MINOR PROJECT REPORT

VESSA

(Vulnerability, Event and Security Systems Analysis)

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DECLARATION

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1. Proposed System Overview

Abstract

VESSA is a next-generation security incident management and analysis platform designed to enhance cybersecurity operations through automation, artificial intelligence, and advanced analytics. Organizations today face increasing threats while struggling with fragmented security tools that require constant switching between multiple systems. This inefficiency results in increased response times, operational bottlenecks, and missed security threats. VESSA resolves these challenges by integrating incident management, threat intelligence, and data analytics into a single, unified platform. It eliminates operational silos and enhances security workflows through machine learning-powered threat detection, structured workflows, and role-based access control (RBAC). Unlike traditional solutions, VESSA is designed for scalability and cost optimization, ensuring that organizations of all sizes can maintain a robust security posture without unnecessary complexity or expenses.

Introduction

Security threats are evolving rapidly, but many organizations are still using outdated security tools that are slow, inefficient, and incapable of handling modern attack techniques. Many well-known security solutions, such as ArcSight, McAfee ESM, and legacy versions of Splunk Enterprise (without Phantom/UEBA), lack built-in integration with SOAR (Security Orchestration, Automation, and Response) and UEBA (User and Entity Behaviour Analytics). As a result, security teams are forced to toggle between multiple tools like QRadar, Cortex XSOAR, and Swimlane to complete an investigation, leading to unnecessary delays and human error.

VESSA eliminates these inefficiencies by offering a single, fully integrated platform that combines real-time security analytics, automation, and advanced threat intelligence. Unlike older SIEM solutions such as IBM QRadar and LogRhythm, which require costly vertical scaling with hardware upgrades, VESSA provides cloud-native horizontal scalability, reducing operational expenses. Additionally, traditional rule-based correlation engines like those in OSSIM and ManageEngine struggle to detect sophisticated threats. VESSA overcomes these limitations with AI-powered anomaly detection, allowing organizations to identify and respond to attacks more effectively. It also offers flexible subscription models, allowing organizations to optimize costs while maintaining high-performance security measures.

Objective

1. Enhanced Security Incident Management
   - Provide an efficient tracking system for security events with detailed metadata, severity levels, and impact-based prioritization.
   - Enable real-time monitoring and centralized logging to track security incidents from detection to resolution.

2. AI-Powered Threat Detection & Correlation
   - Implement machine learning-driven anomaly detection to identify suspicious behaviors that evade traditional rule-based detection.
   - Use vector-based similarity search to correlate related incidents and uncover hidden attack patterns.

3. Seamless Threat Intelligence Integration
   - Automatically enrich security events with threat intelligence feeds (e.g., Recorded Future, VirusTotal) to improve decision-making.
   - Detect and mitigate zero-day threats using advanced behavioral analytics.

4. Automated Incident Response & Workflow Optimization
   - Enable low-code/no-code playbook automation for SOC (Security Operations Center) teams to streamline investigations.
   - Implement structured workflows for incident triage, containment, mitigation, and post-incident analysis.

5. Scalability & Cost Optimization
   - Utilize cloud-native architecture for efficient horizontal scaling without the need for costly hardware upgrades.
   - Offer subscription-based pricing models, allowing organizations to scale their security operations based on their needs.

6. Regulatory Compliance & Data Security
   - Ensure compliance with global security standards (e.g., GDPR, ISO 27001, NIST) by implementing robust encryption, logging, and access controls.
   - Provide role-based access control (RBAC) to limit sensitive data exposure and prevent unauthorized access.

7. User-Friendly Dashboard & Reporting
   - Deliver an intuitive, analytics-driven dashboard for visualizing incidents, response timelines, and key security metrics.
   - Generate detailed security reports with trend analysis and predictive insights for better decision-making.

Literature review

The VESSA (Versatile Enterprise Security and Surveillance Analytics) system integrates AI-driven security analytics, SOAR (Security Orchestration, Automation, and Response), cloud-native threat detection, role-based access control (RBAC), and user and entity behaviour analysis (UEBA), positioning it as a next-generation security platform. Security Incident Management, a critical component of VESSA, benefits from AI-enhanced automation in SOAR, optimizing incident detection and response workflows, minimizing human intervention, and improving reaction time to cyber threats [1].

The integration of SIEM (Security Information and Event Management) and SOAR allows real-time log correlation for faster threat intelligence processing [2]. Behavioural analytics in cybersecurity, where machine learning models identify attack patterns through anomaly detection, further strengthens threat detection capabilities [3]. As cyber threats evolve, cloud-native security architectures enable scalable and low-latency security monitoring, ensuring adaptability in high-demand scenarios [4]. Real-time AI monitoring of infrastructure enhances cloud security by reducing security blind spots [5]. Threat intelligence plays a crucial role in proactive cybersecurity, where external feeds from sources like VirusTotal enhance AI-driven cybersecurity analytics [6]. AI is also leveraged to predict zero-day attacks by identifying correlated threat indicators in multiple security logs [7].

Furthermore, graph-based AI models improve malware classification accuracy, making them integral to automated threat detection workflows [8]. To strengthen access control and compliance, RBAC models have been developed to implement multi-tiered security access, optimizing organizational security management [9]. The introduction of compliance automation in SOAR enables dynamic enforcement of GDPR, ISO 27001, and NIST security standards through policy-based automation [10].

With the rise of quantum computing, quantum-safe encryption techniques are being explored to counteract potential cryptographic vulnerabilities [11]. AI-driven intrusion detection in Open RAN-based networks has also emerged as a critical solution to secure modern cloud-native infrastructures [12]. Self-healing AI-driven cybersecurity systems offer autonomous incident response with minimal human oversight, ensuring proactive and adaptive security measures [13]. Advanced AI-driven anomaly detection and graph-based security analytics contribute to predictive cybersecurity strategies, reducing cyber risk exposure [14].

The integration of automated digital forensic techniques further enhances post-breach security analysis, allowing for efficient incident resolution [15]. The culmination of these technologies enables VESSA to function as a unified, AI-powered security solution, addressing modern cyber threats through behavioural analytics, real-time monitoring, and automated policy enforcement [16][17][18][19][20].

Scope

1. Functional Scope

- Incident Logging & Management: Tracks security incidents metadata, severity levels, & prioritization.
- Threat Intelligence Integration: Enriches incidents with real-time data from multiple sources.
- Automated Security Operations: Implements workflow automation and API-based integrations.
- AI-Driven Detection: Uses machine learning and similarity search for advanced threat identification.
- RBAC & Subscription Management: Offers granular permission control and tier-based feature access.
- Advanced Analytics: Provides search, trend analysis, and anomaly detection for proactive security.

2. Technical Scope

- Scalability & Deployment: Cloud-native microservices (Kubernetes, AWS, Azure, on-prem).
- Data Processing: Uses PostgreSQL, MongoDB, Kafka, and Redis for efficient log management.
- Security & Compliance: Implements AES-256, TLS 1.3, GDPR, and ISO 27001 standards.
- Third-Party Integrations: Connects with SIEM, SOAR, and threat intelligence platforms via APIs.

3. Business & Operational Scope

- Target Audience: SOC teams, security analysts, IT admins, enterprises, and government agencies.
- Industry Use Cases: Banking (fraud detection), Healthcare (HIPAA compliance), E-Commerce (anti-fraud), and Government (cyber defense).
- Customization & Extensibility: Supports multi-tenancy, configurable alerts, and custom playbooks.

4. Future Enhancements

- Emerging Tech: Quantum-safe encryption, real-time threat graphs.
- Autonomous Security: AI-driven automated incident response.
- Behavioural Biometrics: Keystroke/mouse behaviour tracking for insider threat detection.

Tools & Technology

1. Databases & Storage

- MySQL: Stores structured logs with partitioning for fast time-based queries, using `JSON_EXTRACT()` for enriched field searches.
- ChromaDB: Manages vector embeddings for similarity searches (e.g., detecting similar attack patterns via `user_agent`, `body_hash`).
- Redis: Caches API key rate limits, stores threat intelligence lookups with TTL-based expiration.

2. Backend & Microservices

- Flask: Used for building APIs and microservices architecture.
- Kafka: Implements an asynchronous event-driven system for log ingestion and real-time processing.
- JWT (JSON Web Tokens): Ensures secure authentication and API communication.
- REST API: Provides a structured interface for integrating with external tools and services.

3. Machine Learning & AI

- All MiniLM-L6-v2: Generates lightweight embeddings for fast and efficient text-based similarity search.
- DistilBERT: Applied for incident detection and threat classification using NLP-based anomaly detection.

4. Security & Compliance

- AES-256, TLS 1.3: Ensures data encryption at rest and in transit.
- RBAC (Role-Based Access Control): Enforces fine-grained permission management.
- SIEM & SOAR Integration: Compatible with platforms like Splunk, Cortex XSOAR, and QRadar for extended security operations.

Functional Requirements

1. Incident Management & Logging

- Comprehensive Incident Tracking: Logs security events with metadata, timestamps, severity levels, and affected assets.
- Impact-Based Prioritization: Assigns priority levels based on risk assessment to optimize resource allocation.
- File Attachment Support: Enables storing relevant evidence for incident context and analysis.

2. Threat Intelligence & Correlation

- Automated Threat Enrichment: Integrates with external threat intelligence feeds (e.g., VirusTotal, Recorded Future).
- Vector-Based Similarity Search: Identifies patterns and correlations between related incidents.
- Anomaly Detection: Uses AI-driven behavioral analysis to detect suspicious activity.

3. Automated Security Operations

- Workflow Automation: Supports customizable playbooks for incident triage, investigation, containment, and resolution.
- Role-Based Access Control (RBAC): Ensures secure user access with hierarchical role permissions.
- Subscription-Based Feature Access: Offers tiered access to advanced functionalities.

4. Search, Reporting & Analytics

- Advanced Search & Filtering: Enables quick discovery of incidents based on various attributes.
- Trend Analysis & Predictive Insights: Uses machine learning to forecast security risks.

- Customizable Dashboard: Provides real-time visualization of security incidents, KPIs, and system health.

5. Alerts & Notifications

- Real-Time Alerts: Sends notifications via email, Slack, or API webhooks for high-priority incidents.
- Dynamic Rate Limiting: Adjusts alert frequency based on severity and subscription tier.
- Customizable Alert Rules: Allows organizations to define and modify alerting criteria.

6. System Integration & Extensibility

- SIEM & SOAR Compatibility: Integrates with Splunk, QRadar, Cortex XSOAR, and other security tools.
- REST API Support: Enables seamless third-party integrations for log ingestion and response automation.
- Multi-Tenancy & Custom Workflows: Supports different organizations with separate security environments.

Non-Functional Requirements

1. Performance & Scalability

- Cloud-Native Architecture: Uses containerized microservices (Kubernetes) for horizontal scaling.
- High Throughput: Supports ingestion of 10K+ events per second with optimized data pipelines.
- Low Latency: Utilizes in-memory caching (Redis, Memcached) for fast query execution.
- Event-Driven Processing: Implements Kafka-based asynchronous event handling for real-time log streaming.

2. Security & Compliance

- Data Encryption: Ensures AES-256 encryption for data at rest and TLS 1.3 for secure communication.
- RBAC & Multi-Tier Access Control: Enforces fine-grained permission management for different user roles.
- Regulatory Compliance: Adheres to GDPR, NIST, and ISO 27001 standards for data protection and auditing.
- Threat Intelligence Integration: Enriches security events with real-time threat intel sources (e.g., Recorded Future, Anomalies).

3. Reliability & Fault Tolerance

- Geo-Redundant Deployment: Ensures high availability with failover mechanisms across multiple data centers.
- Self-Healing Architecture: Uses automated load balancing and failure recovery to maintain uptime.
- Data Retention & Archiving: Implements log rotation and archival policies for long-term compliance storage.

4. Usability & Accessibility

- Intuitive Web Interface: Provides a modern dashboard with customizable views and real-time analytics.
- Low-Code/No-Code Playbook Automation: Reduces manual security operations dependency.
- Multi-Tenancy Support: Enables organizations to manage security operations across different business units.
- Role-Based Dashboards: Allows users to customize views based on security roles (SOC analyst, admin, compliance officer).

5. Maintainability & Extensibility

- Modular Microservices: Enables independent service updates without affecting system availability.
- Open API Architecture: Supports RESTful APIs & Webhooks for third-party integrations.
- Logging & Monitoring: Uses Prometheus & Grafana for real-time system health tracking.
- Backward Compatibility: Ensures seamless updates without breaking existing integrations.

2. Methodology

The VESSA system follows a modular and scalable approach to ingesting, analyzing, and responding to cybersecurity threats. This methodology integrates machine learning, real-time threat detection, and automated incident response within a cloud-native security framework. The process consists of the following key components: data ingestion, preprocessing, feature engineering, model training, and real-time threat detection, with a focus on efficient log storage, retrieval, and automated response orchestration.

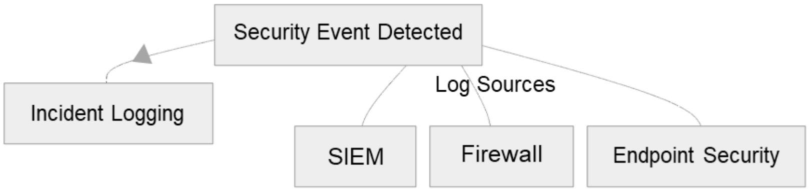

Fig: Security Events Logging in VESSA

1. Data Collection & Ingestion

VESSA collects logs from multiple security sources, ensuring comprehensive visibility into network activity and potential threats. Data sources include:

- Web server logs (Apache, Nginx) – Includes IPs, user agents, request methods, response codes.
- Application logs – Tracks authentication attempts, session activities, and anomalies.
- CDN/WAF logs – Captures blocked requests, bot detection, and threat signatures.
- Network logs – Provides insights into traffic patterns, port scans, and anomalous connections.

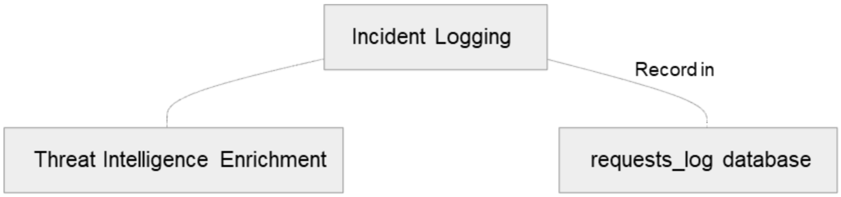

Fig: Purpose of Data Collection in VESSA

Data Pipeline Architecture

- API Gateway receives log data → Redacts Personally Identifiable Information (PII) → Stores structured data in MySQL.
- ChromaDB generates vector embeddings of high-cardinality fields such as user_agent and payload hashes, enabling similarity-based anomaly detection.
- Redis caches threat intelligence lookups and API rate limits, ensuring low-latency queries for known threats.

Each request is assigned a unique ID, and logs are partitioned in MySQL for efficient time-based querying, reducing query latency during incident investigations.

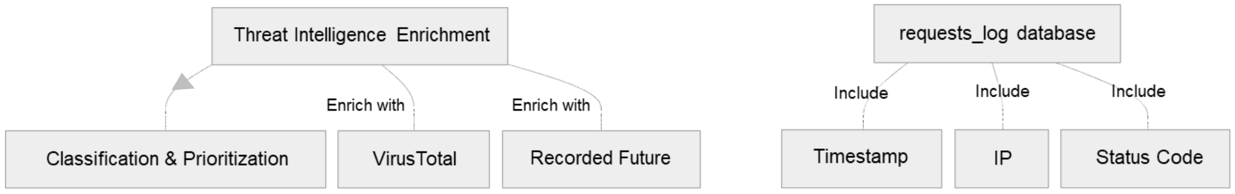

Fig: Processing of Data in VESSA

2. Data Preprocessing & Feature Engineering

To ensure high-quality model training and real-time analytics, collected data undergoes extensive preprocessing and feature engineering:

- Normalization: Converts IPs into integer representations or hashes for fast indexing.
- Encoding Categorical Features: Converts HTTP methods, response codes, and user agent strings into numerical representations for model compatibility.
- Handling Missing Values: Fills missing data using forward/backward imputation or assigns default categories.
- Feature Engineering:
  - Request rate per IP (detects potential brute-force attempts).
  - Payload entropy analysis (flags obfuscated or encoded payloads).
  - Session-based behavioral analysis (analyzes user activity over time).
  - Geo-location tagging (enriches logs with geospatial threat intelligence).
  - Vector embeddings for text-heavy fields (e.g., user-agent, payloads) to enable similarity-based detection using ChromaDB.

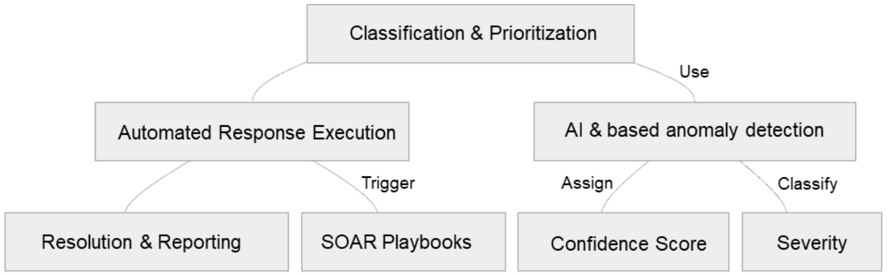
Classification & Prioritization
Use
Automated Response Execution
AI & based anomaly detection
Trigger
Assign
Classify
Resolution & Reporting
SOAR Playbooks
Confidence Score
Severity

Fig: Artificial Intelligence in VESSA

3. Threat Detection & Model Training

VESSA employs AI-powered detection techniques to classify threats based on structured logs and vector embeddings. Supervised, semi-supervised, and unsupervised learning approaches are used, depending on the availability of labeled data:

3.1 Supervised Learning (If labeled data is available)

- Classification Models:
    - Random Forest, XGBoost – Used for structured log data.
    - Deep Learning (LSTMs, Transformers) – Detects sequential attack patterns in log streams.
- Imbalanced Data Handling:
    - SMOTE (Synthetic Minority Over-sampling Technique) or class-weight adjustments are applied if malicious logs are underrepresented.

3.2 Unsupervised Learning (If labeled data is limited)

- Anomaly Detection Models:
    - Isolation Forest, Autoencoders – Identify deviations from normal request behaviour.
    - K-Means Clustering – Groups log entries into benign vs. suspicious activity based on learned patterns.

3.3 Semi-Supervised Learning (Leveraging both labeled and unlabeled data)

- Self-training models initially trained on labeled data refine their decision-making using unlabeled data.
- Reinforcement Learning: The model continuously improves its detection accuracy based on feedback from security analysts.

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4. Real-Time Threat Analysis & Incident Response

VESSA integrates SOAR (Security Orchestration, Automation, and Response) to automate threat mitigation and reduce response times. The workflow consists of:

4.1 Threat Detection Pipeline

1. Redis checks if an IP is already blocklisted.
2. ML model queries ChromaDB for similarity-based detection (e.g., "Find all requests with similar payload structures").
3. If an attack is suspected:
    - The is_malicious flag is set to True, and a confidence_score is assigned.
    - Threat intelligence feeds (e.g., VirusTotal, AbuseIPDB) enrich the log with external risk indicators.

4.2 Automated Response via SOAR

- If confidence_score > threshold, an automated playbook triggers:
    - Blocks the IP or session in Redis with TTL-based expiration.

    - Sends an alert to SOC analysts with contextualized risk factors.
    - Generates a report including the attack timeline, source information, and recommended mitigation steps.
- If confidence_score is moderate, the request is flagged for further investigation and presented to analysts via SIEM dashboards (Grafana, Kibana).

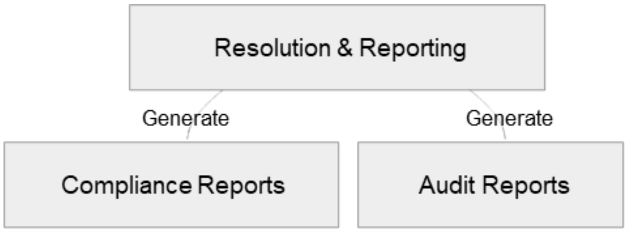

Fig: Reporting in VESSA

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5. Model Deployment & Continuous Learning

To maintain high detection accuracy, VESSA follows a continuous model training and evaluation cycle:

- Batch & Real-time Training:
    - Logs from confirmed security incidents are fed back into the training dataset, allowing the model to adapt to evolving attack patterns.
    - Kafka-based event streaming enables real-time updates to the detection pipeline.
- Federated Learning (Optional for Multi-Tenant Deployments):
    - Security models can be trained across multiple organizations while preserving data privacy.
    - Each participating organization contributes to the global model without sharing raw security logs.
- Adversarial Training (Mitigating Evasion Attacks):
    - Attackers may attempt to bypass detection using adversarial input modifications.
    - GAN-based (Generative Adversarial Networks) augmentation is used to simulate attack variations, improving the model’s ability to recognize evasive threats.

---

6. Scalability & Asynchronous Processing

To ensure scalability for large enterprises, VESSA leverages asynchronous processing architectures:

- Message Queues (Kafka, RabbitMQ): Handles high-throughput log ingestion and ensures logs are processed asynchronously without impacting real-time detection.

- Distributed Processing (Apache Flink, Spark Streaming): Supports real-time streaming analytics for large-scale network environments.
- Elasticsearch & Snowflake: Store historical logs for forensic analysis, allowing analysts to trace attack origins over long timeframes.

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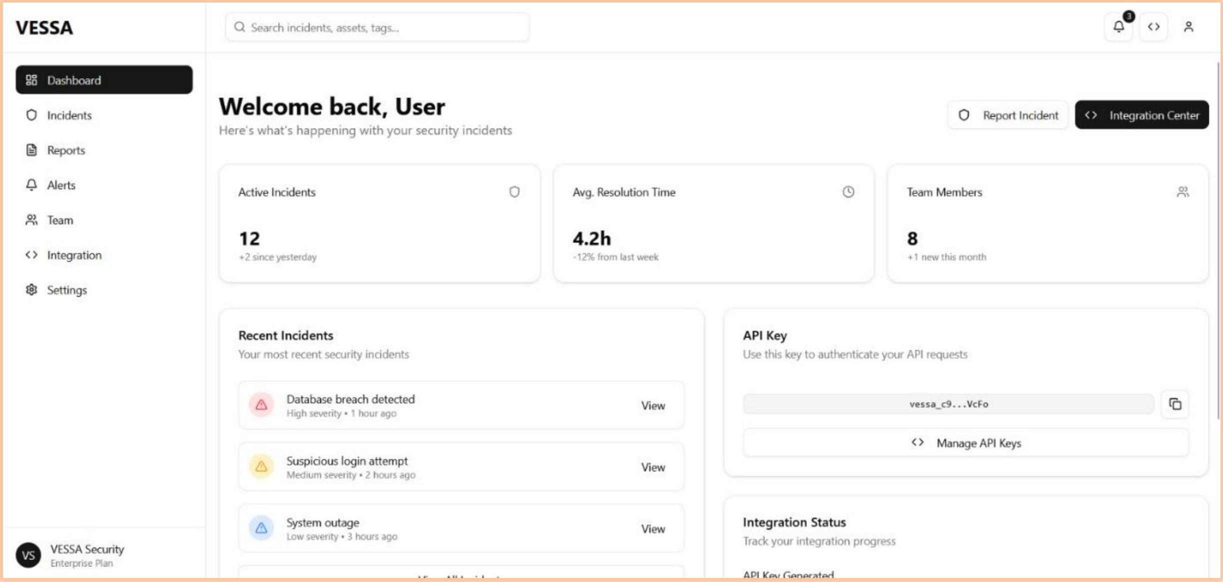

VESSA

Search incidents, assets, tags...

Dashboard
Incidents
Reports
Alerts
Team
Integration
Settings

VS VESSA Security
Enterprise Plan

Welcome back, User

Here's what's happening with your security incidents

Report Incident | Integration Center

Active Incidents	Avg. Resolution Time	Team Members
12	4.2h	8
+2 since yesterday	-12% from last week	+1 new this month

Recent Incidents

Your most recent security incidents

Database breach detected High severity • 1 hour ago	View
Suspicious login attempt Medium severity • 2 hours ago	View
System outage Low severity • 3 hours ago	View

API Key

Use this key to authenticate your API requests

vessa_c9...VcFo

Manage API Keys

Integration Status

Track your integration progress

API Key Generated

Fig: VESSA Webpage Showcase, Dashboard

3. Challenges & Innovation Opportunities

Challenges

- Data Quality & Labeling: Labeled data is crucial for supervised learning but may be scarce or inconsistent.
- Model Explainability: Security teams need interpretability tools to understand why an alert was triggered.
- Scalability: High-volume logging environments require efficient data indexing, retrieval, and storage solutions.

Opportunities for Innovation

- Deep Learning on Raw Logs: Traditional security models rely on handcrafted features. Future work can explore transformers and self-supervised learning to detect threats without feature engineering.
- Federated Learning for Threat Intelligence: Multiple organizations can train security models collaboratively while preserving data privacy.
- Adversarial Training for Threat Resilience: Generating synthetic attack patterns can enhance model robustness against evasion techniques.

4. Future Work

The evolution of AI-driven cybersecurity presents new opportunities for advancing security automation, threat intelligence, and cloud-native security. Future enhancements to the VESSA system will focus on integrating AI-driven autonomous security operations that can dynamically respond to threats without human intervention. Self-healing cybersecurity systems, driven by reinforcement learning, will enable real-time threat mitigation, proactive remediation, and predictive intelligence to prevent attacks before they occur [13]. Additionally, federated learning models will be implemented to allow secure, distributed AI training across multiple organizations, improving threat intelligence sharing without compromising data privacy [8].

Another critical area of development is quantum-safe encryption. With quantum computing on the rise, current encryption standards such as RSA and ECC will become vulnerable to decryption attacks. Future work will explore the implementation of post-quantum cryptography (PQC) algorithms, such as lattice-based, hash-based, and multivariate-quadratic equations cryptosystems, ensuring that sensitive enterprise data remains secure against future quantum-based cyber threats [11].

The behavioral biometrics and insider threat detection module will be another focus area. AI-powered user behaviour analytics (UBA) will monitor keystrokes, mouse dynamics, and login frequency to detect anomalies that indicate compromised credentials or insider attacks. By integrating continuous authentication techniques, VESSA can prevent unauthorized access in real-time and mitigate social engineering attacks [6].

Enhancements in threat intelligence automation will also be a key research direction. Currently, threat intelligence feeds are integrated manually into security operations, but automated knowledge graphs will allow AI to correlate indicators of compromise (IOCs) and provide contextual risk scoring for emerging cyber threats [7]. This will improve zero-day threat detection and attack surface monitoring, reducing the time from threat discovery to mitigation.

From an architectural perspective, VESSA will expand its multi-cloud security capabilities, integrating serverless computing security frameworks that offer greater efficiency and scalability for enterprise environments. Additionally, policy-based security automation will be improved to enforce compliance standards (GDPR, ISO 27001, NIST) dynamically, allowing businesses to automatically adapt to evolving regulatory requirements without manual intervention [10].

Finally, AI-driven deception technologies such as honey tokens, decoy networks, and adversarial AI will be explored to mislead and detect cyber adversaries early in the attack chain. By incorporating deception-based defense mechanisms, VESSA can actively manipulate attacker decision-making and prevent advanced persistent threats (APTs) from escalating within enterprise environments [12].

5. Conclusion

The VESSA system represents a transformative approach to enterprise security, leveraging AI-driven threat detection, SOAR automation, cloud-native scalability, and behavioral analytics to provide a comprehensive cybersecurity solution. The literature review highlights how modern security challenges such as incident response delays, insider threats, and zero-day vulnerabilities can be effectively mitigated using machine learning, advanced threat intelligence, and automated security orchestration [1][3][5]. By integrating multi-tier role-based access control (RBAC), federated threat intelligence, and automated compliance enforcement, VESSA ensures data security while adhering to global regulatory standards [9][10].

The shift toward quantum-safe encryption and self-healing cybersecurity systems will enable future-proof security measures against both classical and quantum-based cyber threats [11]. With continued research in autonomous AI security, deception-based threat mitigation, and federated learning, VESSA will remain at the forefront of enterprise cybersecurity innovations.

In conclusion, as cyber threats become more sophisticated, security solutions must evolve beyond traditional SIEM and rule-based defenses. The next generation of cybersecurity will rely on AI-powered automation, predictive analytics, and adaptive security frameworks, all of which form the foundation of VESSA’s advanced security architecture. Future research will focus on expanding AI capabilities, integrating cloud-native security advancements, and enhancing autonomous security operations, ensuring that enterprises remain resilient against emerging threats in an increasingly complex cyber landscape [18][20].