PROCESS CONTROL SYSTEMS FORUM

EMERALD Monitoring and Situational Awareness in Process Control Networks

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Collaborating to Advance Control System Security

Outline

- Threats
- Session Overview
- Review of vulnerability demonstration
- The EMERALD/PCS IDS appliance
- Monitoring and Situational awareness in the attack scenario

Note: Technology is only part of the picture, and does little without addressing "People and Process"

Threats to Process Control Systems

- Automation is ubiquitous in critical infrastructure
- Formerly proprietary standards, isolated networks (Security through obscurity and isolation)
- Increasingly, open standards (TCP/IP), common platforms, interconnected to business systems
- Of interest to hacktivists, terrorists

Vulnerabilities in Testbed Architecture

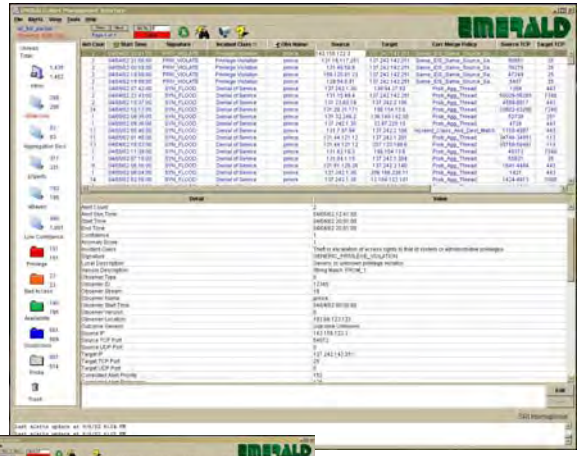
- Vulnerability scenario leverages common tactics and tools against a representative PCS/corporate networked system
- Imagine the scenario as having happened to another system, and consider similarities to your system
- We considered variations in topology and configuration
- Scenario progression depends on common problems identified during assessments and site visits

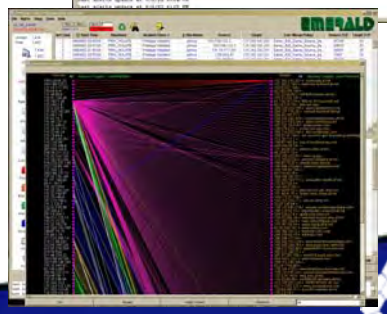
Integrated Monitoring and Correlation

- Barrier defenses (switches, firewalls, network segmentation) are essential, but
- Monitoring is essential to detect when these have been bypassed or penetrated
- One detection approach may not alert on a critical exploit
- Correlation of related events provides the operator coherent situational awareness

EMERALD IDS for PCS

- **Multi-algorithm IDS appliance**
  - Pattern Anomaly
  - Bayes analysis of TCP headers
  - Stateful protocol analysis (eXperts)
  - Complemented by custom SNORT ruleset
- **Alerts (potentially from multiple IDS appliances) forwarded to correlation framework**
- **PCS Enhancements**
  - Digital Bond PCS rule set
  - Model-Based Detection
  - MODBUS service discovery





Intrusion Detection Approaches

- **Signature: Match traffic to a known pattern of misuse**
  - Stateless: String matching, single packet
  - Stateful: Varying degrees of protocol and session reconstruction
  - Can be very specific and accurate
  - Typically does not generalize to new attacks
- **Anomaly: Alert when something "extremely unusual" is observed**
  - Learning based, sometimes statistical profiling
  - In practice, not used much because of false alarms
  - Learning systems are also subject to concept drift

Intrusion Detection Approaches (2)

- **Probabilistic (Statistical, Bayes): A middle ground, with probabilistically encoded models of misuse**
  - Some potential to generalize
- **Model based (some group this with anomaly detection): Alert when observed behavior is outside of a model or specification**
  - High potential for generalization and leverage against new attacks

Our Hypothesis

- **By comparison to enterprise systems, control systems exhibit comparatively constrained behavior:**
  - Fixed topology
  - Regular communication patterns
  - Limited number of protocols
  - Simpler protocols
- **As such, model-based IDS approaches may be more feasible**
- **Such an approach nicely complements a signature system**
- **Benefits are a compact, inherently generalized knowledge base and potential to detect zero day attacks**

Protocol Model: Individual fields

- **MODBUS function codes are one byte**
  - 256 possible values, but
  - MSB is used by servers to indicate exception
  - Valid range for requests is 1-127
- **Range is partitioned into public, user-defined, and reserved**
  - This suffices to construct a “weak specification” model
- **Many actual devices support a much more limited set of codes**
  - Permits stronger, more tailored model

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Protocol Model: Dependent Fields

- **Encode acceptable values of a field given the value of another field**
  - Dependent fields include length, sub-function codes, and arguments
  - For example, “read coils” function implies the length field is 6
  - For other function codes, length varies but a range can be specified
- **Specifications for multiple ADUs: future work**

