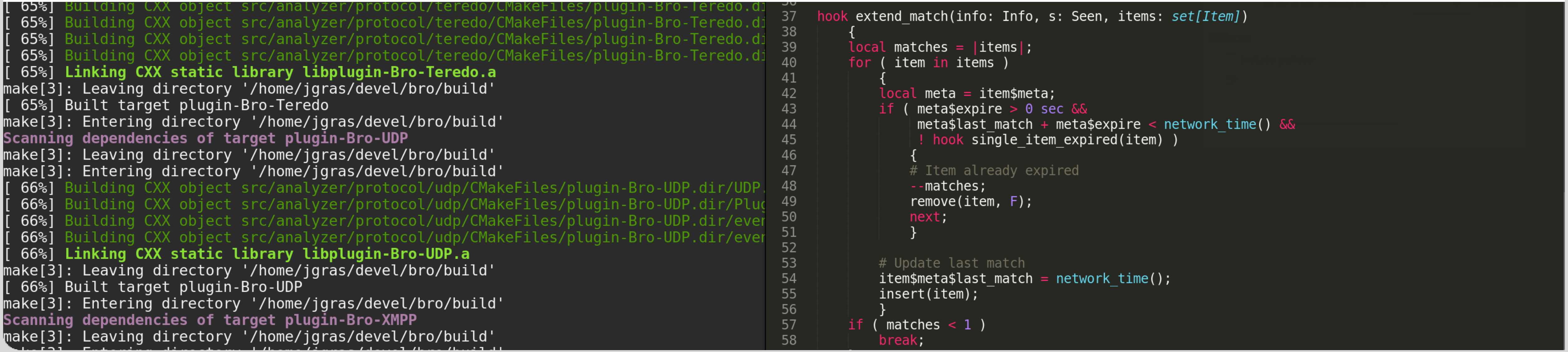
Bro @ KIT

Jan Grashöfer, Christian Titze, Matthias Grundmann

DECENTRALIZED SYSTEMS AND NETWORK SERVICES RESEARCH GROUP (DSN)
INSTITUTE OF TELEMATICS, FACULTY OF INFORMATICS



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1. Improving Threat Intelligence matching
   Jan

2. Security-oriented Performance Analysis
   Christian

3. Ransomware detection in academic environments
   Matthias

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Jan Grashöfer

IMPROVING THREAT INTELLIGENCE MATCHING

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The Intelligence Framework

Indicator Type	Example
ADDR	192.0.2.42, 2001:db8::23
SUBNET	192.0.2.0/24, 2001:db8::/32
URL	~~http://~~example.com/test/
SOFTWARE	Mozilla/5.0…
EMAIL	malicious@example.com
DOMAIN	www.example.com
USER_NAME	not used
CERT_HASH	38762cf...bb7f0a
PUBKEY_HASH	ee4aa5…0a750c
FILE_HASH	5bd9d8…39b8d1
FILE_NAME	infected.pdf

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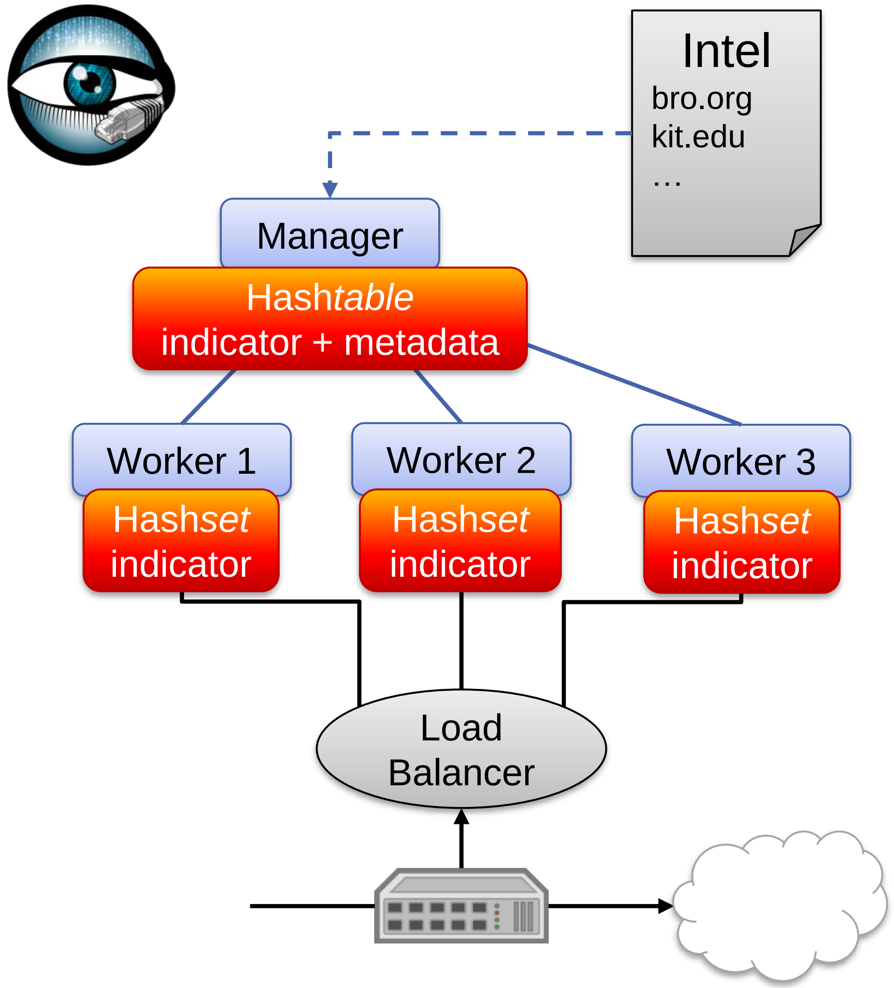
Improve Intel Matching



- Bro supports clustering to scale
  - Manager → coordination
  - Worker → traffic processing
- Intelligence Framework
  - Manages indicator + metadata
  - Distributes indicators for matching
- Requirements:
  - Efficient matching
  - Support removal
- Idea: Use Cuckoo Filter?

