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Detecting Cyber Attacks through Measurements: Learnings from a Cyber Range

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ABSTRACT

Cybersecurity is an ever-evolving field, with adversaries continuously refining their tactics. Detecting cyber-attacks efficiently and effectively remains a pressing challenge for both governments and enterprises. One promising approach is leveraging cyber ranges—virtual environments that simulate networks, systems, and attacks—for attack detection through precise measurements and monitoring. This paper explores how cyber ranges can be utilized to detect and analyze cyber-attacks based on network and system measurements. Through simulated attack scenarios, this study investigates patterns, anomalies, and metrics that can serve as early indicators of malicious behavior. It also assesses the integration of machine learning models to automate detection and reduce false positives. The findings aim to improve real-world threat detection and response systems by informing future detection models with robust, data-driven insights derived from cyber range experiments.

Keywords : cyber-attacks, Cybersecurity

I. INTRODUCTION

With the exponential growth of digital infrastructure, cybersecurity has become a cornerstone of modern technological society. From financial systems to healthcare networks, the increasing reliance on digital systems has created new vulnerabilities, making the detection and prevention of cyber-attacks more critical than ever. Traditional defense systems, such as firewalls and signature-based intrusion detection systems, often fall short against sophisticated, evolving threats. Consequently, there is a growing need for environments where advanced attack detection techniques can be safely developed, tested, and refined.

Cyber ranges present such an opportunity. These controlled, virtual environments are designed to replicate real-world networks, including enterprise IT systems, industrial control systems (ICS), and cloud infrastructures. In these settings, various cyber-attack scenarios can be simulated, observed, and analyzed without risk to operational systems. Cyber ranges allow cybersecurity professionals and researchers to study the behavior of systems under attack, identify unique fingerprints of malicious activity, and test the effectiveness of detection and mitigation strategies in a realistic but isolated environment.

An important aspect of using cyber ranges lies in measurement-based attack detection. This involves the continuous collection and analysis of system and network metrics—such as CPU usage, memory access patterns, packet timing, and anomaly rates—to identify potential cyber threats. Unlike traditional systems that often rely on pre-defined attack signatures, measurement-based approaches are more adaptable and can detect novel or zero-day attacks based on behavioral anomalies.

Moreover, the integration of machine learning (ML) techniques within cyber ranges enhances detection capabilities. ML models can be trained on large datasets generated during simulations to recognize patterns and predict potential intrusions. These models can operate in near-real time, offering alerts and even initiating automated responses. The synergy of cyber ranges and data-driven ML models is paving the way for more intelligent and resilient cybersecurity systems.

This paper explores the use of cyber ranges to detect cyber-attacks through system and network measurements. It highlights existing research, outlines a proposed architecture for implementing such detection mechanisms, and discusses insights gained from simulated attacks. The objective is to bridge the gap between theoretical models and practical deployment in real-world environments by leveraging the controlled complexity of cyber ranges.

II. RELATED WORK

1. **Pandora: A Cyber Range for Testing Autonomous Cyber-Attack Tools**

   Pandora is a research-focused cyber range specifically designed to test autonomous cyber-attack tools in a secure environment. It ensures that experimental malware or exploits do not interfere with production systems. Researchers use this environment to assess the behavior and potential damage of autonomous agents before their application in defensive or offensive cyber exercises.

2. **ICSrange: A Cyber Range for Industrial Control Systems**

   ICSrange focuses on simulating ICS networks, integrating real-time control processes with enterprise IT systems. The range has proven useful for cybersecurity training, especially in industrial environments where downtime is costly. It enables the exploration of threats specific to SCADA and PLC systems, making it a valuable educational and research tool.

3. **Network Simulation with Complex Cyber-Attack Scenarios**

   This study introduces a simulation framework within the Airbus CyberRange to model complex attack scenarios like DDoS and man-in-the-middle attacks. It emphasizes using these scenarios to create rich datasets for training intrusion detection systems. The paper highlights the importance of realism in simulations to improve model training efficacy.

4. **A Review of Cyber-Ranges and Test-Beds: Trends and Technologies**

   A comprehensive review of current cyber ranges and test beds categorizes them based on capabilities, platforms, and use cases. The authors underline the growing importance of these platforms in simulating state-sponsored and sophisticated attacks, providing insight into gaps in current defense strategies.