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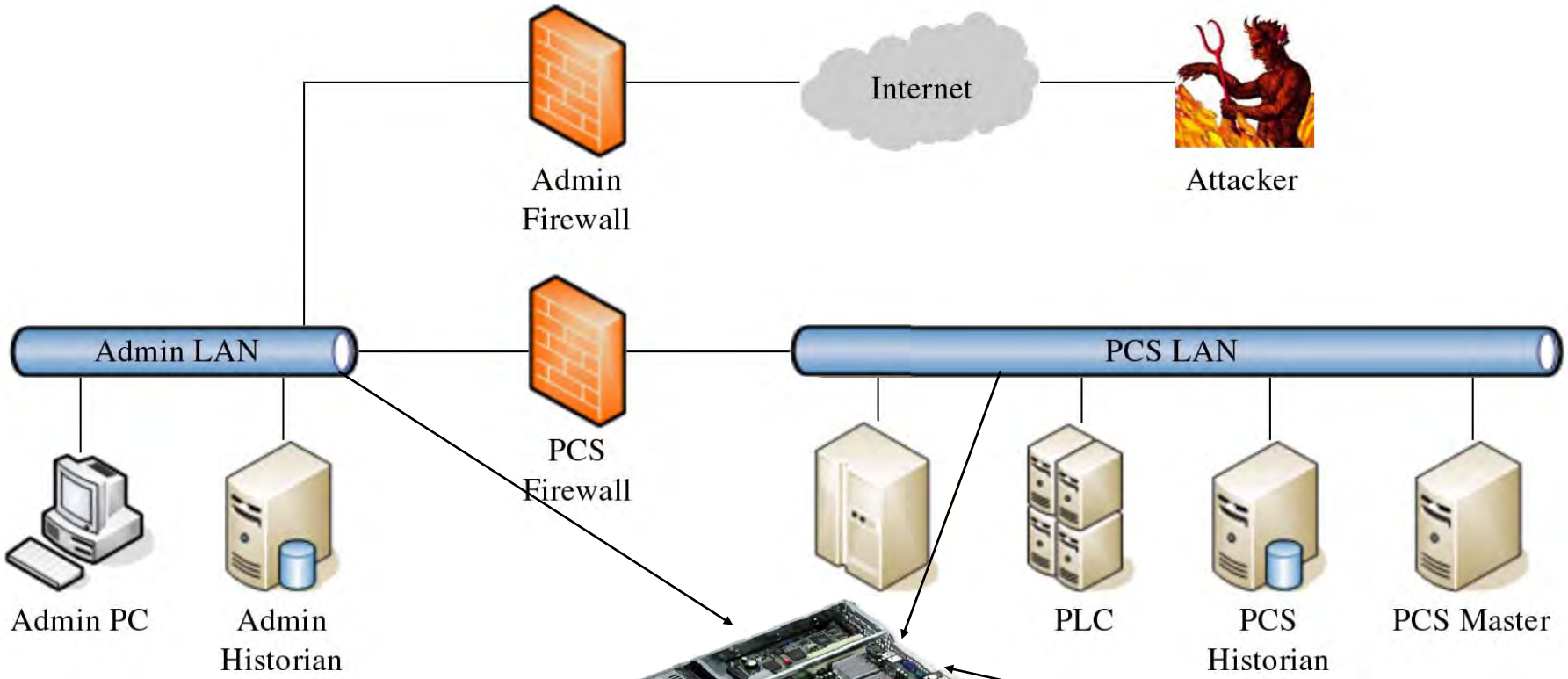
Detecting Unusual Communication Patterns

- Communications between the various LAN's are restricted by policy
- Attacker exploits some allowed paths (admin historian to PCS historian) but over disallowed protocols
- Detection of exceptions is via SNORT rules
- More complex networks (more devices) can be accommodated via IP address assignment with appropriate subnet masks

Detecting Changes in Server/Service Availability

- **EMERALD TCP service monitoring**
  - New service discovery (suspicious in a “stable” system)
  - Service up/down/distress
- **EMERALD for PCS includes analogous capability for MODBUS function codes**
  - Alerts when a device responds to a new function code (MODBUS service discovery)
  - Alerts when a function code previously considered valid for a device results in error replies

Testbed Architecture



PCS-Enabled NIDS/Mcorr Appliance

Alerts and Diagnostics
- SHARP (PNNL)
- SecSS (Tulsa)
- APT (UIUC)

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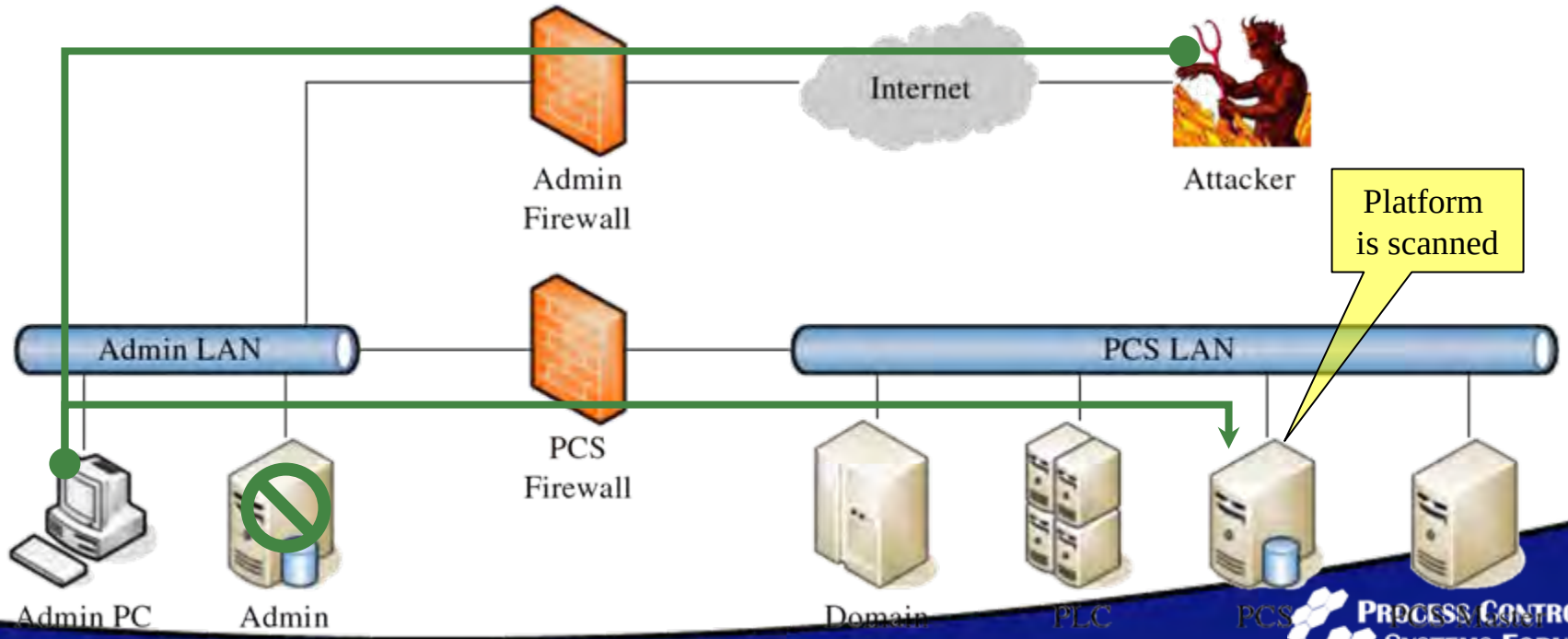
Vulnerability Scenario

