Analyzing the Cyber-Resilience of Autonomic Software-defined OT Networks in offshore wind Power Plants.

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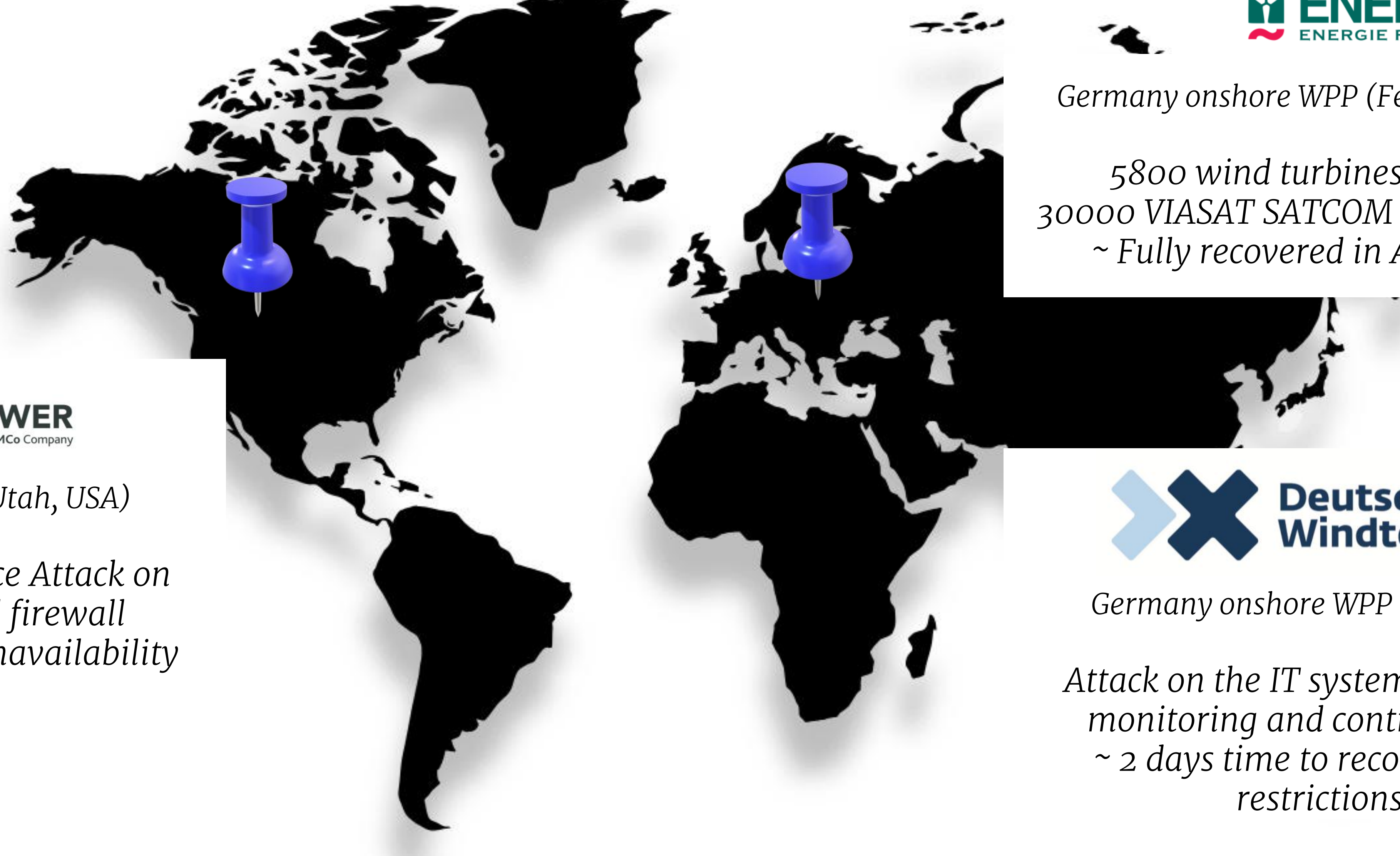
Cyber-security Quagmire in Offshore Wind Power Plants



ENERCON
ENERGIE FÜR DIE WELT

Germany onshore WPP (February 2022)

5800 wind turbines affected
30000 VIASAT SATCOM compromised
~ Fully recovered in April 2022

S·POWER
An AES and AIMCo Company

March 2019 (Utah, USA)

Denial of Service Attack on
Cisco-based firewall
~12hr system unavailability

Deutsche
Windtechnik

Germany onshore WPP (April 2022)

Attack on the IT systems managing
monitoring and control of WTGs
~ 2 days time to recover (minor
restrictions)

“The key notion of cyber resilience is
acceptance of cyber compromise as a likely event,
and the system suffering as a result;
the focus is on the system’s ability to recover and adapt,
not just resist.”

Alexander Kott & Igor Linkov (2021)
US Combat Capabilities Development Command’s Army Research Laboratory

Utrecht University

1. *Kott, A. and Linkov, I., 2021. To Improve Cyber Resilience, Measure It. IEEE Computer, 54(2), Feb.2021, pp.80-85.*
2. *Kott, A. and Theron, P., 2020. Doers, Not Watchers: Intelligent Autonomous Agents Are a Path to Cyber Resilience. IEEE Security & Privacy, 18(3), pp.62-66.*
3. *I. Kamara, “European cybersecurity standardisation: a tale of two solitudes in view of Europe’s cyber resilience,” Innovation: The European Journal of Social Science Research, pp. 1–20, 2024.*