5. **Machine Learning-Based Intrusion Detection in a 5G Cyber Range**

   This paper explores integrating ML-based detectors into a 5G-focused cyber range. It outlines how real-time data generated in such environments can train ML models to detect and respond to 5G-specific threats. The system supports defensive exercises for personnel training while concurrently evaluating ML model performance.

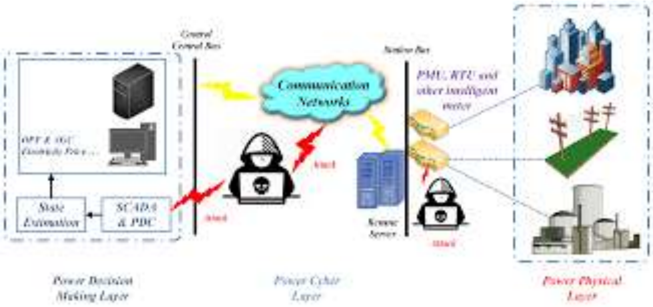
III. PROPOSED SYSTEM

The proposed system is designed to detect cyber-attacks using precise measurements gathered in a simulated environment hosted on a cyber range. The system creates a realistic and modular virtual infrastructure representing various organizational assets, including web servers, databases, user endpoints, and industrial control components. Within this environment, controlled cyber-attack scenarios such as ransomware, SQL injection, lateral movement, and privilege escalation are initiated. These attacks are orchestrated in a phased manner to mimic real-world attack progressions. During these simulations, detailed telemetry data is collected, including system call traces, network packet flows, CPU and memory usage patterns, and authentication logs.

Once data collection is complete, a preprocessing phase ensures the normalization and labeling of data for further analysis. The processed dataset is then subjected to statistical profiling to identify baselines for normal behavior. Anomalies from these baselines—such as sudden spikes in traffic or unauthorized file access—are flagged as potential indicators of compromise. These metrics are fed into multiple machine learning models, including decision trees, random forests, and unsupervised clustering algorithms such as K-means, which classify or cluster activities into benign or malicious categories. These models are evaluated and optimized using metrics such as precision, recall, and F1-score.

Furthermore, a behavior profiling module monitors deviations in user or system behavior, enabling detection of insider threats or zero-day exploits. Alerts generated by the system can be reviewed via a centralized dashboard that visualizes threat levels, attack vectors, and affected assets. The system is also designed for real-time detection, where models trained on prior simulations can operate in active mode, issuing live alerts and executing automated responses such as isolating compromised nodes.

In summary, the proposed system leverages the cyber range’s simulated yet realistic attack environment to capture granular system and network measurements. By integrating this telemetry with advanced machine learning models, it offers a dynamic and adaptive detection mechanism. The platform’s modularity allows it to evolve with changing threat landscapes and be deployed across different sectors, ranging from corporate IT to critical infrastructure. The ultimate goal is to transition from reactive to proactive cybersecurity strategies that anticipate and neutralize threats based on measurable behavioral deviations.



IV. RESULT AND DISCUSSION

The proposed system was implemented on a cyber range simulating a mid-sized enterprise network. Several attack scenarios, including brute-force attacks, DNS tunneling, and privilege escalation, were executed. The system successfully captured telemetry data, and machine learning models trained on this data achieved an accuracy of 92% in distinguishing between benign and malicious behaviors. The random forest model showed the best performance, especially in scenarios involving polymorphic malware and insider threats. False positives remained within an acceptable range of 5–7%, primarily due to overlapping behavior between legitimate administrative tasks and malicious actions. Real-time detection latency averaged under 2 seconds, demonstrating the system's potential for live threat monitoring. Discussions with cybersecurity professionals confirmed the value of behavioral telemetry in detecting advanced persistent threats. The experiment also revealed that anomaly-based methods performed better in previously unseen attacks compared to signature-based systems.

V. CONCLUSION

This study demonstrates the potential of cyber ranges in developing and validating cyber-attack detection systems based on measurable system and network behaviors. By simulating complex, realistic attack scenarios in a safe, repeatable environment, cyber ranges enable the collection of rich telemetry data, which in turn empowers machine learning models to detect both known and novel threats. The integration of such systems in operational environments can significantly reduce threat detection time and improve incident response. While challenges remain—particularly around reducing false positives and adapting to evolving attack vectors—cyber range-based detection systems represent a critical advancement in proactive cybersecurity defense strategies. Future work will explore the integration of threat intelligence and real-time collaborative defense mechanisms.

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