- **Demonstration**



Detections

- **Scans: Bayes sensor, unusual comms**
  - Aggregation presents thousands of probes as single alert
- **Compromise exploits (UPnP): SNORT Bleeding Edge**
- **tftp: Unusual Comms**
- **MODBUS Exploits: New Modbus services, spec based detection, Digital Bond set**

Alerts

EMERALD Alert Management Interface

File Alerts View Tools Help

emerald_db
Showing: Inbox

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Go To 1
Online

I3P

23 Inbox
15 EMERALD
2 UIUC
6 UTULSA
Trash

Alert Gen Time	Alert Count	Start Time	Signature	Incident Class	Obs Name	Source	Target
01/17/07 16:14:41	9	01/17/07 15:53:36	DYN_UNAUTHORIZED_T...	Connection Violation	snort_ipv4	10.0.0.1... [2]	10.0.0.1... [4]
01/17/07 16:12:20	2	01/17/07 15:11:51	IncompleteMBTransaction	Suspicious Usage	cis.utulsa.edu-modbus...	10.0.0.10	10.0.0.101
01/17/07 16:12:19	10866	01/17/07 15:05:48	DYN_UNAUTHORIZED_T...	Connection Violation	snort_ipv4	10.0.0.10... [2]	10.0.0.101... [2]
01/17/07 16:09:50	29	01/17/07 15:49:32	DYN_BLEEDING-EDGE_...	Privilege Violation	AlertMgr	192.168.0.100	10.0.0.11
01/17/07 16:09:50	217	01/17/07 15:43:59	PORT_SCAN	Probe	eBayes-TCP	192.168.0.100	10.0.0.11
01/17/07 16:09:50	7	01/17/07 15:49:32	DYN_BLEEDING-EDGE_...	Privilege Violation	snort_ipv4	192.168.0.100	10.0.0.11
01/17/07 16:05:01	3	01/17/07 15:04:32	newEntryLog	Action Logged	cis.utulsa.edu-modbus...	10.0.0.10	10.0.0.101
01/17/07 16:00:58	2	01/17/07 15:58:59	DYN_BLEEDING-EDGE_...	Privilege Violation	snort_ipv4	10.0.0.11	10.0.0.10
01/17/07 15:58:01	1	01/17/07 15:58:01	NEW_SVC	Suspicious Usage	eBayes-TCP-host	192.168.0.100	10.0.0.11
01/17/07 15:51:46	4618	01/17/07 15:43:55	DYN_UNAUTHORIZED_...	Connection Violation	AlertMgr	192.168.0.100	10.0.0.11
01/17/07 15:51:46	4621	01/17/07 15:50:21	DYN_UNAUTHORIZED_...	Connection Violation	AlertMgr	10.0.0.11	192.168.0.100
01/17/07 15:51:45	4619	01/17/07 15:50:21	DYN_UNAUTHORIZED_...	Connection Violation	snort_ipv4	10.0.0.11	192.168.0.100
01/17/07 15:51:45	4617	01/17/07 15:43:55	DYN_UNAUTHORIZED_...	Connection Violation	snort_ipv4	192.168.0.100	10.0.0.11
01/17/07 15:27:59	8	01/17/07 15:22:47	DYN_MODBUS_TCP_W...	Suspicious Usage	snort_ipv4	10.0.0.7	10.0.0.100
01/17/07 15:27:59	31	01/17/07 15:22:47	DYN_UNAUTHORIZED_T...	Connection Violation	snort_ipv4	10.0.0.7... [2]	10.0.0.7... [2]
01/17/07 15:26:29	2	01/17/07 14:24:37	mbWriteViolation	Integrity Violation	cis.utulsa.edu-modbus...	10.0.0.7	10.0.0.100
01/17/07 15:26:29	2	01/17/07 14:24:37	RogueDeviceViolation	Connection Violation	cis.utulsa.edu-modbus...	10.0.0.7	10.0.0.100
01/17/07 15:22:47	7	01/17/07 15:05:48	SUSPICIOUS	Suspicious Usage	AlertMgr	10.0.0.7... [2]	10.0.0.100... [2]
01/17/07 15:20:13	4	01/17/07 14:14:36	newEntryLog	Action Logged	cis.utulsa.edu-modbus...	10.0.0.10	10.0.0.100
01/17/07 15:07:00	2	01/17/07 15:05:48	NEW_MB_UNIT	Suspicious Usage	emodbus	10.0.0.10	10.0.0.100... [2]
01/17/07 14:35:48	1	01/17/07 14:35:48	APT_FW	Access Violation	APT	0.0.0.0	10.0.1.0
01/17/07 14:35:47	1	01/17/07 14:35:47	APT_FW	Access Violation	APT	172.16.1.0	0.0.0.0
01/17/07 14:22:19	1	01/17/07 14:22:19	newEntryLog	Action Logged	cis.utulsa.edu-modbus...	10.0.0.7	10.0.0.100

Detail	Value
Corr Alert Rank Std	0.0
Command	MB_READ_INPUT_REGISTERS_FC
Command Arguments	transaction ID: 73
Correlated Observer Location	172.16.10.120
Correlated Observer Namelist	cis.utulsa.edu-modbus-passive-scanner
Dynamic Signature	DynSig-0
class	10
code_name	Incomplete Modbus Transaction
description	This sensor has detected an incomplete modbus transaction, due to a time-out or the re-use of an active