Securing software-defined OT Networks in offshore wind power plants

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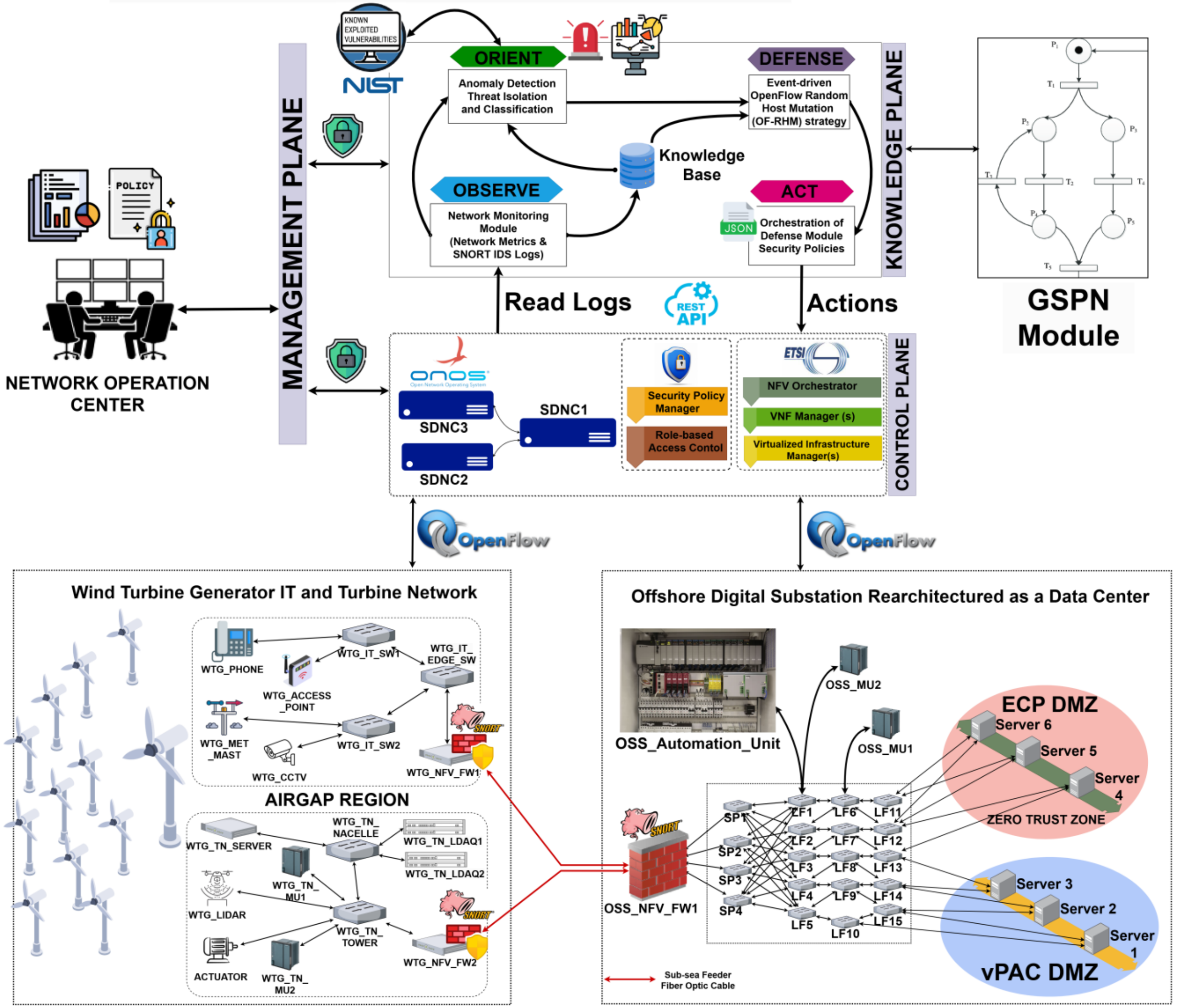
https://services.nvd.nist.gov/rest/json/cves/2.0?cveId={cve_id}
```



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Jafarian, J. H., Al-Shaer, E., & Duan, Q. (2012). "OpenFlow Random Host Mutation: Transparent Moving Target Defense Using Software Defined Networking." Proceedings of the First Workshop on Hot Topics in Software Defined Networks (HotSDN '12).

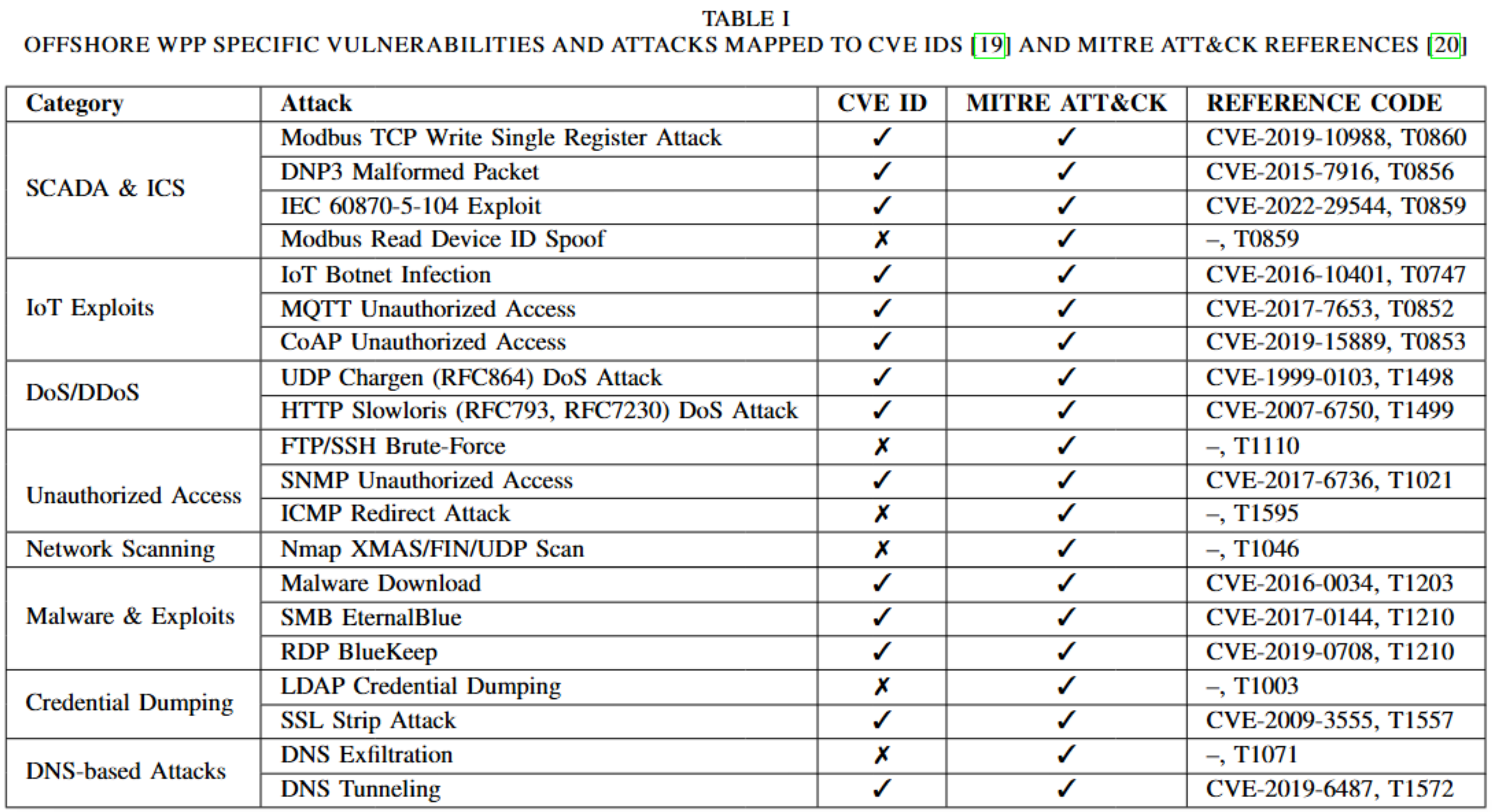
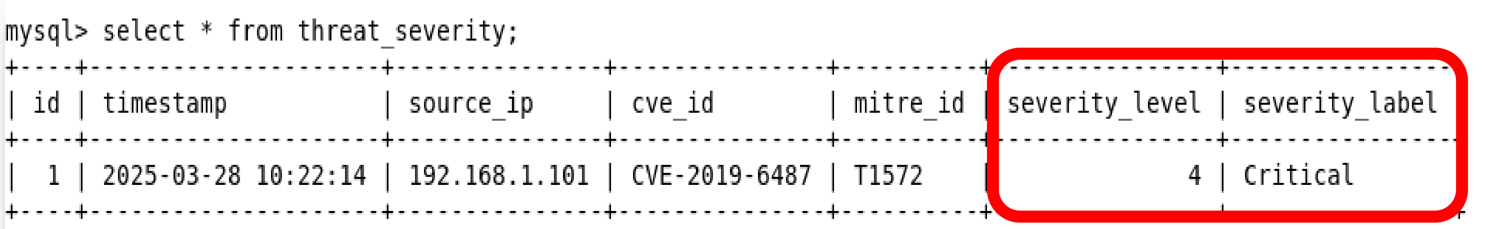


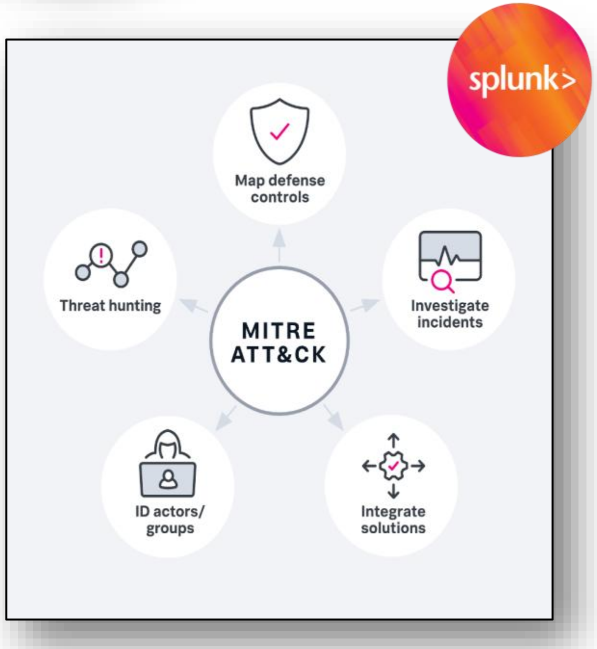
TABLE I
OFFSHORE WPP SPECIFIC VULNERABILITIES AND ATTACKS MAPPED TO CVE IDS [19] AND MITRE ATT&CK REFERENCES [20]

Category	Attack	CVE ID	MITRE ATT&CK	REFERENCE CODE
SCADA & ICS	Modbus TCP Write Single Register Attack	✓	✓	CVE-2019-10988, T0860
	DNP3 Malformed Packet	✓	✓	CVE-2015-7916, T0856
