	TELUS Communications Inc.	697	4.3
5	6327	Shaw Communications Inc.	454	2.8

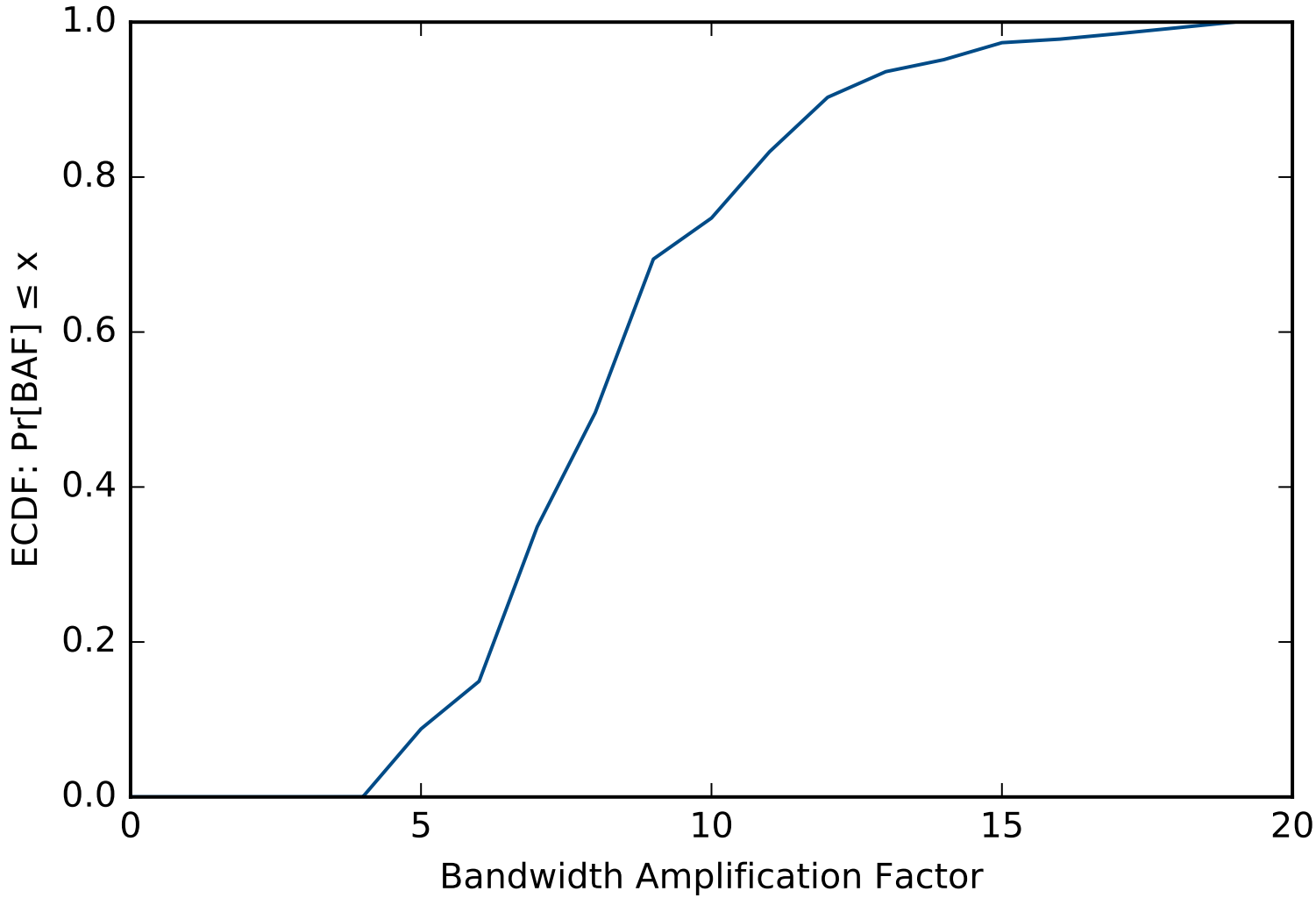

Figure 1: Distribution of BAF for our generic *ReadPropertyMultiple* amplification payload used in scans.

Table 4: Property BAF and payload BAF as mean over *all*, top *50 %* and top *10 %* amplifiers.