Edit

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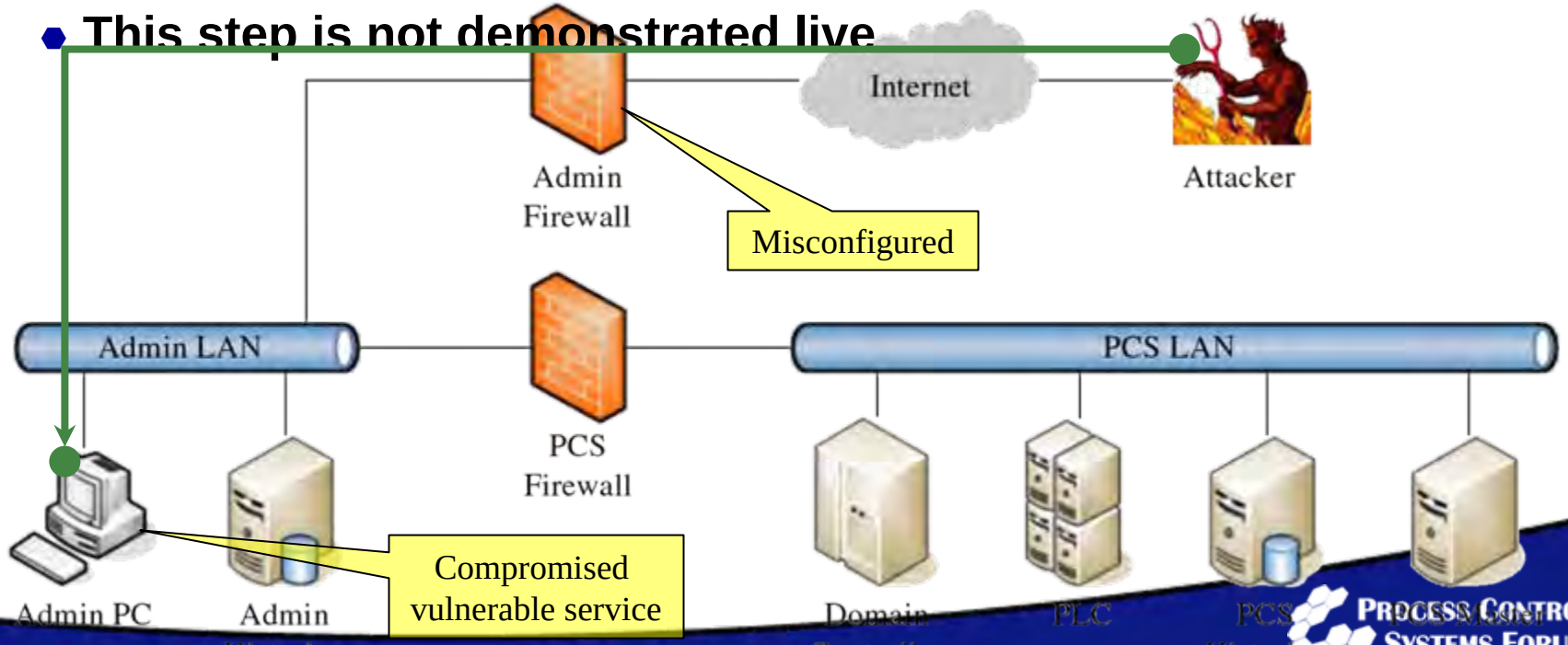
Summary

- Barrier protections are essential in PCS
  - DMZ
  - Switches, firewalls, VPN
- IDS is an important orthogonal defense
  - Detect probe, bypass, penetration
- Multi-component, multi-approach detection provides complementary views of an attack
- Alert correlation presents actionable situational awareness picture

Backup

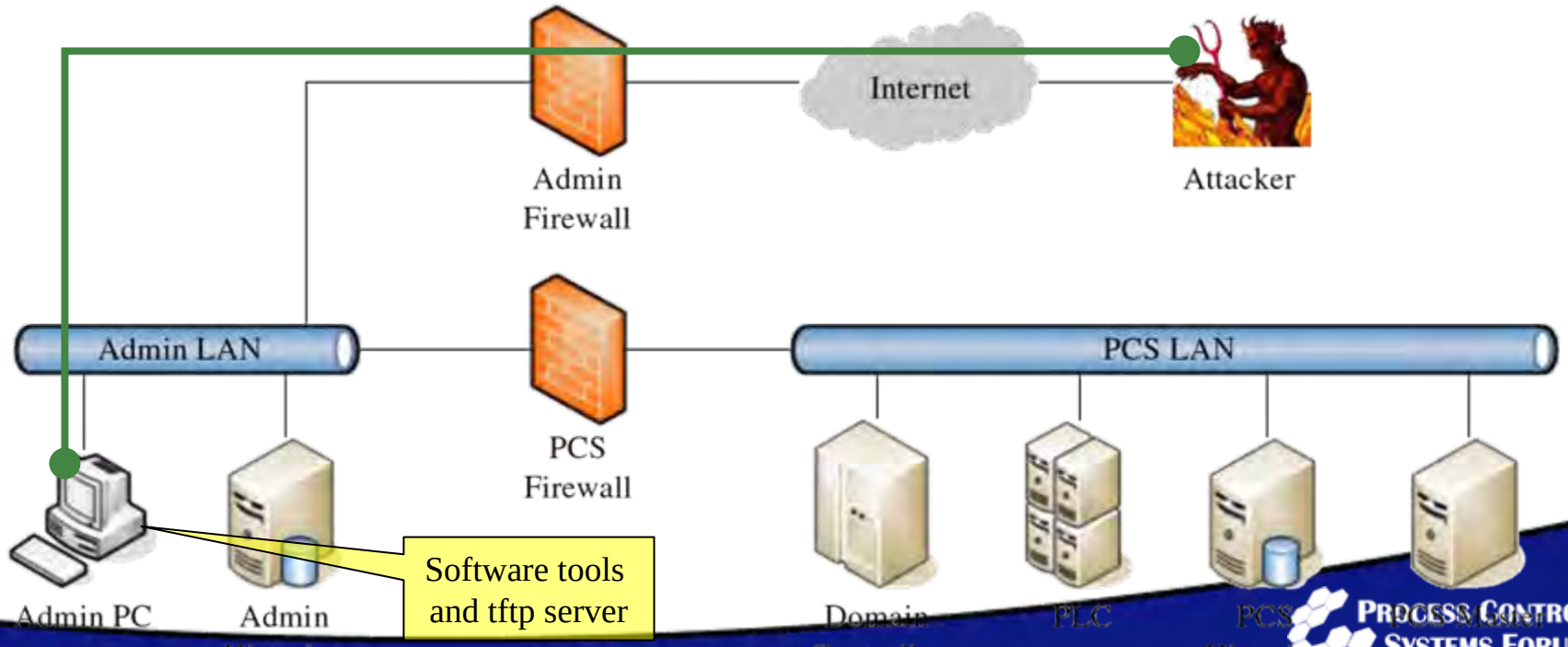
Vulnerability Scenario, Step 1

- Firewall misconfiguration allows access and compromise of a PC
- Host-based firewall fails to prevent the compromise
- Future events will issue from this platform, directed by the attacker
- This step is not demonstrated live