	IEC 60870-5-104 Exploit	✓	✓	CVE-2022-29544, T0859
	Modbus Read Device ID Spoof	✗	✓	–, T0859
IoT Exploits	IoT Botnet Infection	✓	✓	CVE-2016-10401, T0747
	MQTT Unauthorized Access	✓	✓	CVE-2017-7653, T0852
	CoAP Unauthorized Access	✓	✓	CVE-2019-15889, T0853
DoS/DDoS	UDP Chargen (RFC864) DoS Attack	✓	✓	CVE-1999-0103, T1498
	HTTP Slowloris (RFC793, RFC7230) DoS Attack	✓	✓	CVE-2007-6750, T1499
Unauthorized Access	FTP/SSH Brute-Force	✗	✓	–, T1110
	SNMP Unauthorized Access	✓	✓	CVE-2017-6736, T1021
	ICMP Redirect Attack	✗	✓	–, T1595
Network Scanning	Nmap XMAS/FIN/UDP Scan	✗	✓	–, T1046
Malware & Exploits	Malware Download	✓	✓	CVE-2016-0034, T1203
	SMB EternalBlue	✓	✓	CVE-2017-0144, T1210
	RDP BlueKeep	✓	✓	CVE-2019-0708, T1210
Credential Dumping	LDAP Credential Dumping	✗	✓	–, T1003
	SSL Strip Attack	✓	✓	CVE-2009-3555, T1557
DNS-based Attacks	DNS Exfiltration	✗	✓	–, T1071
	DNS Tunneling	✓	✓	CVE-2019-6487, T1572



