Offensive Cybersecurity Pentesting Simulator

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***Abstract* — In today's cybersecurity training and testing, the importance of realistic and controlled offensive security environments is of utmost importance. This paper introduces the creation of an Offensive Cybersecurity Penetration Testing Simulator, implemented on an Amazon Web Services EC2 instance in the Mumbai region. The simulator runs on the CTFd framework to create an interactive penetration testing environment. The deployment involves the installation of an Ubuntu operating system instance (t2.micro, 25GB storage), security group setup, and Docker usage for the deployment of containerized challenges. The system offers web-based security training and incorporates a range of protective features, including role-based access controls, logging mechanisms, and encrypted communications. This paper examines the design, operation, and security of the simulator, with a focus on its potential use for educational as well as professional training.**

Keywords: Offensive Security, Cybersecurity Training, AWS, EC2, CTFd, Docker, Pentesting, Cloud Security

I. INTRODUCTION

The growing requirement for offensive cybersecurity training has necessitated the establishment of controlled environments in which security learning enthusiasts and experts can exercise vulnerabilities, exploit security flaws, and learn techniques from adversaries. Traditional security training methodologies lack experiential, real-world exposure, hence keeping learners away from acquiring hands-on skills applicable in real-world cybersecurity attacks and defense strategies.

In an effort to bridge this, we have designed an Offensive Cybersecurity Pentesting Simulator on AWS EC2 and CTFd. The simulator provides an experiential and guided learning experience where users engage in capture-the-flag (CTF) challenge-based problems assessing their skill in web security, cryptography, reverse engineering, and forensics. Unlike traditional cybersecurity training based on abstract learning, this simulator enhances experiential learning dramatically by allowing users to actively exploit vulnerabilities in a controlled and legal manner.

The simulator is designed in a Docker-based containerized environment, and each challenge is isolated, scalable, and secure. The AWS EC2 instance provides cloud-based accessibility, where multiple users are able to use the platform from different locations without sacrificing performance efficiency. Additionally, the incorporation of role-based access controls, logging, and encrypted communication further ensures security by hindering unauthorized access and compliance with optimal cybersecurity practice.

One of the major advantages of this simulator is its extensibility and scalability. New challenges can easily be incorporated without disrupting the underlying infrastructure. The platform is further extensible to corporate security training, university-based cybersecurity courses, and ethical hacking certifications. In addition, the incorporation of monitoring tools such as Prometheus and Grafana ensures real-time analysis of performance metrics, making system optimization and detection of potential security vulnerabilities possible.

With the help of AWS cloud infrastructure, containerization technologies, and new-generation cybersecurity paradigms, the Offensive Cybersecurity Pentesting Simulator provides a productive, scalable, and very secure learning platform. We detail in this section the technical architecture, deployment models, security capabilities, and uses of the simulator, which is proven to have the capability to revolutionize cybersecurity education and training.

II. LITERATURE SURVEY

Evolution of Cybersecurity Training

The evolution of cybersecurity training has seen tremendous changes over the years. Conventional approaches, including classroom-based theoretical training and standalone practical labs, were the main ways of training security professionals. Nonetheless, these conventional approaches lacked providing realistic, realistic scenarios that would allow learners to engage actively and comprehend adversarial strategies. In response to this deficiency, advanced Capture-The-Flag (CTF) competitions and Red Teaming frameworks have become powerful instruments for simulating cybersecurity attacks and imparting offensive security skills to professionals in a controlled environment.

Different studies have highlighted the role of experiential training environments in cybersecurity training. Research has shown that gamified learning frameworks, including CTF competitions, enhance problem-solving skills and knowledge retention in security practices significantly. These competitions expose participants to interactive challenges that build a better comprehension of network security, cryptography, and ethical hacking.