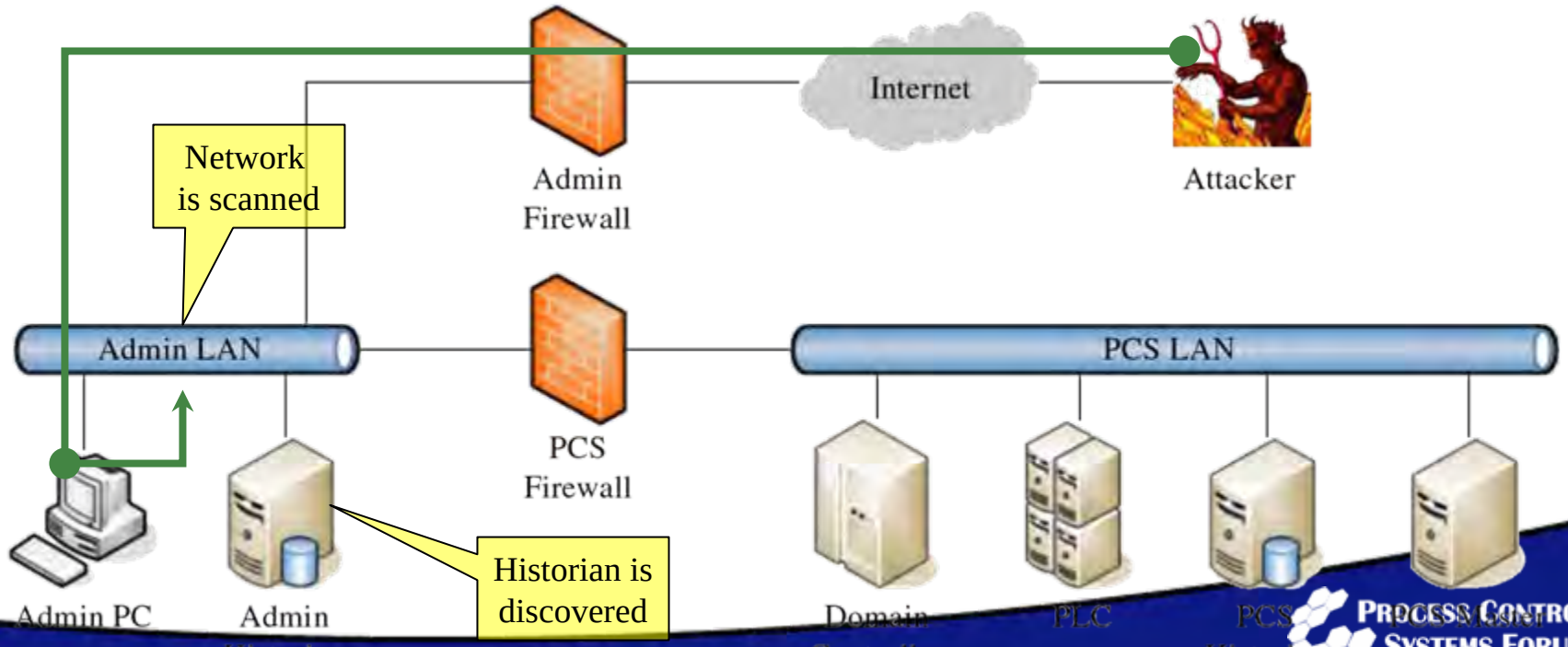
Vulnerability Scenario, Step 2

- Download software tools to the compromised Admin PC
- Set up a tftp server for later distribution