```
mysql> select * from threat_severity;
+----+---------------------+---------------+---------------+----------+----------------+----------------+
| id | timestamp           | source_ip     | cve_id        | mitre_id | severity_level | severity_label |
+----+---------------------+---------------+---------------+----------+----------------+----------------+
|  1 | 2025-03-28 10:22:14 | 192.168.1.101 | CVE-2019-6487 | T1572    |              4 | Critical       |
+----+---------------------+---------------+---------------+----------+----------------+----------------+
```

Points to the vulnerabilities and is suited for threat severity classification (Z) in the DEFENSE Module.



Threat modelling, Incident classification, and attack behavior detection in the multi-log ingestion at the ORIENT Module.

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https://services.nvd.nist.gov/rest/json/cves/2.0?cveId={cve_id}
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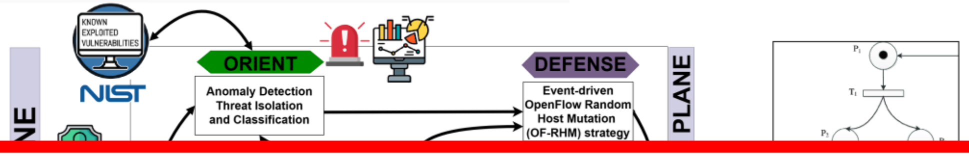