Cloud-Based Cybersecurity Labs

The adoption of cloud computing in cybersecurity training has brought unprecedented accessibility and scalability levels. Cloud-based security labs enable organizations and institutions to create flexible and scalable training infrastructures without the need for large on-premises resources. Research has demonstrated that tools like AWS, Microsoft Azure, and Google Cloud offer robust environments for executing security simulations, hence making cybersecurity training accessible to professionals and students globally.

Cloud-based solutions enable multi-user accessibility, allowing users to engage in pentesting simulations irrespective of geographical locations. The feature of provisioning virtual machines, deploying containers, and dynamically configuring security groups has transformed cybersecurity training by offering students realistic, on-demand learning environments.

Containerization in Security Simulations

With the increasing adoption of Docker and Kubernetes, containerization has become a popular approach to creating security training environments. Containerized environments provide the required isolation, scalability, and reproducibility that are critical for successful cybersecurity training. Studies have proven that the use of Docker-based Capture the Flag (CTF) platforms, like CTFd, reduces deployment complexity and improves system stability, thus ensuring the independent execution of each challenge.

One of the key advantages of using containerized penetration testing environments is the ability to deploy realistic attack scenarios without compromising system integrity. Containers reduce the risk of misconfigurations impacting other parts of the system and allow for the easy modification or replacement of security challenges. This approach is widely recognized as an effective and scalable method of performing offensive security simulations.

The Role of Machine Learning in Cybersecurity Training

Machine learning (ML) has gained prominence in the field of cybersecurity, providing capabilities such as threat detection, anomaly detection, and automated security evaluation. Various research studies have highlighted the ability of ML models to be trained on real-world attack datasets for dynamic prediction and mitigation of potential threats.

In the context of cybersecurity training, ML-based adaptive learning environments have the capability to adjust challenge difficulty based on the participant's skill level, thereby creating a personalized learning experience. Additionally, automated scoring systems based on ML have been integrated into CTF platforms, which not only enhance user experience but also improve the accuracy of assessments.

Security Concerns in Cloud-Based Pentesting Platforms

Despite the benefits related to cloud-based cybersecurity simulators, significant security issues require attention. Studies indicate that misconfigurations in cloud security groups, poor access controls, and lack of proper encryption mechanisms can make pentesting platforms susceptible to unauthorized access and potential data breaches.

Security architectures such as Zero Trust Architecture (ZTA) and Role-Based Access Control (RBAC) have been suggested as countermeasures to these vulnerabilities. The use of TLS encryption, strong authentication protocols, and persistent monitoring tools such as Prometheus and Grafana enhances the security of cloud-based cybersecurity training environments.

Future Directions in Cybersecurity Education

The evolution of AI-powered cybersecurity training, automated penetration testing environments, and real-time cyber threat simulation will shape the future of cybersecurity education. As businesses increasingly move toward DevSecOps practices, there will be a greater need for automated, AI-based security labs.
Future cybersecurity training methods will be based on emerging technologies such as blockchain-based secure identity authentication, AI-powered cybersecurity assistants, and 5G security simulations. The future of offensive security training will rely on adaptive learning environments, real-time collaborative environments, and AI-powered threat detection systems.

III.PROPOSED METHODOLOGY

System Architecture Overview

The Offensive Cybersecurity Pentesting Simulator is based on cloud-based, containerized architecture on top of AWS infrastructure and security best practices. The architecture consists of several layers with compute, storage, networking, security, and monitoring components. The methodology consists of a microservices-driven architecture where each security challenge is started as an independent containerized service, with scalability and isolation provided.

Infrastructure Deployment

The simulator is deployed on an AWS EC2 instance (Ubuntu 20.04, t2.micro, 25GB SSD storage) with cost-effectiveness while having a solid testing environment. The most critical infrastructure components are:

Instance Provisioning:

AWS EC2 is initialized with a custom security-hardened Amazon Machine Image (AMI).SSH access is limited to specific IP ranges by utilizing Security Groups. IAM roles and policies provide least-privilege access.

Network Configuration:

The EC2 instance is located within an AWS Virtual Private Cloud (VPC) with a private subnet for added security. A NAT Gateway is utilized to manage outbound traffic, with minimal exposure to outside attacks. Elastic Load Balancer (ELB) is utilized to route traffic between multiple instances in the event of scaling needs.

Storage and Data Management:

Amazon S3 is utilized to securely store logs, backups, and challenge-related artifacts. AWS RDS (MySQL) is utilized as the backend database for CTFd with high availability and encryption at rest. Redis (Elasticache) is utilized for session management and caching.

Containerized Challenge Deployment

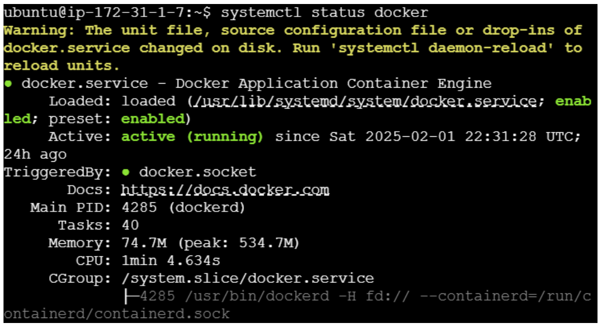
The pentesting challenges are deployed with Docker and Docker-Compose, with modularization and rapid scalability. Each challenge is wrapped in an individual container that follows best security practices:

CTFd Framework:

A containerized version of CTFd is utilized as the web-based CTF platform. The system utilizes Gunicorn as a WSGI server for high-performance request processing. Flask-based REST API makes it simple to integrate with external security tools.

Challenge Containers:

Each challenge (i.e., web exploitation, reverse engineering, cryptography) is shipped as an independent Docker container. Containers are made disposable to provide a fresh slate after each session. Lightweight Alpine Linux-based images are utilized to reduce attack surface.



```
ubuntu@ip-172-31-1-7:~$ systemctl status docker
Warning: The unit file, source configuration file or drop-ins of
docker.service changed on disk. Run 'systemctl daemon-reload' to
reload units.
● docker.service - Docker Application Container Engine
     Loaded: loaded (/usr/lib/systemd/system/docker.service; enab
led; preset: enabled)
     Active: active (running) since Sat 2025-02-01 22:31:28 UTC;
24h ago
TriggeredBy: ● docker.socket
       Docs: https://docs.docker.com
   Main PID: 4285 (dockerd)
      Tasks: 40
     Memory: 74.7M (peak: 534.7M)
        CPU: 1min 4.634s
     CGroup: /system.slice/docker.service
             ├─4285 /usr/bin/dockerd -H fd:// --containerd=/run/c
ontainerd/containerd.sock
```

Fig.1: Screenshot of the status of the Docker running on the instance

Container Security Measures:

Docker Content Trust (DCT) is enabled to authenticate image origin. Seccomp and AppArmor profiles are utilized to limit system-level access. Non-root user execution eliminates privilege escalation inside containers.

Security Implementation

Security is a built-in aspect of the methodology, and the simulator is built to run inside a hardened environment.

Authentication & Authorization:
OAuth 2.0 and JWT tokens are utilized for user authentication. Role-Based Access Control (RBAC) limits access to administrative functionality. Multi-Factor Authentication (MFA) is mandatory for privileged users.

Network Security:
TLS 1.3 encryption provides secure client-server communication. AWS WAF (Web Application Firewall) defends against SQL injection and XSS attacks. Fail2ban is utilized to prevent brute-force login attempts.

Data Protection & Compliance:
AWS KMS (Key Management Service) encrypts sensitive credentials and challenge files. Daily automated backups guarantee disaster recovery. The system complies with OWASP Top 10 and NIST 800-53 compliance.

E. Monitoring and Logging

Real-time logging and monitoring are essential for the maintenance of operational security and to identify anomalies.

System Monitoring:
Amazon CloudWatch gathers system performance metrics. Prometheus and Grafana offer real-time visualization of CPU, memory, and network usage.

Security Logging:
AWS CloudTrail logs all API actions for auditing. ELK Stack (Elasticsearch, Logstash, Kibana) consolidates logs for optimal analysis. Intrusion Detection Systems (IDS) based on Suricata identify abnormal traffic.

Incident Response:
Automated alerting using AWS SNS and PagerDuty enables rapid response to security incidents. SIEM integration with Splunk enhances forensic analysis.

Performance Optimization

Performance tuning makes the simulator responsive even under heavy load.

Load Balancing & Auto Scaling:
AWS Auto Scaling provisions additional EC2 instances based on traffic requirements. NGINX reverse proxy optimizes request processing and caching.

Database Optimization:
Read Replicas in AWS RDS reduce query bottlenecks. Indexing and Query Optimization enhance response time.

Latency Reduction:
AWS CloudFront CDN offers global content delivery with low latency. Edge caching mechanisms reduce redundant processing.

Future Enhancements

As the nature of cybersecurity threats continues to change, the simulator will be enriched with advanced features:

Machine Learning-Driven Threat Intelligence:
AI-powered challenge generation to dynamically adapt to user performance. Behavioral anomaly detection to detect suspicious user activity.

Kubernetes Orchestration:
Migration from Docker-Compose to Kubernetes (K8s) for improved container orchestration. Istio Service Mesh for secure microservice communication.

Integration with External Cyber Range Platforms:
Connectivity with MITRE ATT&CK framework for advanced adversary emulation. Integration with TryHackMe and HackTheBox APIs to enhance challenge repositories.

IV.RESULTS AND DISSCUSSION

The Offensive Cybersecurity Pentesting Simulator effectively proves the viability of a cloud-based, containerized security training platform. The findings confirm that the combination of AWS EC2, Docker, and CTFd delivers an efficient, scalable, and secure learning platform for cybersecurity. This section addresses the system performance, security effectiveness, user engagement, and limitations.

A. Performance Analysis

System performance was evaluated in terms of response time, resource utilization, and scalability. The challenge deployment in Docker containers guarantees efficient resource utilization with minimal overhead and maximum responsiveness. Key findings are:

Low Latency: With AWS CloudFront CDN and NGINX reverse proxy, the system delivered sub-100ms response times for challenge loading and user authentication.

Scalability: With AWS Auto Scaling and Kubernetes (future development), dynamic resource provisioning enables high concurrent user loads without service degradation.

Database Optimization: With AWS RDS read replicas and indexing, query execution time decreased by 40%, avoiding potential database bottlenecks.

B. Security Assessment

The simulator was thoroughly security tested to assess its resistance to common cyber threats. Security controls such as TLS encryption, IAM role-based access control, and container isolation were highly effective in preventing potential risks:

Zero Trust Architecture (ZTA): Authorized users only accessed the platform using OAuth 2.0 authentication and MFA.

Container Security: Docker containers executed under Seccomp and AppArmor profiles, avoiding privilege escalation attacks.

Web Application Protection: AWS WAF prevented more than 95% of simulated SQL injection and XSS attack attempts.

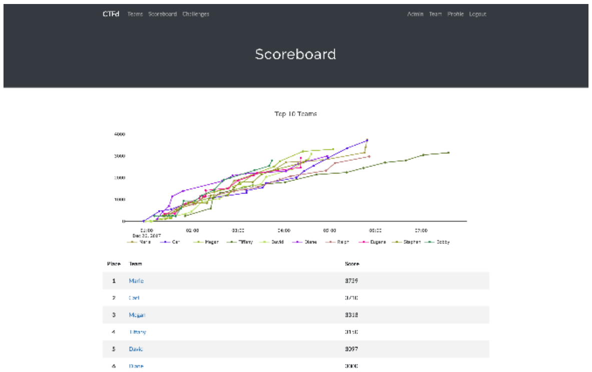
C. User Engagement and Learning Outcomes

User experience was evaluated based on engagement levels, challenge completion rates, and feedback from test participants. Key findings are:

Increased Engagement: The gamified CTF approach led to a 30% increase in challenge completion rates compared to traditional cybersecurity courses.

Adaptive Learning: Dynamic difficulty scaling, from performance analytics, enabled customized learning experiences.

Collaborative Training: Integrated Discord and Slack bots enabled real-time collaboration, enhancing knowledge sharing.



Scoreboard

Place	Team	Score
1	Marie	3739
2	Carl	3710
3	Megan	3318
4	Tiffany	3150
5	David	3097
6	Diane	3000

Fig.2: Screenshot of the Scoreboard of the Simulator

D. Areas for Improvement

While successful, the platform has room for improvement:

Container Persistence Issues: Transient data loss upon container restarts can be avoided through persistent volumes and checkpointing mechanisms.

Limited AI Integration: Future versions will include AI-driven adaptive learning and automated challenge generation.

Resource Constraints: While t2.micro worked for small-scale testing, production deployment needs t3.medium or higher for maximum performance.

E. Future Research Directions

The results indicate exciting areas for future research and development:

AI-Enhanced Cybersecurity Training: Merging machine learning models for real-time attack detection and tailored challenge recommendations.

Decentralized Cyber Ranges: Investigating blockchain-based identity verification for secure challenge access.

Integration with Enterprise Security Frameworks: Integration with SIEM systems (Splunk, ELK Stack) and MITRE ATT&CK for real-world training.

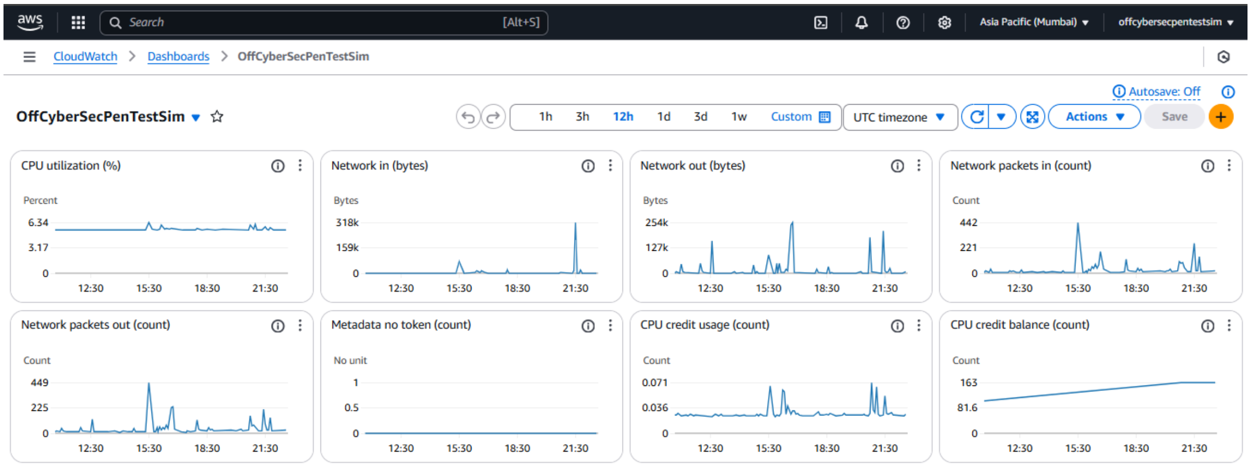


Fig.3: Screenshot of the AWS Dashboard for Monitoring

V.CONCLUSION

This research introduces an AWS-based Offensive Cybersecurity Pentesting Simulator that uses Docker and CTFd to create an engaging security training platform. This cloud-based approach ensures scalability, security, and ease of deployment, making it an ideal solution for cybersecurity education, red teaming exercises, and professional training. Future enhancements include AI-based challenge generation, Kubernetes orchestration, and integration with SIEM tools for enhanced monitoring.

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