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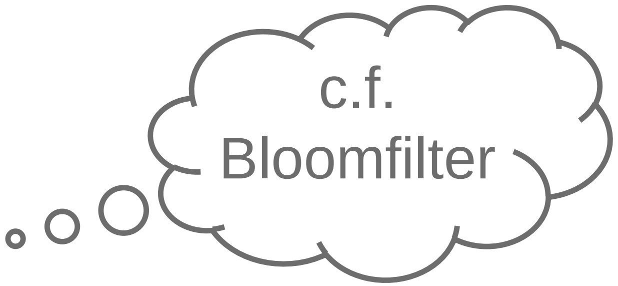
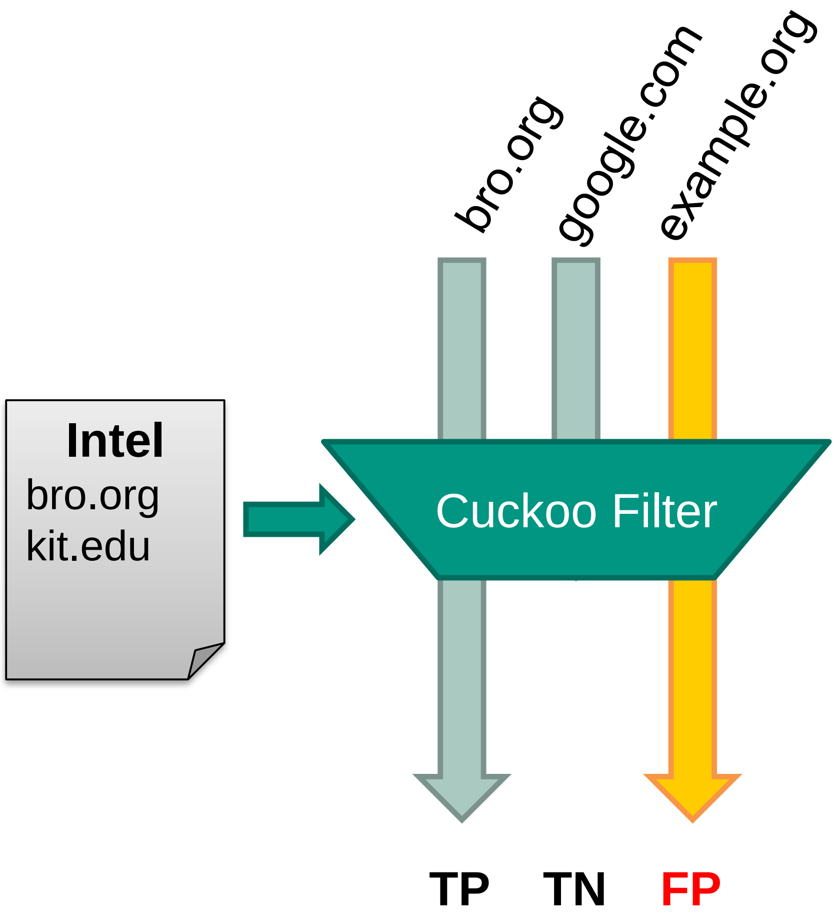
Cuckoo Filter*

- Probabilistic data structure
  - High space efficiency
  - False Positives (FP) but **never** False Negatives!
  - FP-Probability tunable → space tradeoff
- Support removal





* B. Fan, D. G. Andersen, M. Kaminsky, und M. D. Mitzenmacher, „Cuckoo Filter: Practically Better Than Bloom“, 2014, S. 75–88.

Cuckoo Filter – Exploration

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- New implementation **cuculiform** (C++)
  - allows runtime configuration → script-land interface
  - discovered implementation and configuration pitfalls

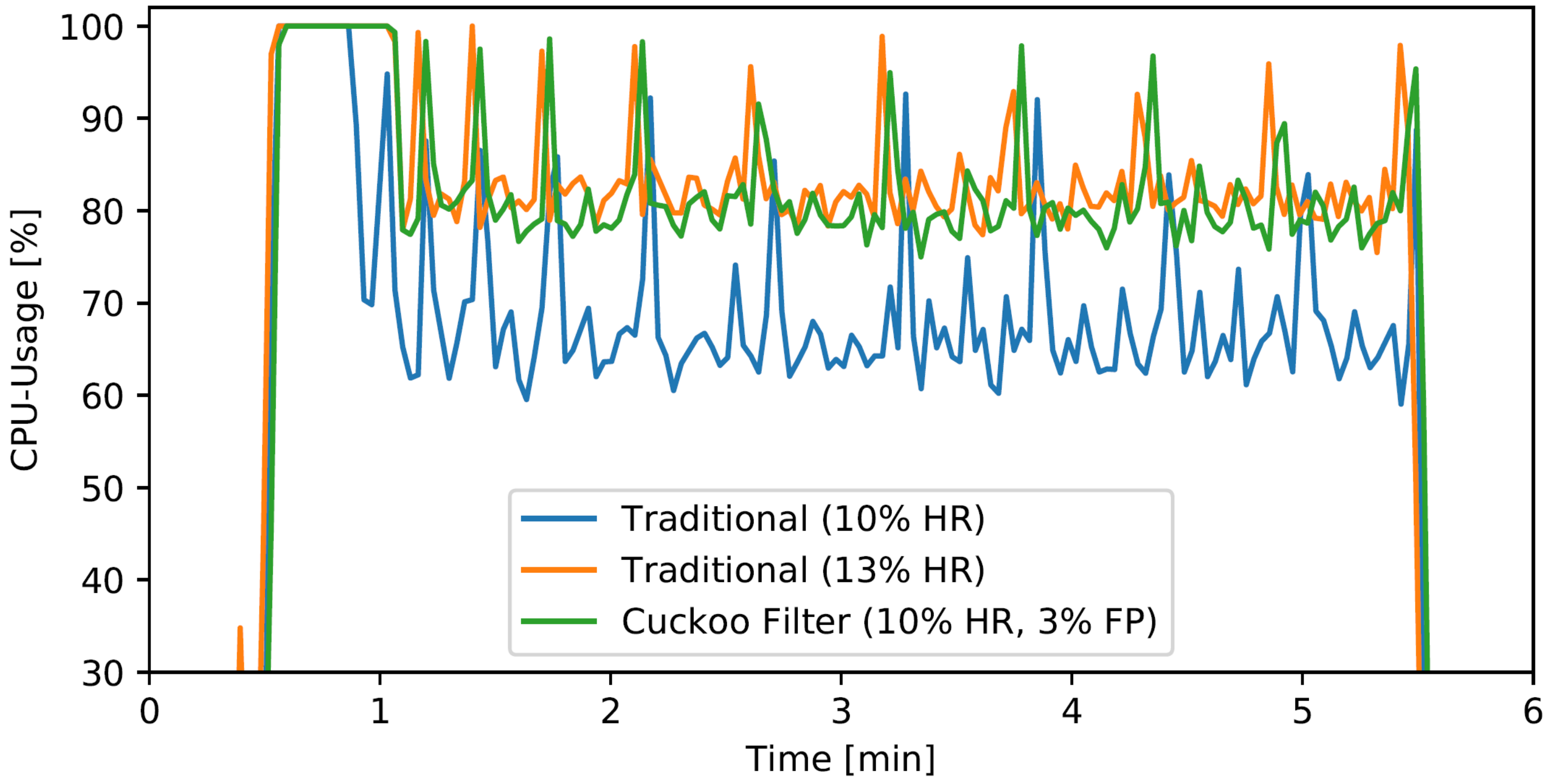
- Comparison of different Implementations

Implementation	Structure Size [KiByte]	FP-Rate [%]	Lookup-Time [μs]
Bro Hashtable	211 202.8	-	1.7589
Bro Hashset	145 666.8	-	1.9281
Reference	1 024.0	2.9794	0.9637
Rust	1 024.0	2.9789	1.0847
Cuculiform	1 024.0	2.9787	1.3746

Fingerprint size 8 bit, 4 elements per bucket, 1 Mi elements capacity, mean of 1 000 runs (confidence intervals negligible)

50 workers → save ~10 GB

Cuckoo Filter – Integration into Bro



- CPU-Usage on worker nodes varying data structure and Hit Rate (HR)

▶ Overhead occurs on the worker!

Future Work

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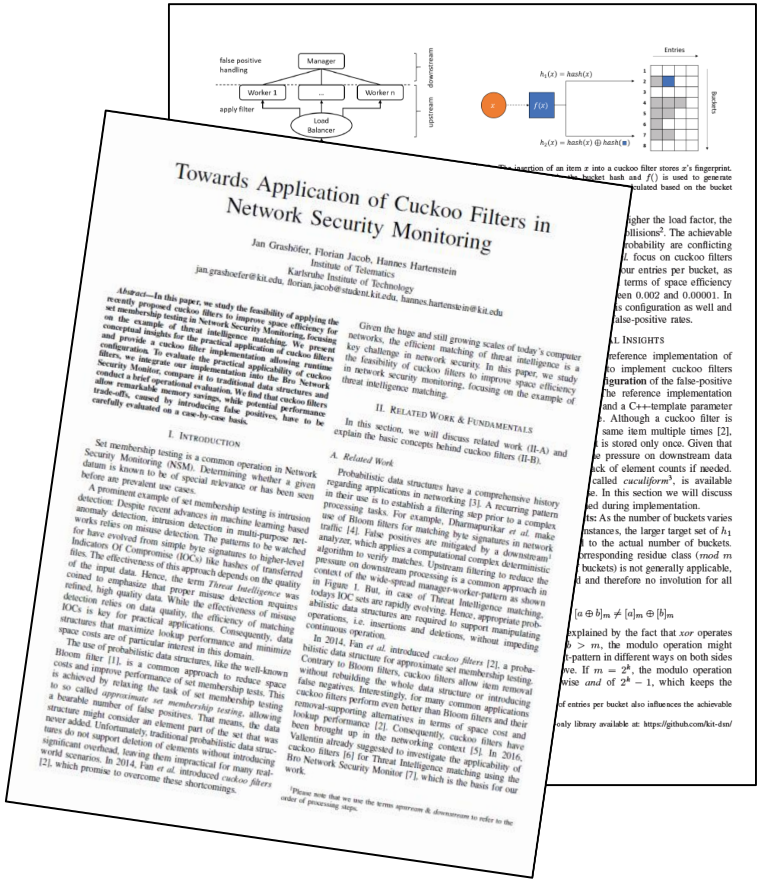
- Estimate typical Intel Framework workloads
  - Number of Indicators
  - Connections per Hour
- FP-Rate ≠ FP-Probability
  - Assume google.com yields a false positive → FP-Rate degrades
  - Solution: Adaptive Cuckoo Filter*
- ► "Real-life" benchmarks


Towards Application of Cuckoo Filters in Network Security Monitoring

Jan Grashöfer, Florian Jacob, Hannes Hartenstein

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I. Introduction

II. Related Work & Fundamentals

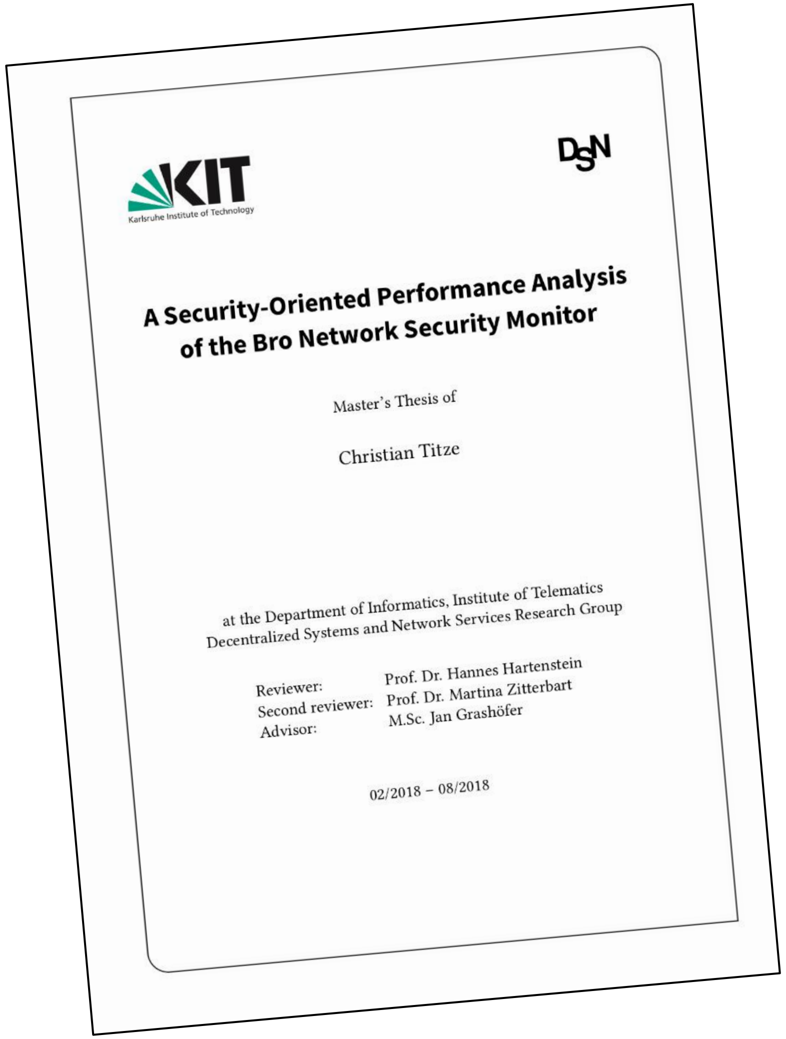
A. Related Work

* M. Mitzenmacher, S. Pontarelli, und P. Reviriego, „Adaptive Cuckoo Filters", in *2018 Proceedings of the Twentieth Workshop on Algorithm Engineering and Experiments (ALENEX)*, S. 36–47.

Christian Titze

SECURITY-ORIENTED PERFORMANCE ANALYSIS

Research Question & Possible Answer



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A Security-Oriented Performance Analysis of the Bro Network Security Monitor

Master's Thesis of

Christian Titze

at the Department of Informatics, Institute of Telematics
Decentralized Systems and Network Services Research Group

Reviewer:	Prof. Dr. Hannes Hartenstein
Second reviewer:	Prof. Dr. Martina Zitterbart
Advisor:	M.Sc. Jan Grashöfer

02/2018 – 08/2018

? How can network traffic be leveraged to impact the performance of Bro?

! By exploiting the structure of text-based application-layer protocols to excessively generate events.

Structure of Text-Based App-Layer Protocols

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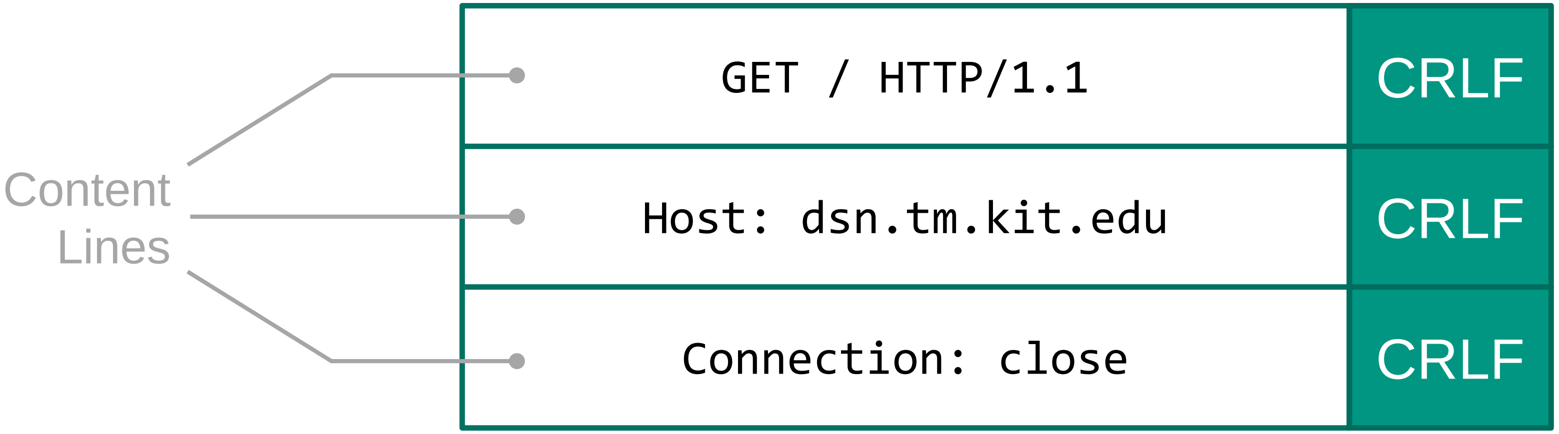
- Structure of virtually all text-based application-layer protocols [1]:

- For example, HTTP:



[1] Michael Mai. *"Dynamic Protocol Analysis for Network Intrusion Detection Systems"*. Diplomarbeit. Technische Universität München, September 2005.

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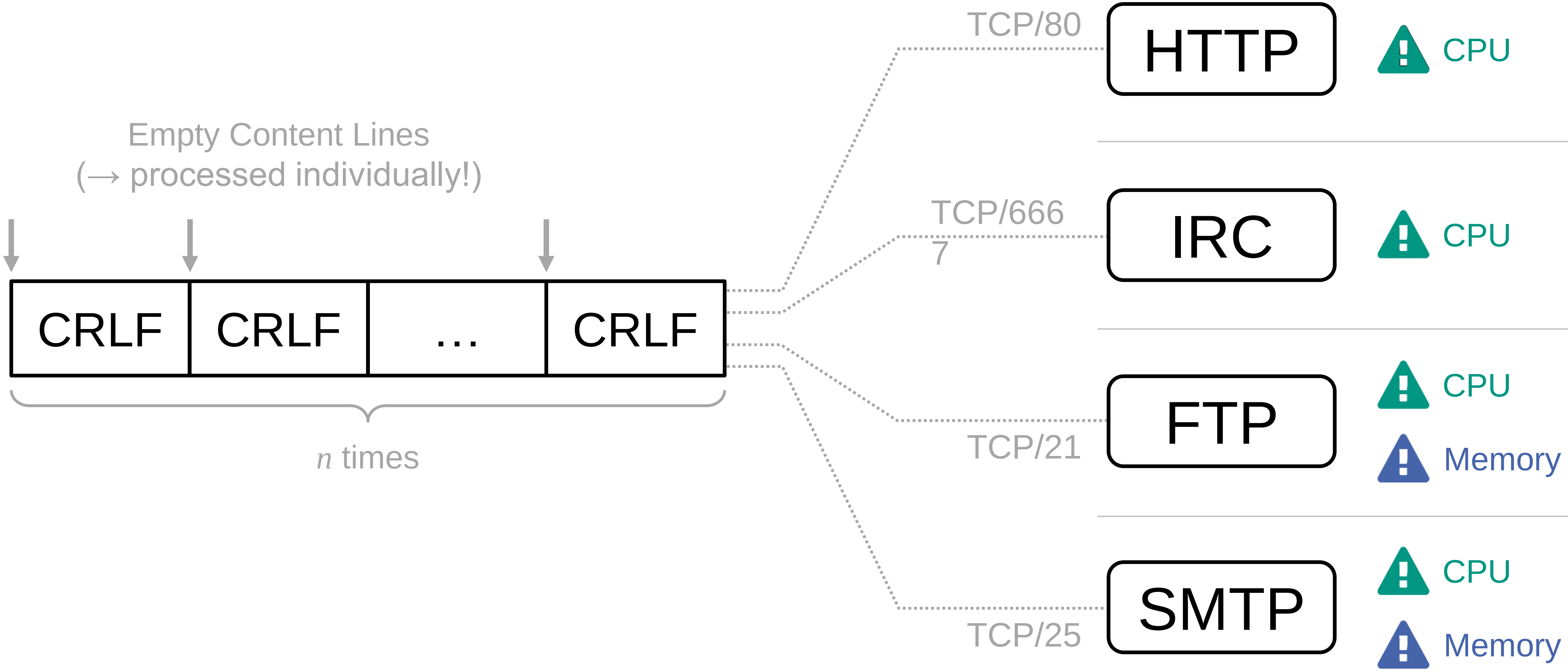
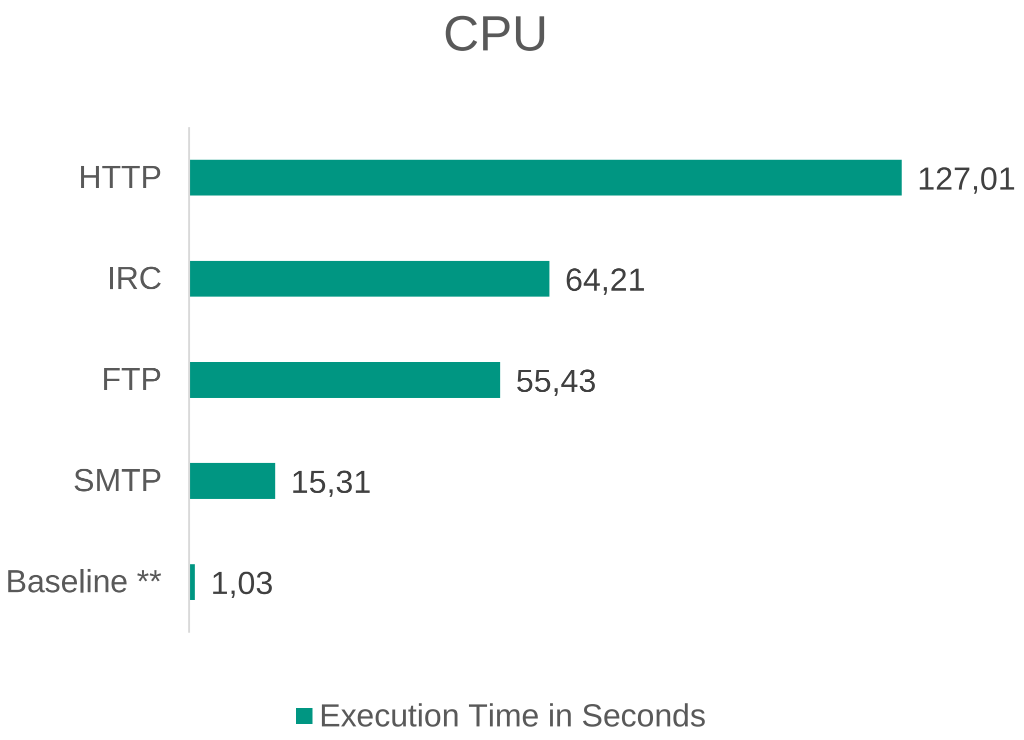
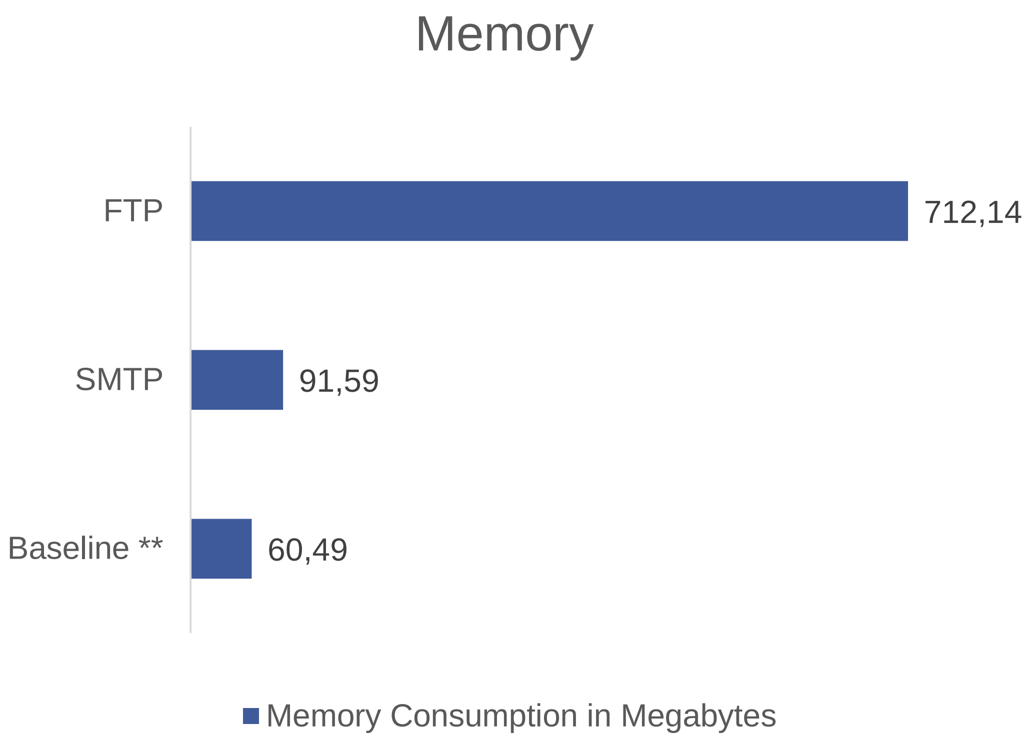
Attack Traffic



Performance Impact *





2.1 MB
Attack Traffic

1500
Packets

* Numbers are for 1 Million CRLFs. Increase is linear with number of CRLFs.
** With DPD's port detection off or when sent to non-vulnerable Analyzer.

CPU Impact

- Caused by **excessive number of handled events**
- Normally: Only low-level events occur in excessive numbers
- Here: Empty content lines trigger other events excessively

Memory Impact

- Every empty content line is treated as a new “request”
- State is kept about each “request”
- Each “request” is added to a queue of pending commands

SMTP	FTP
~ 30 Bytes Allocated per CRLF	~ 640 Bytes Allocated per CRLF

Thank You!

“The monitor will be attacked.”

— Vern Paxson, *Bro: A System for Detecting Network Intruders in Real-Time*

Matthias Grundmann

RANSOMWARE MONITORING IN ACADEMIC ENVIRONMENTS

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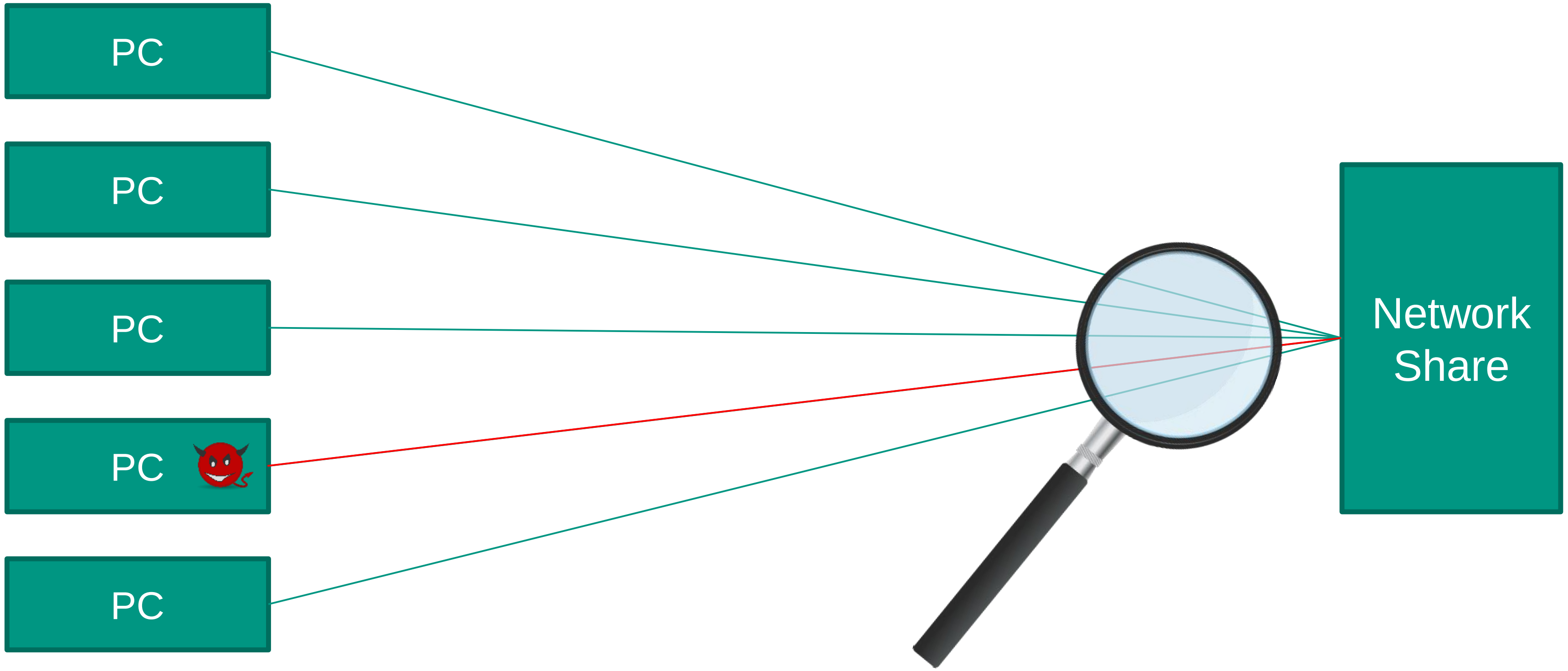
The Problem

- We want to detect active ransomware as fast as possible

Our Approach

- Monitor SMB traffic to network shares
- Can we detect encryption of files?



Comparing Two Files…

```
00000350: 5500 0000 5600 0000 5700 0000 5800 0000  U...V...W...X...
00000360: 5900 0000 5a00 0000 5b00 0000 5c00 0000  Y...Z...[...\...
00000370: 5d00 0000 5e00 0000 5f00 0000 6000 0000  ]...^..._...`...
00000380: 6100 0000 6200 0000 6300 0000 6400 0000  a...b...c...d...
00000390: 6500 0000 6600 0000 6700 0000 6800 0000  e...f...g...h...
000003a0: 6900 0000 6a00 0000 6b00 0000 6c00 0000  i...j...k...l...
000003b0: 6d00 0000 6e00 0000 6f00 0000 7000 0000  m...n...o...p...
000003c0: 7100 0000 7200 0000 7300 0000 7400 0000  q...r...s...t...
000003d0: 7500 0000 7600 0000 7700 0000 7800 0000  u...v...w...x...
000003e0: 7900 0000 7a00 0000 7b00 0000 7c00 0000  y...z...{...|...
000003f0: 7d00 0000 7e00 0000 7f00 0000 8000 0000  }...~...........
00000400: 5200 6f00 6f00 7400 2000 4500 6e00 7400  R.o.o.t. .E.n.t.
00000410: 7200 7900 0000 0000 0000 0000 0000 0000  r.y.............
00000420: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000430: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000440: 1600 0500 ffff ffff ffff ffff 0100 0000  ................
00000450: 108d [illegible] 9b4f [illegible] 86ea 00aa 00b9 29e8  ...d.O........).
00000460: 0000 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]  ................
00000470: 3775 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]  7u..O...........
00000480: 5000 6100 7700 6500 7200 5000 [illegible] 6900  P.o.w.e.r.P.o.i.
00000490: 6e00 7400 2000 4400 6f00 6300 7500 6d00  n.t. .D.o.c.u.m.
000004a0: 6500 6e00 7400 0000 0000 0000 0000 0000  e.n.t...........
000004b0: 0000 0000 0000 [illegible] 0000 [illegible] [illegible] 0000  ................
000004c0: 2800 0201 0200 [illegible] 0300 [illegible] [illegible] ffff  (...............
000004d0: 0000 0000 0000 [illegible] [illegible] [illegible] [illegible] 0000  ................
000004e0: 0000 0000 0000 [illegible] 0000 0000 [illegible] 0000  ................
000004f0: 0000 0000 0a00 0000 bd96 0000 0000 0000  ................
00000500: 0500 5300 7500 6d00 6d00 6100 7200 7900  ..S.u.m.m.a.r.y.
00000510: 4900 6e00 6600 6f00 7200 6d00 6100 7400  I.n.f.o.r.m.a.t.
00000520: 6900 6f00 6e00 0000 0000 0000 0000 0000  i.o.n...........
00000530: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000540: 2800 0201 0400 0000 ffff ffff ffff ffff  (...............
00000550: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000560: 0000 0000 0000 0000 0000 0000 0000 0000  ................
00000570: 0000 0000 5100 0000 d8e2 0000 0000 0000  ....Q...........
00000580: 0500 4400 6f00 6300 7500 6d00 6500 6e00  ..D.o.c.u.m.e.n.
00000590: 7400 5300 7500 6d00 6d00 6100 7200 7900  t.S.u.m.m.a.r.y.
000005a0: 4900 6e00 6600 6f00 7200 6d00 6100 7400  I.n.f.o.r.m.a.t.
000005b0: 6900 6f00 6e00 0000 0000 0000 0000 0000  i.o.n...........
000005c0: 3800 0201 ffff ffff ffff ffff ffff ffff  8...............
000005d0: 0000 0000 0000 0000 0000 0000 0000 0000  ................
000005e0: 0000 0000 0000 0000 0000 0000 0000 0000  ................
000005f0: 0000 0000 0000 0000 e001 0000 0000 0000  ................
```

Entropy: 2.48

```
00000350: fae9 9d29 4b85 2d4b 5c2d f338 6ebe b4ad  ...)K.-K\-.8n...
00000360: 5aad 1ca8 9e71 1880 cc2c cd66 e277 4334  Z....q...,.f.wC4
00000370: d328 d646 2663 f731 8e69 39e6 f8bf 4443  .(.F&c.1.i9...DC
00000380: e124 99f1 ea8f d4f3 0a27 f8a8 873b b685  .$.......'...;..
00000390: 47db c243 dc89 dfd6 cbbd 5d39 ac91 8342  G..C......]9...B
000003a0: aeb4 19ac 2b80 4d1d aaaf 917a 152b 5c25  ....+.M....z.+\%
000003b0: 61e0 05f7 1454 6e42 4cf6 7f1e fdf8 c4da  a....TnBL.......
000003c0: 44d4 b570 6caf 69a0 cf6d 8fea c103 aadd  D..pl.i..m......
000003d0: fd56 e8ec 2bf0 4f40 0e03 510f 002e 5497  .V..+.O@..Q...T.
000003e0: fe91 05bb 4efe e126 c8b4 3454 29f1 2cda  ....N..&..4T).,.
000003f0: a012 39d1 8320 1575 ca72 e0ca 5cc0 729c  ..9.. .u.r..\.r.
00000400: 9df4 b1fe b3b3 f136 24c6 982f 672d dd95  .......6$../g-..
00000410: a84a 49b8 16e9 4b6f 5b01 5e2b 06d8 15ea  .JI...Ko[.^+....
00000420: 8595 6c92 a5a4 ad74 1769 3f3f c98d 2aff  ..l....t.i??..*.
00000430: ab66 0ffe 3e57 8be5 3406 fdbc 667f 3f64  .f..>W..4...f.?d
00000440: 3e82 bd43 d616 41f3 0263 e016 5eac 8f6d  >..C..A..c..^..m
00000450: 06c5 [illegible] b8df [illegible] 29ab a88e b71d 71e3  ..z&..>T).....q.
00000460: 70f7 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]  [illegible].....R....k..
00000470: c6f4 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]  ...4).....s5....
00000480: 43b4 [illegible] 8f10 [illegible] 7cae [illegible] [illegible] [illegible]  C.......|....Y..
00000490: 80c1 8ef0 084c 6c1d 6fb2 2b02 cb13 [illegible]  .....Ll.o.+....\
000004a0: 0a0b 516c 0b13 6d26 71c9 9881 9d22 0859  ..Ql..m&q....".Y
000004b0: 4f3f 8717 e523 [illegible] a3f4 [illegible] [illegible] f551  O?...#)........Q
000004c0: 1883 23ed bf07 [illegible] a683 [illegible] [illegible] 858b  ..#...e......S..
000004d0: 52b9 df8d b249 [illegible] 2590 [illegible] [illegible] cd7d  R....I."%.*....}
000004e0: a64f 51a6 6df5 [illegible] b409 [illegible] [illegible] a5d0  .OQ.m..=../.....
000004f0: 01db f212 e417 78ed c0ed c047 72cd 8023  ......x....Gr..#
00000500: 2961 5b55 6b9c 4cc0 5516 4471 9ddf f370  )a[Uk.L.U.Dq...p
00000510: 3ce0 26b2 1a03 0533 ebf5 bc0d 2767 128d  <.&....3....'g..
00000520: 875b f7e9 ce19 aa87 9f05 bf6e 88fe 8509  .[.........n....
00000530: a76a 66e2 d1bd 3253 f8dc 2858 4541 c55d  .jf...2S..(XEA.]
00000540: 581b 309d ef72 85e2 1163 567b 23ca 493e  X.0..r...cV{#.I>
00000550: 18f2 f871 5895 7794 d379 40eb d646 7dec  ...qX.w..y@..F}.
00000560: c7d7 e171 4ade 7125 567e de4b 282b e517  ...qJ.q%V~.K(+..
00000570: 4d9a 40ae b8e5 ca4a 824f d250 8f50 e9da  M.@....J.O.P.P..
00000580: 4510 ae14 b835 29d3 ca97 7eab 7607 f398  E....5)...~.v...
00000590: 0aec c816 635f 0c5e c4d9 2540 6f05 899e  ....c_.^..%@o...
000005a0: 8721 4283 daf5 9aec f1a2 1079 1e82 703f  .!B........y..p?
000005b0: df1a fd6c 74cb dce4 b4e3 f96a 9d69 95ff  ...lt......j.i..
000005c0: 844c 5046 fd35 698a 5fa4 5ac0 cb68 4d7c  .LPF.5i._.Z..hM|
000005d0: 8acb a729 f002 3473 134b 7d80 6cea c188  ...)..4s.K}.l...
000005e0: 0880 8f4e 0b6e 71be 6d6e 2703 e516 e651  ...N.nq.mn'....Q
000005f0: 501a 5d17 f7af 2ea8 97af 2145 3410 e222  P.]......!E4.."
```

Entropy: 7.69

Detecting Encryption of Files

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- Idea: Use entropy to detect encryption
- Compare entropy of SMB_READ and SMB_WRITE requests
- Implementation
  - Bro script
  - For every SMB_READ
    - Calculate entropy of first 2 kB
    - Store entropy in cache for 10 min
  - For every SMB_WRITE
    - Check if entry for read in cache
    - Calculate entropy of first 2 kB
    - Compare entropy
    - Alert if entropy increased by more than threshold