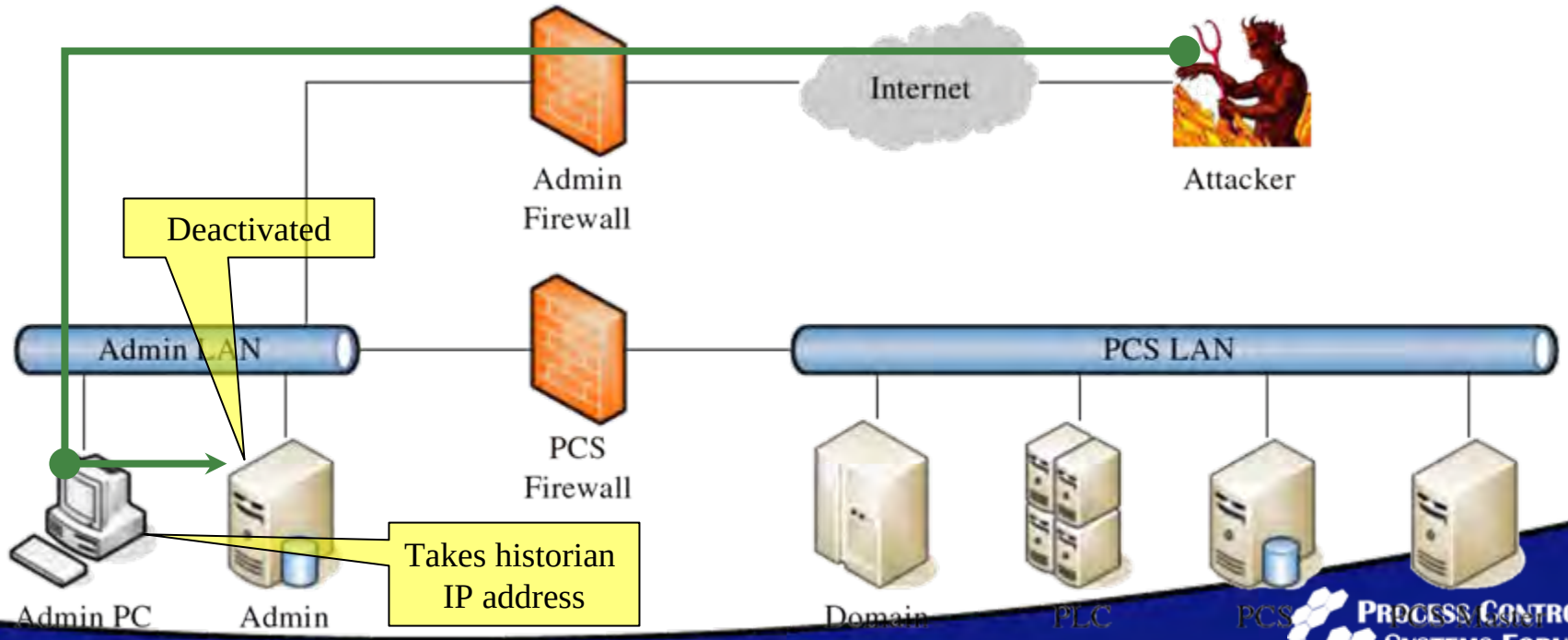
Vulnerability Scenario, Step 3

- Scan the administrative network
- Discover the Admin Historian
- Does not see the PCS network



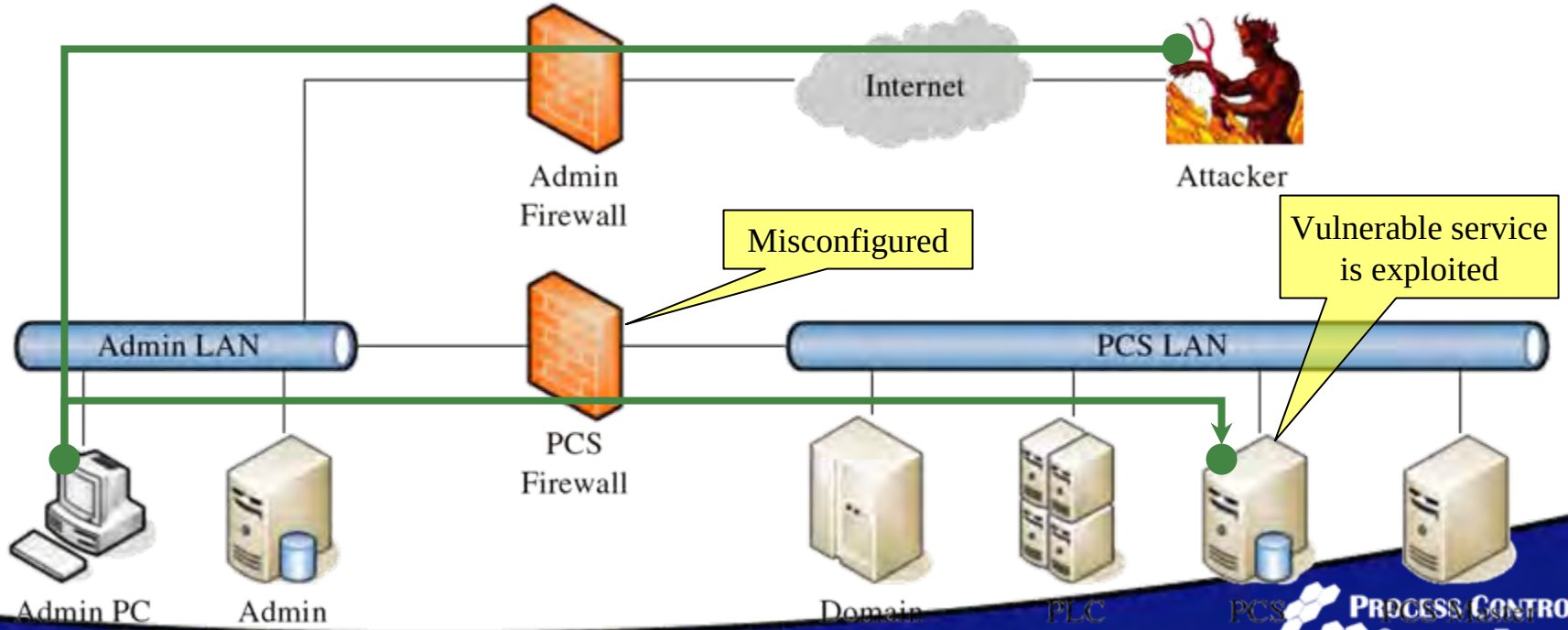
Vulnerability Scenario, Step 4

- Achieve elevated access to the Admin Historian
- Discover relationship to PCS Historian across firewall
- Push the Admin Historian off the network and assume its address



