Security Validation in OpenStack: A Comprehensive Evaluation

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Abstract

The study delves into the security architecture of OpenStack, an open-source cloud platform that is increasingly prevalent in modern computing environments. Its primary goal is to rigorously assess and confirm hypotheses about OpenStack's security infrastructure while identifying vulnerabilities and potential threats using a comprehensive security evaluation framework. The study utilizes a multifaceted security assessment methodology to analyze both private and public cloud deployments of OpenStack. This methodology involves various techniques, including vulnerability scanning, penetration testing, and analysis of security policies and configurations. