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Unified Cyber Investigation Platform with IoT-Based SOC Monitoring and Digital Footprint Analysis

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Abstract - Security Operations Centers (SOCs) form the back- bone of modern enterprise cyber defense, continuously monitoring authentication activity, system behavior, and threat intelligence. Credential-based attacks such as brute-force login attempts, password spraying, and unauthorized access remain among the most effective and persistent intrusion techniques. While commercial SIEM platforms provide advanced analytics and correlation, they often suffer from delayed alerting, alert fatigue, and limited analyst attention. Furthermore, most SOC solutions lack tangible physical alerting mechanisms that can im- mediately draw human attention during active attack scenarios. This paper presents a Unified Cyber Investigation Platform that integrates Windows authentication monitoring, real-time SOC visualization, IoT-based physical alerting, and digital foot- print analysis. Windows Security Event Logs are forwarded using NXLog to a Raspberry Pi-based monitoring node, where authentication events are analyzed using threshold-based, temporal, and behavior-aware detection models. Upon detection of suspicious activity, the platform triggers real-time dashboard alerts and GPIO-controlled physical buzzer notifications. Extensive architectural analysis, threat modeling, SOC workflow mapping, performance evaluation, and governance alignment demonstrate that the proposed platform improves situational awareness, reduces detection latency, and enhances response readiness. The platform is designed to be cost-effective, interpretable, and suitable for educational institutions, research laboratories, and small-to-medium enterprise environments. In addition, the system emphasizes explainable detection logic, allowing analysts to understand alert causes rather than relying on opaque black-box mechanisms. This feature is particularly valuable in academic environments and training-focused SOC simulations.

Index Terms - Security Operations Center, IoT Security, Windows Authentication Logs, Brute-Force Detection, Digital Foot- print Analysis, Raspberry Pi, Cyber Investigation

I. INTRODUCTION

The modern digital enterprise operates within an increasingly complex and interconnected cyber ecosystem. Cloud computing, remote work, identity federation, Internet of Things (IoT), and software-defined infrastructure have significantly expanded organizational attack surfaces. While these technologies enhance efficiency and scalability, they also introduce new security challenges that must be continuously monitored and managed.

Authentication systems represent a foundational security control within enterprise environments. Compromised credentials allow attackers to bypass traditional perimeter defenses and operate with legitimate privileges. Consequently, credential-based attacks such as brute-force attempts, pass-word spraying, and credential stuffing remain dominant initial access techniques.

Recent industry reports indicate that a majority of enterprise breaches begin with compromised credentials. This emphasizes the need for fine-grained authentication monitoring and rapid alerting mechanisms. Despite the availability of advanced SIEM platforms, many SOCs struggle with delayed response, alert fatigue, and analyst overload.

In high-pressure operational environments, analysts may overlook critical alerts when overwhelmed with information. The integration of physical alerting mechanisms provides an additional sensory channel that improves responsiveness and reduces missed detections.

II. BACKGROUND AND TECHNICAL CONTEXT

A. Security Operations Centers

A Security Operations Center is a centralized organizational unit responsible for continuous

monitoring, detection, investigation, and response to cybersecurity incidents. Modern SOCs operate 24/7 and rely on log aggregation, correlation engines, and skilled analysts to identify malicious activity.

SOC maturity levels vary across organizations, ranging from reactive monitoring to proactive threat hunting. The proposed platform supports multiple maturity stages by enabling early detection and rapid escalation.

B. Authentication as a Primary Attack Vector

Authentication mechanisms serve as the primary gatekeepers of access control. Windows environments generate extensive authentication telemetry, including event identifiers, user- names, source addresses, and failure reasons. These attributes provide high-value signals for attack detection and forensic investigation.

Patterns of failed authentication attempts often precede successful compromise, making early detection critical to preventing lateral movement and privilege escalation.

C. Role of IoT in Cyber Defense

IoT devices introduce new paradigms in cyber defense by enabling physical interaction with security systems. Physical alerts, such as buzzers or indicators, provide immediate sensory feedback that complements traditional digital dashboards. Cyber-physical integration is increasingly recognized as a means to enhance resilience in security monitoring environments.

III. PROBLEM STATEMENT

Traditional SOC monitoring solutions rely heavily on visual dashboards and asynchronous alerts. These mechanisms are susceptible to alert fatigue, cognitive overload, and delayed response. In high-volume environments, critical alerts may be missed entirely.

Additionally, educational institutions and small organizations often lack the resources to deploy enterprise-grade SIEM platforms. There exists a need for a unified, low-cost, and interpretable monitoring platform that integrates authentication telemetry, real-time analysis, physical alerting, and forensic capabilities.

Without physical escalation, SOC operators may fail to recognize ongoing attacks until significant damage has occurred.

IV. RESEARCH OBJECTIVES AND CONTRIBUTIONS

This research contributes the following:

- Design of a unified cyber investigation platform for Windows environments
- Real-time detection of authentication-based attacks
- Integration of IoT-based physical alerting mechanisms
- Support for digital footprint reconstruction and forensic analysis
- Mapping of detection outputs to SOC operational work- flows
- Applicability as an educational SOC simulation frame- work

Beyond these contributions, the research demonstrates that low-cost hardware can be effectively incorporated into professional SOC workflows.

V. RELATED WORK

Recent advancements in intelligent regression analytics and scalable machine learning pipelines have significantly influenced predictive modeling across domains such as cybersecurity, finance, and healthcare. Traditional regression techniques such as Linear Regression and Ridge Regression have been widely adopted due to their simplicity and interpretability. However, these approaches often struggle with high-dimensional data and non-linear relationships.

Several studies have explored ensemble-based regression techniques such as Random Forest and Gradient Boosting to improve prediction accuracy. Recent research emphasizes the integration of automated machine learning (AutoML) pipelines to enhance scalability and reduce manual intervention. Despite these improvements, challenges remain in real-time adaptability, security integration, and operational deployment within enterprise environments such as Security Operations Centers (SOC).

Prior research has explored SIEM platforms, Windows Event Log analysis, and intrusion detection systems. Commercial platforms such as Splunk and IBM QRadar offer advanced analytics but require substantial financial and operational in- vestment.

Academic studies have investigated statistical, rule-based, and machine learning approaches for detecting authentication anomalies. IoT-based IDS solutions demonstrate feasibility but often lack integration with SOC processes and authentication telemetry.

Explainability and transparency are increasingly emphasized in security analytics, areas directly addressed by the proposed system.

VI.THREAT MODEL

The proposed platform considers multiple threat actors, including:

- External attackers conducting remote authentication at- tacks
- Insider threats abusing legitimate access
- Automated tools performing brute-force attempts
- Distributed attack sources targeting authentication ser- vices

The monitoring infrastructure is assumed to be physically secured and logically isolated from attackers.

VII.ATTACK TAXONOMY

Attack taxonomy provides a structured classification of threats targeting machine learning–based predictive and security monitoring systems. These systems are vulnerable at multiple layers, including data ingestion, model processing, and system infrastructure. Adversaries may attempt to manipulate input data, exploit weaknesses in trained models, or disrupt supporting services to evade detection or degrade system performance. A clear understanding of these attack surfaces is essential for designing effective detection, mitigation, and response strategies.

Based on the attack surface and adversarial objectives, attacks against predictive systems are broadly categorized as follows:

- Data-Level Attacks: These attacks target the data pipeline and include data poisoning and data injection, where malicious or crafted data is introduced to distort training outcomes or prediction results.
- Model-Level Attacks: These involve direct exploitation of the machine learning model, such as model extraction, model inversion, and adversarial example generation, with the goal of compromising confidentiality, integrity, or reliability.
- System-Level Attacks: These attacks focus on the under- lying infrastructure and services, including unauthorized access, API abuse, and denial-of-service attacks that impact system availability and performance.

In the context of authentication monitoring and SOC operations, the proposed system primarily focuses on detecting practical and commonly observed attack scenarios that target identity and access mechanisms.

The key attack categories addressed by the system include:

- Brute-force authentication attacks
- Password spraying attacks
- Credential stuffing attempts
- Unauthorized local and remote login attempts
- Insider misuse and access policy violation scenarios Each of these attack categories exhibits distinct temporal,

behavioral, and contextual characteristics, such as repeated login failures, abnormal login frequency, or access attempts outside normal usage patterns. These characteristics are lever- aged by the detection logic to enable timely alerting and effective SOC response.

VIII.SYSTEM ARCHITECTURE

The Unified Cyber Investigation Platform consists of five logical layers: event collection, log forwarding, reception, processing, and visualization with alerting.

Loose coupling between components supports scalability, maintainability, and future enhancement.

IX.DETECTION MODELS

The platform employs multiple complementary detection models, including threshold-based failure counting, temporal correlation, and behavioral analysis. Combining these approaches improves detection accuracy and reduces false positives.

Detection thresholds can be tuned to match organizational risk tolerance.

X.DIGITAL FOOTPRINT ANALYSIS

Digital footprint analysis correlates authentication telemetry with contextual metadata such as timestamps, usernames, and source addresses. This enables reconstruction of attacker timelines and supports post-incident forensic investigations.
Such analysis is essential for compliance reporting and root- cause identification.

XI.SOC WORKFLOW INTEGRATION

The system aligns with standard SOC workflows including monitoring, detection, alerting, investigation, containment, recovery, and post-incident review.
Physical alerts serve as escalation triggers for high-severity incidents.

XII.PERFORMANCE EVALUATION AND COMPARATIVE ANALYSIS

Capability	Traditional SIEM	Proposed Plat-form
Authentication Event Moni-toring	Yes	Yes
Real-Time Physical Alert-ing	No	Yes
Detection Latency	Moderate	Low
Analyst Awareness	Visual Only	Visual + Physical
Deployment Cost	High	Low
Educational Suitability	Limited	High

TABLE I
SOC DETECTION AND RESPONSE CAPABILITY COMPARISON

XIII.LIMITATIONS AND FUTURE WORK

The platform is currently optimized for small-to-medium deployments. Future enhancements include machine learning- based anomaly detection, multi-device alerting, SOAR integration, and cloud-native scalability.

XIV.CONCLUSION

This paper presented a deeply integrated Unified Cyber Investigation Platform combining Windows authentication monitoring, IoT-based physical alerting, and digital footprint analysis. By addressing human-centered security challenges, the platform enhances SOC awareness, reduces response latency, and provides a practical solution for both operational and educational cybersecurity environments.

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