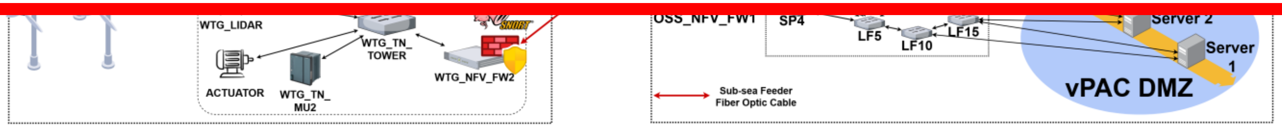

KNOWN EXPLOITED VULNERABILITIES
NIST
NE
ORIENT
Anomaly Detection Threat Isolation and Classification
DEFENSE
Event-driven OpenFlow Random Host Mutation (OF-RHM) strategy
PLANE
P1
T1

Proposed Approach:
Autonomic, event-driven OpenFlow Random Host Mutation (OF-RHM) Framework

OpenFlow Random Host Mutation (OF-RHM) is a key Moving Target Defense technique designed for use with OpenFlow-based software defined networks

> *"Moving Target Defense (MTD) is a cyber-resilience strategy <u>introduces dynamism</u> into the protected systems and networks, thereby <u>increasing the uncertainty and complexity for attackers</u> while maintaining usability for legitimate users."*
> *Jafarian et al., 2012*



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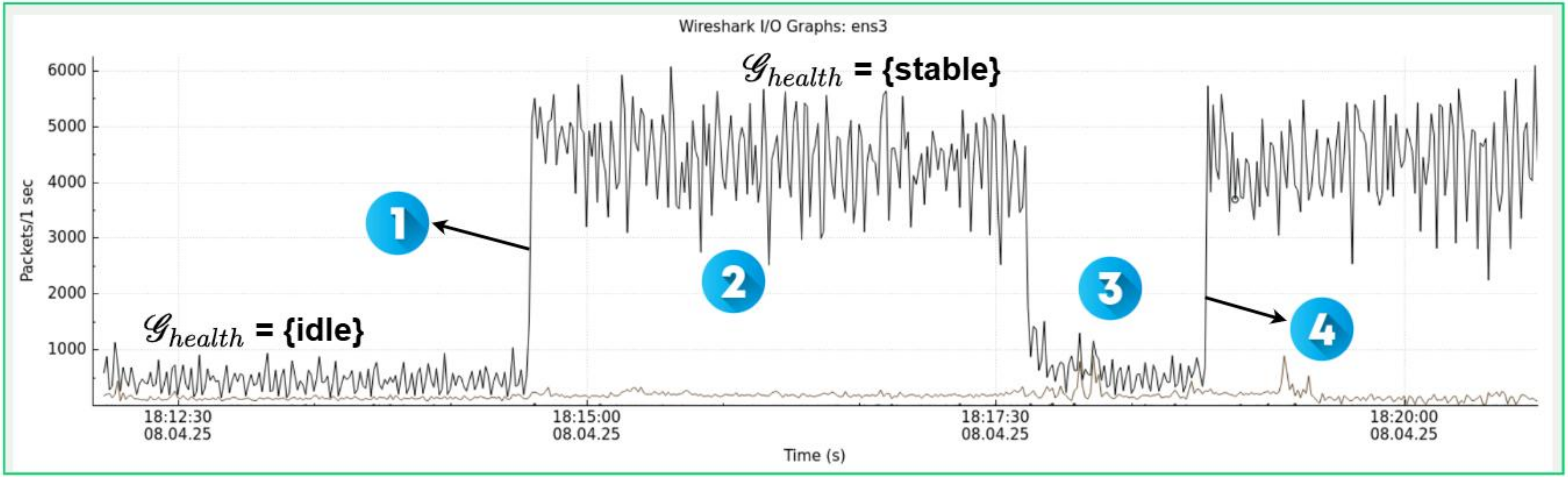
Jafarian, J. H., Al-Shaer, E., & Duan, Q. (2012). "OpenFlow Random Host Mutation: Transparent Moving Target Defense Using Software Defined Networking." Proceedings of the First Workshop on Hot Topics in Software Defined Networks (HotSDN '12).

Cyber Resilience? How do we measure it?

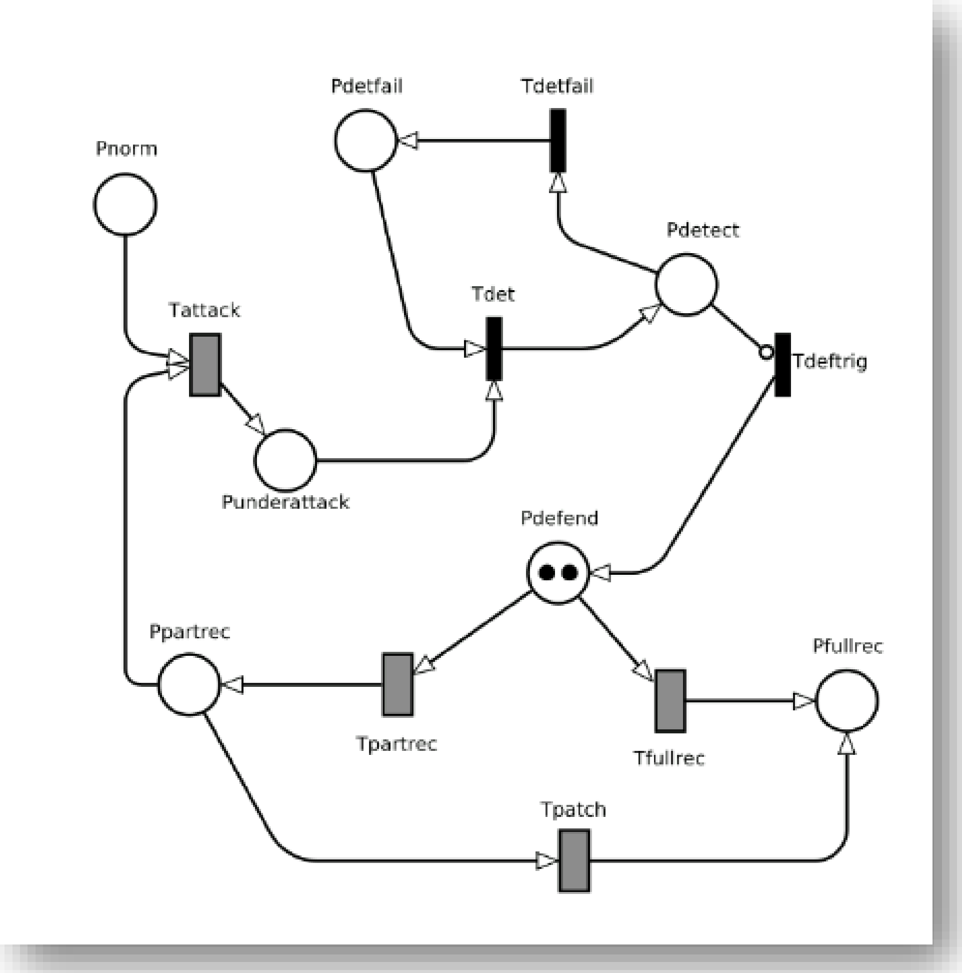
1. *Network behavior and performance indicators of Cyber-Resilience*



Wireshark capture of network throughput (packets/sec) under both reconnaissance and late-stage (DDoS) attacks for 10 minutes.

Cyber Resilience? How do we measure it?

2. *Quantitative Assessment using Generalised Stochastic PetriNets (GSPN)*



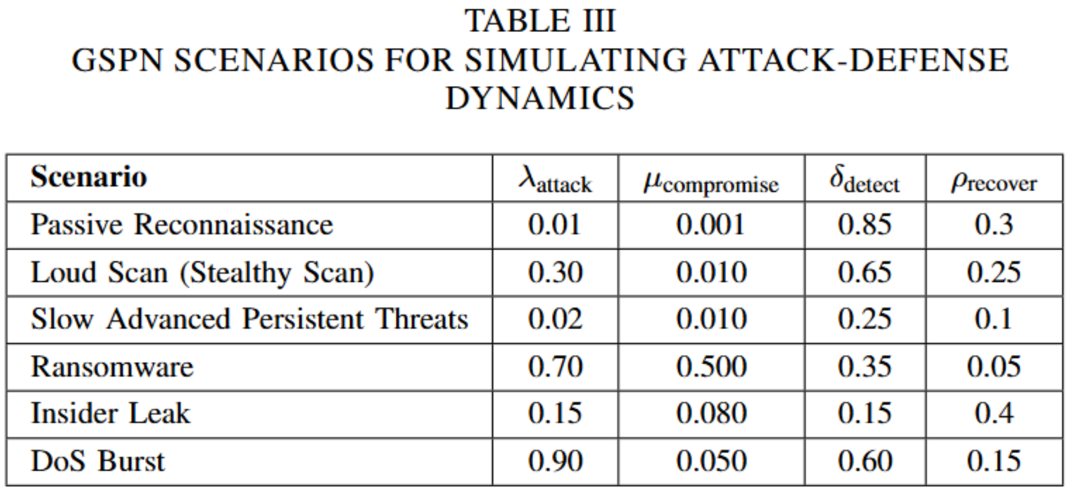


TABLE III
GSPN SCENARIOS FOR SIMULATING ATTACK-DEFENSE DYNAMICS

Scenario	λ_{attack}	$\mu_{\text{compromise}}$	δ_{detect}	ρ_{recover}
Passive Reconnaissance	0.01	0.001	0.85	0.3
Loud Scan (Stealthy Scan)	0.30	0.010	0.65	0.25
Slow Advanced Persistent Threats	0.02	0.010	0.25	0.1
Ransomware	0.70	0.500	0.35	0.05
Insider Leak	0.15	0.080	0.15	0.4
DoS Burst	0.90	0.050	0.60	0.15

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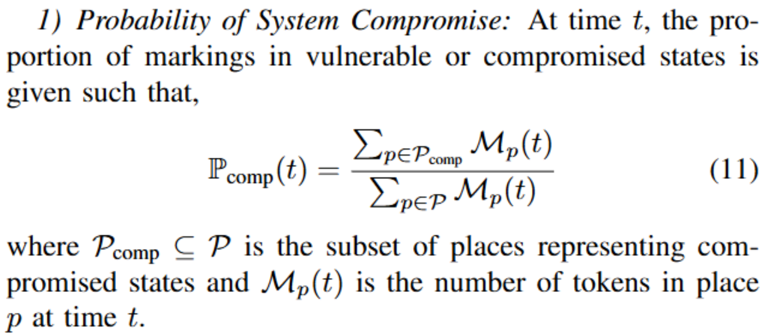
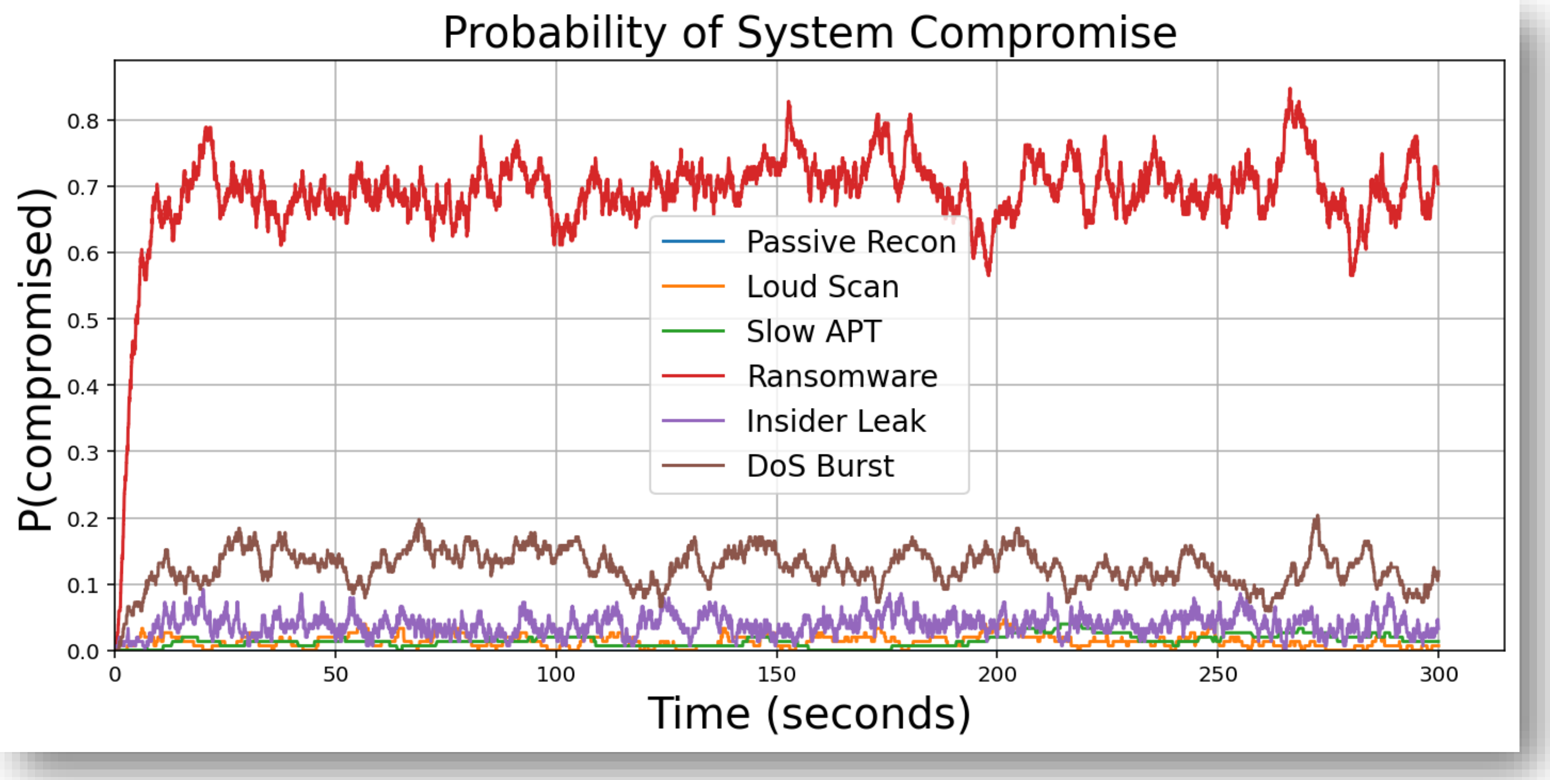


1) Probability of System Compromise: At time t, the proportion of markings in vulnerable or compromised states is given such that,

$$\mathbb{P}_{\text{comp}}(t) = \frac{\sum_{p \in \mathcal{P}_{\text{comp}}} \mathcal{M}_p(t)}{\sum_{p \in \mathcal{P}} \mathcal{M}_p(t)} \qquad (11)$$

where $\mathcal{P}_{\text{comp}} \subseteq \mathcal{P}$ is the subset of places representing compromised states and $\mathcal{M}_p(t)$ is the number of tokens in place p at time t.



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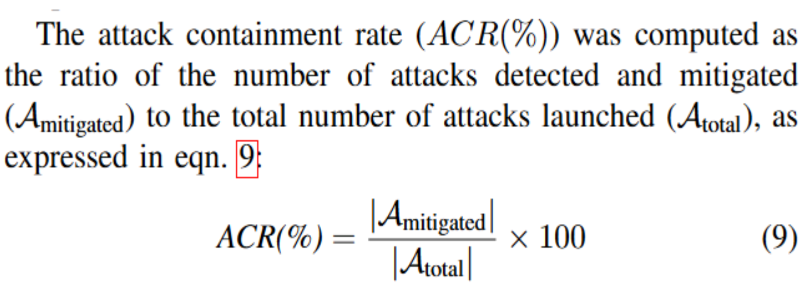
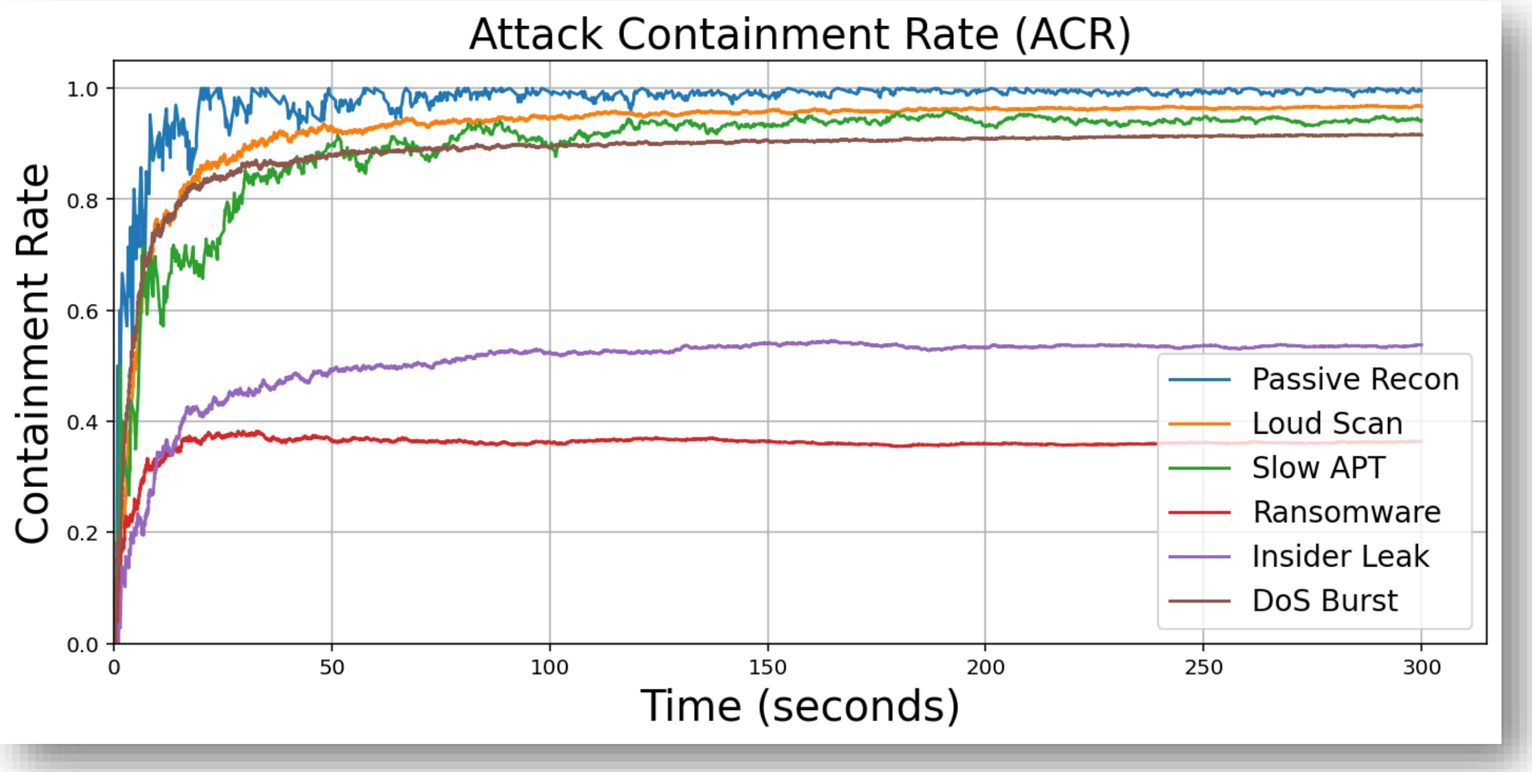


The attack containment rate ($ACR(\%)$) was computed as the ratio of the number of attacks detected and mitigated ($\mathcal{A}_{\text{mitigated}}$) to the total number of attacks launched ($\mathcal{A}_{\text{total}}$), as expressed in eqn. 9:

$$ACR(\%) = \frac{|\mathcal{A}_{\text{mitigated}}|}{|\mathcal{A}_{\text{total}}|} \times 100 \tag{9}$$