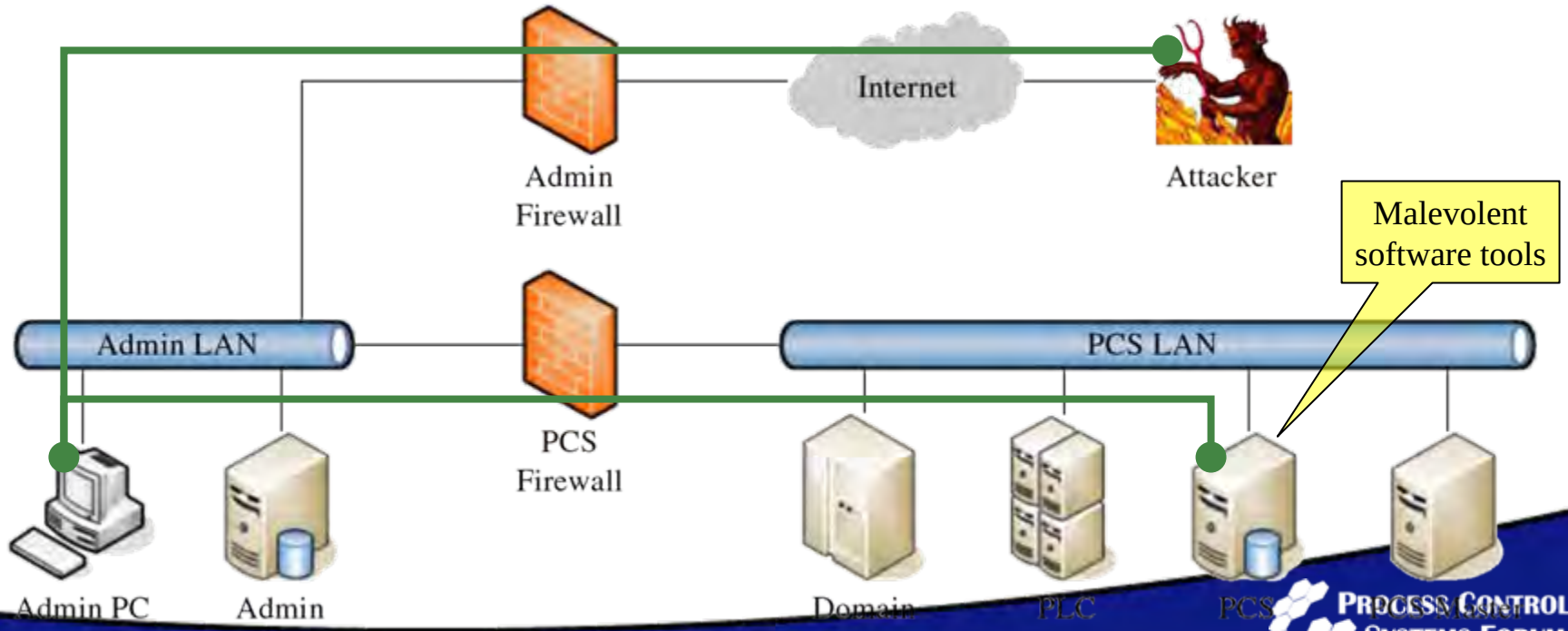
Vulnerability Scenario, Step 6

- Firewall configuration allows visibility of potential vulnerabilities
- Discover vulnerable authentication service on the PCS Historian
- Exploit to connect with system privilege to the PCS Historian



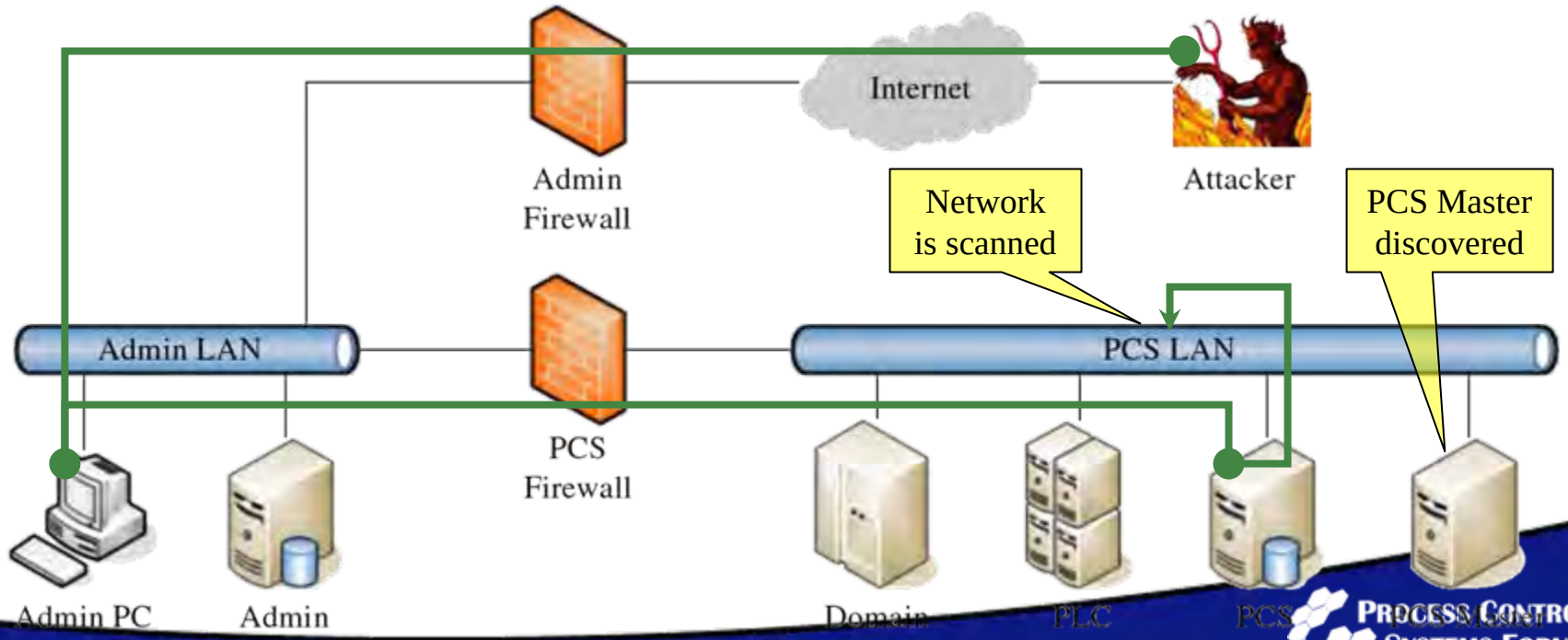
Vulnerability Scenario, Step 7

- Download a "rogue master" and other tools from the Admin PC
- PCS Historian is now the launching point for subsequent events