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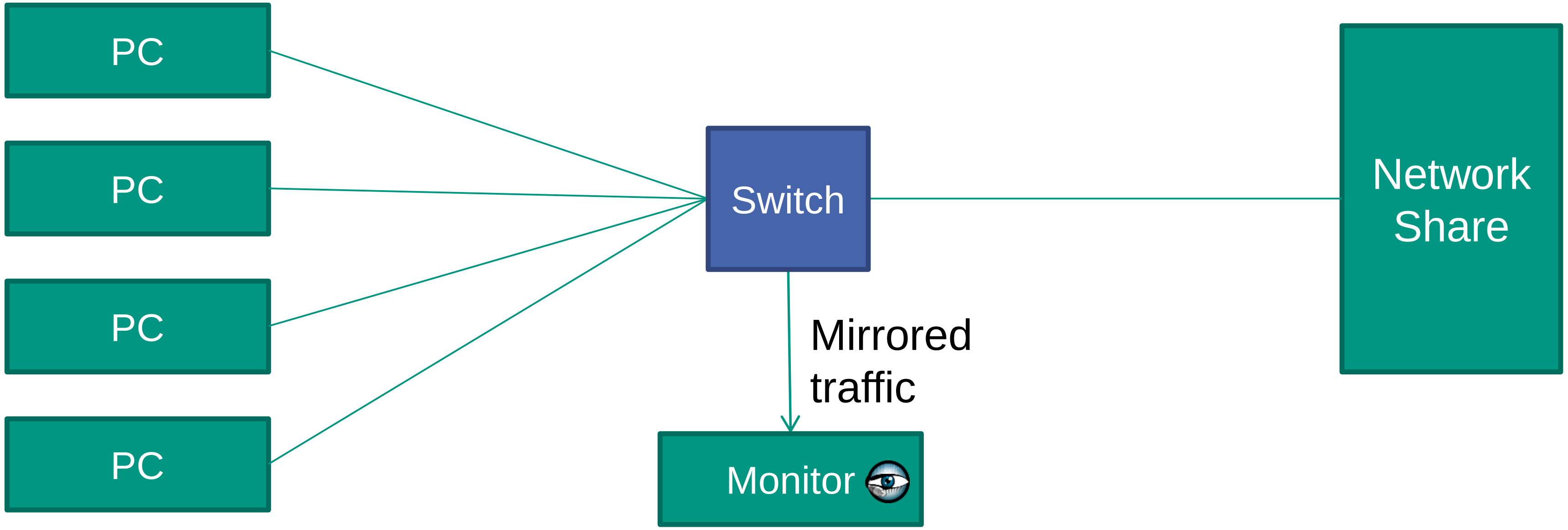
Related Work

- Mike Stokkel, Fox-IT (Delft)
  - Presentation at BroCon ’16
  - Detect writing of high-entropy files
    - Alert when more files encrypted than threshold
- D.A.C. Mülders, TU Eindhoven
  - Master thesis „Network based Ransomware Detection on the Samba Protocol”
  - Offline analysis of combination of read and write requests
    - Calculate difference of entropy and file size
    - Detect encryption and compression
- Eduard Steinmiller, Andreas Baumeister
  - KASTEL-Lab „Security“ in winter term 2017/18
  - Online analysis by observation of difference of moving average of entropy of read and write requests

Setup for Evaluation

- Evaluation needs
  - Real user traffic
  - Real ransomware traffic
- Use KIT's university network for evaluation
  - Setup monitors SMB traffic to shared folders



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Challenges

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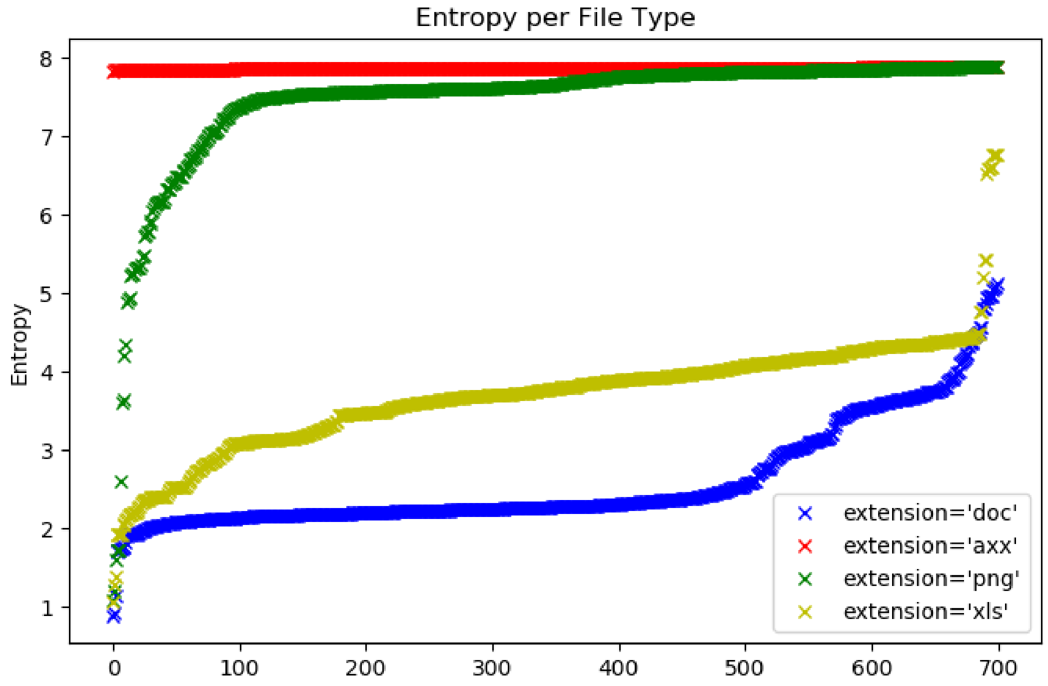
- Link SMB_READ and SMB_WRITE requests to same file
  - SMB file id not unique, so use tuple of SMB file id and connection uid
- Keeping state
  - Store entropy of read file, compare when same file written
- Process traffic of up to 8 Gbit/s
  - Package drops during traffic peaks
- Handling of false positives
  - Single encrypted file is no reason for alarm
  - Use SumStats framework to collect encryption incidents
  - Only alert if 5 encryptions in 30 seconds
- Privacy
  - Exclude shares with home directories

Current State and Open Questions

- Detection quality
  - Encrypting multiple files in folder successfully detected
  - Few false positives
- Working on secure setup for tests with real ransomware



- Is entropy the best measure to detect encryption of files?
  - Maybe use randomness tests?
  - Analysis of file extensions and mime types?
  - Analysis of access patterns?

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Summary: Bro @ KIT

1. Improving Threat Intelligence matching with Bro
2. Security-oriented Performance Analysis
3. Ransomware detection in academic environments

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