Attack Containment Rate (ACR)

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Cyber Resilience? How do we measure it?

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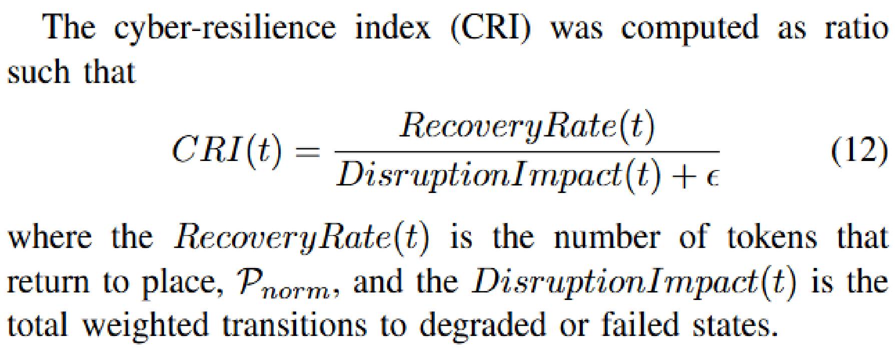
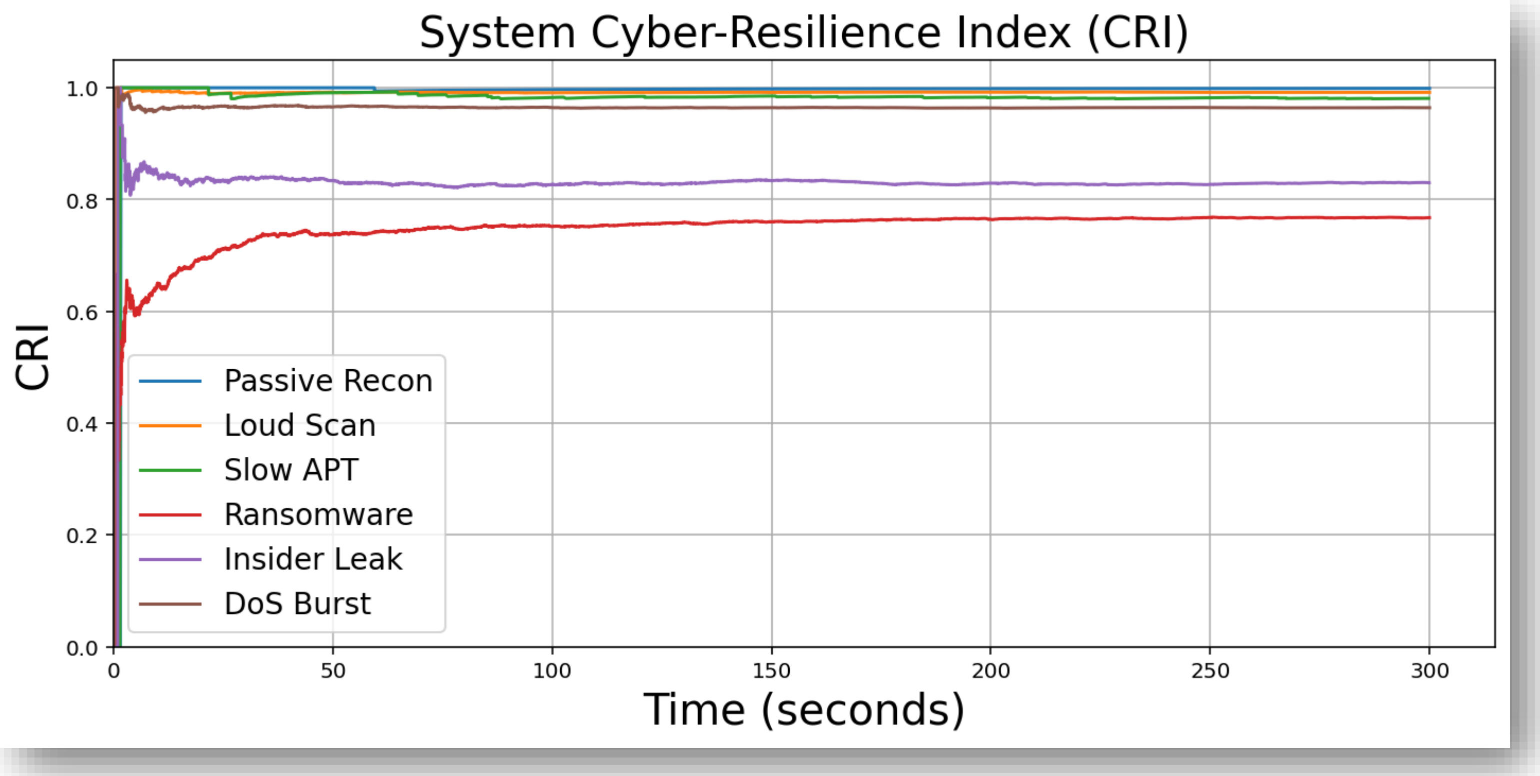


The cyber-resilience index (CRI) was computed as ratio such that

$$CRI(t) = \frac{RecoveryRate(t)}{DisruptionImpact(t) + \epsilon} \tag{12}$$

where the $RecoveryRate(t)$ is the number of tokens that return to place, $\mathcal{P}_{norm}$, and the $DisruptionImpact(t)$ is the total weighted transitions to degraded or failed states.

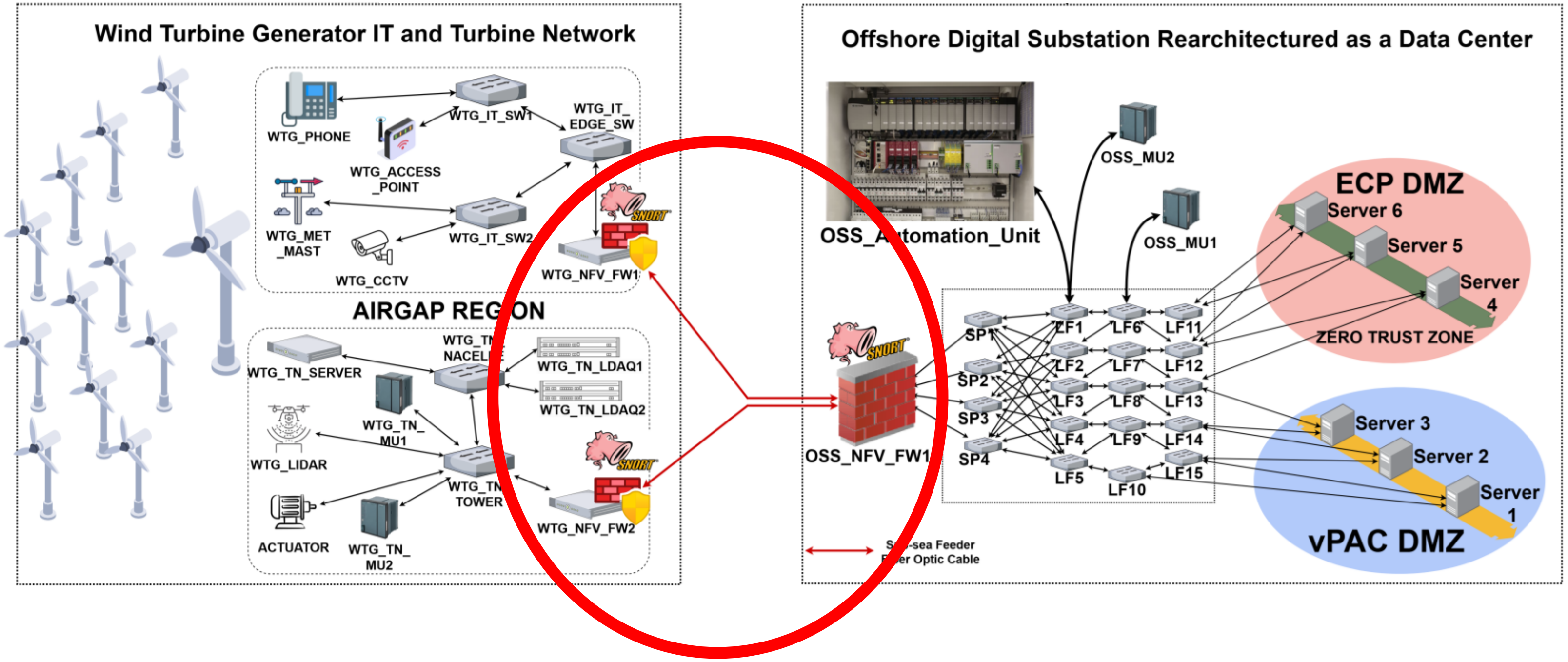


Insights from Testbed Transient Studies

False positive Rate or a case of over-defending?

The $FPR(\%)$ was computed as:

$$FPR(\%) = \frac{False\ Positives}{Total\ Alerts} \times 100$$



Q&A

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InnoCyPES
Innovative Tools for Cyber-Physical Energy Systems