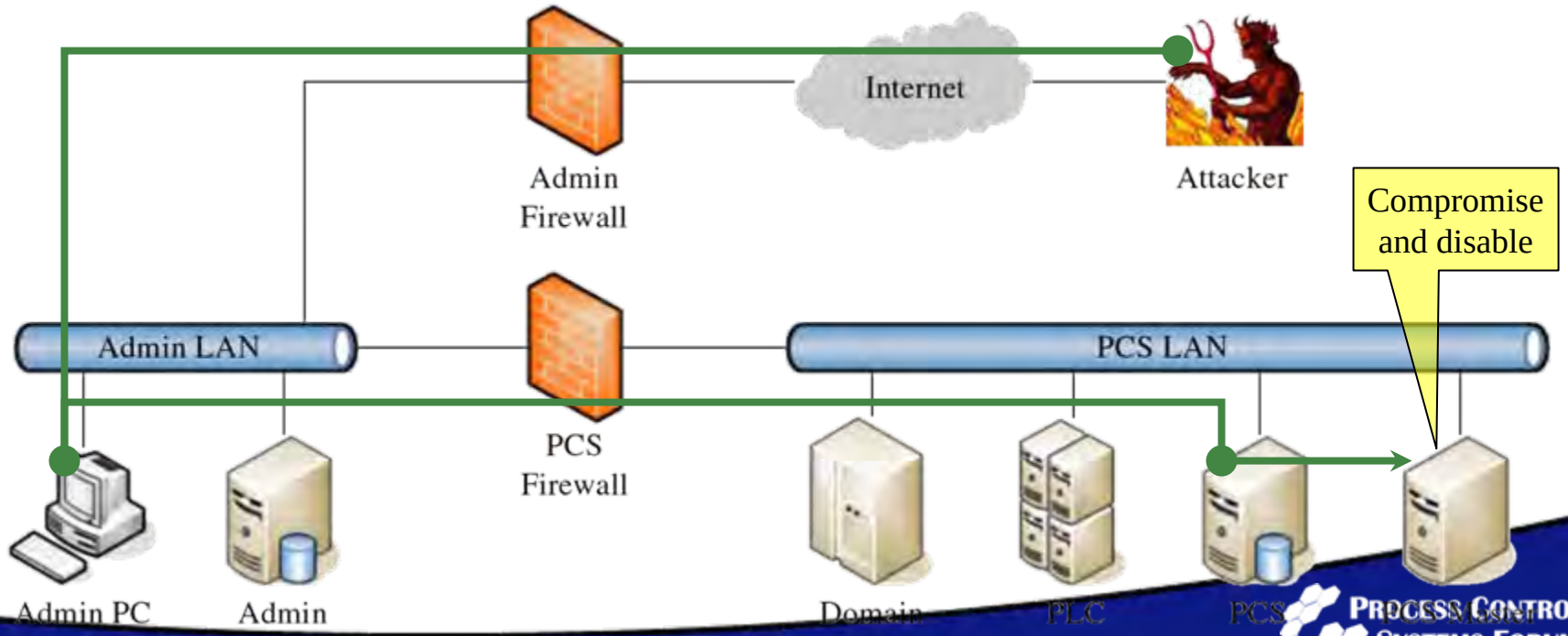
Vulnerability Scenario, Step 8

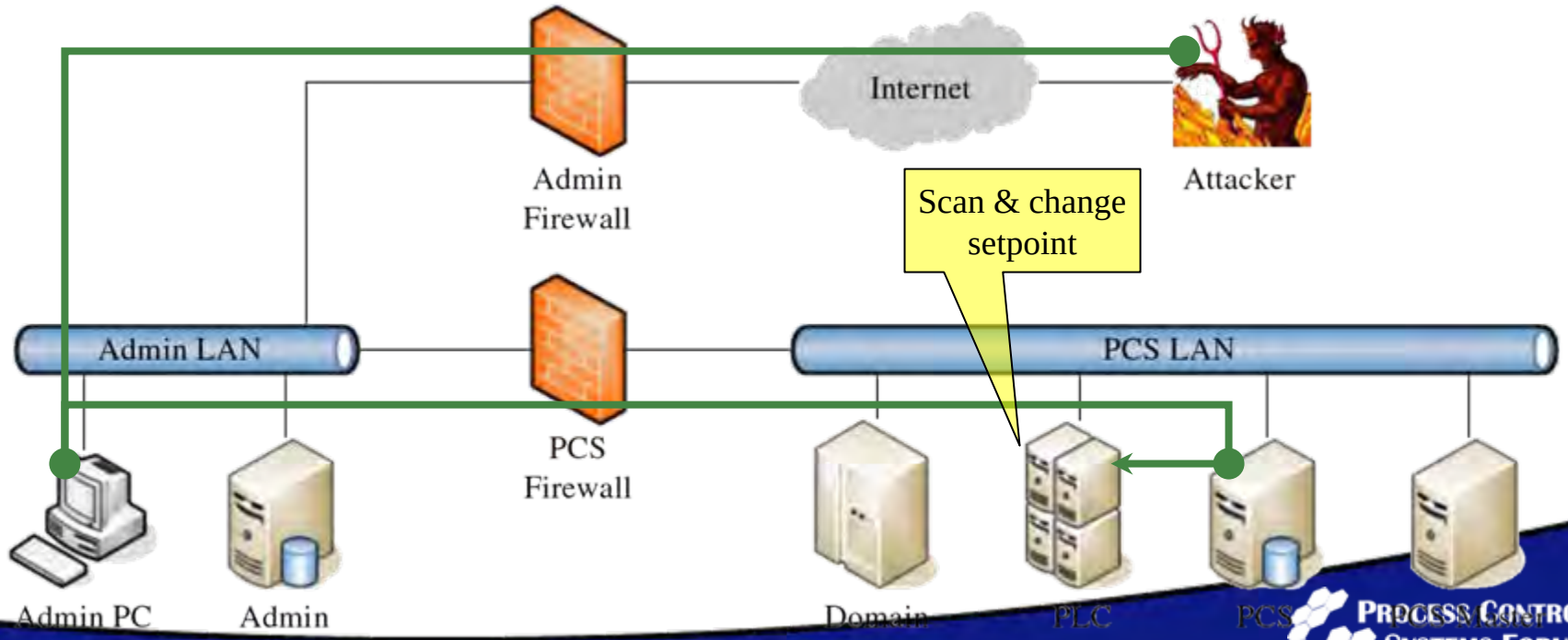
- Scan the PCS network
- Discover a vulnerable PCS Master box



Vulnerability Scenario, Step 9

- Exploit buffer overflow flaw in a vulnerable messenger service
- Disable the PCS Master



Vulnerability Scenario, Step 10

- Scan on the PCS LAN for Modbus-communicating platforms
- Send unauthentic Modbus command to change a PLC setpoint