		Property BAF			Payload BAF		
Property	Amplifiers	all	50 %	10 %	all	50 %	10 %
model_name	14 072	6.2	8.3	8.5	1.5	1.7	1.7
vendor_name	14 072	9.0	13.9	14.5	1.8	2.2	2.3
firmware_revision	14 072	11.2	19.6	35.0	2.0	2.8	4.2
app_sw_version	14 071	5.9	10.3	14.0	1.5	1.9	2.2
object_name	14 039	6.8	9.1	11.0	1.6	1.8	2.0
description	13 741	5.5	10.9	13.0	1.4	1.9	2.1
location	13 360	2.5	5.1	7.5	1.1	1.4	1.6
serial_number	2316	4.9	5.6	5.0	1.4	1.4	1.4
profile_name	1958	5.0	7.0	7.0	1.5	1.8	1.8
property_list	1389	141.0	193.8	200.0	7.3	9.7	10.0

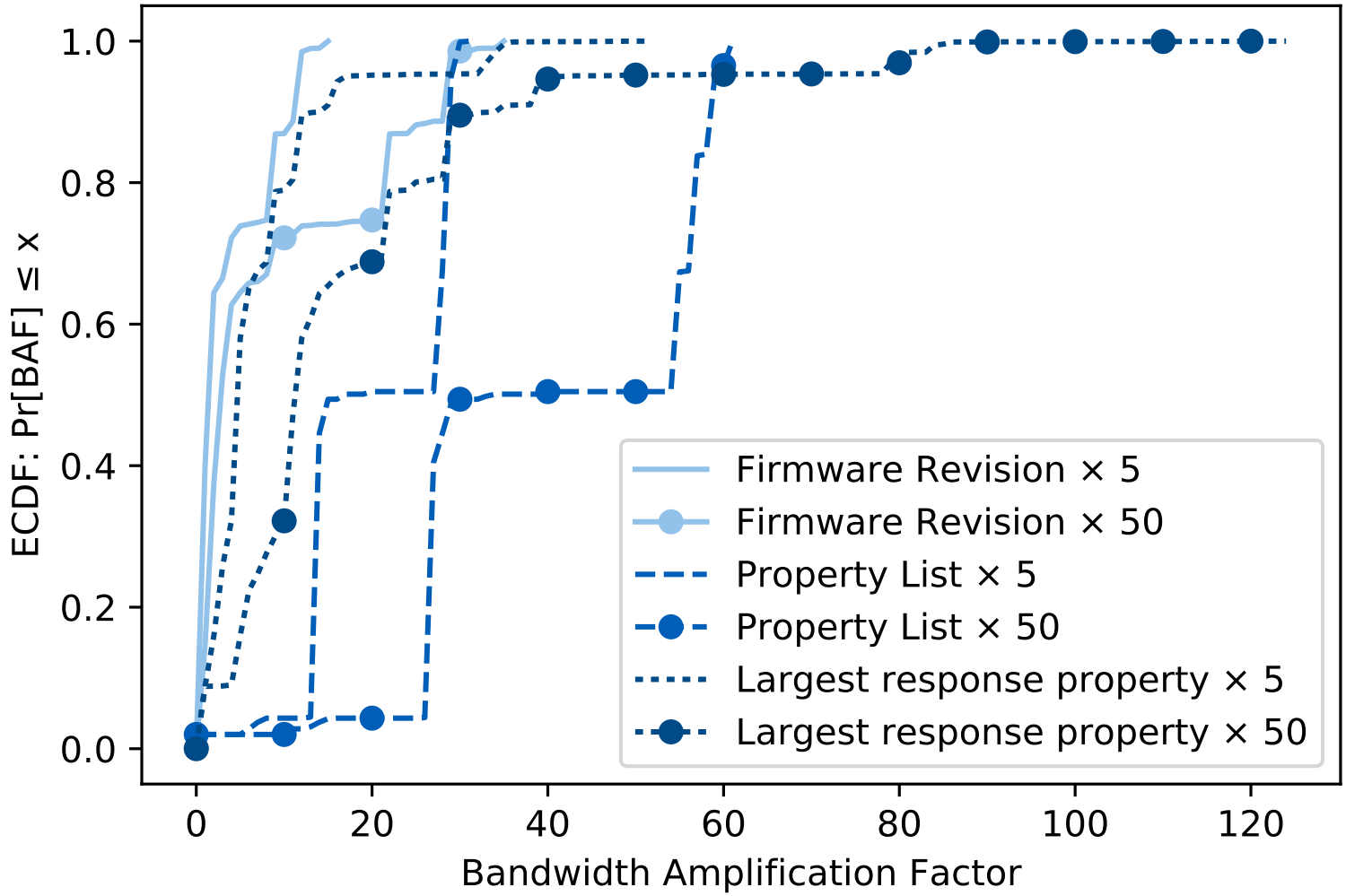

Figure 2: Payload BAF when issuing multiple requests for the same property (within a single Multi-Property packet).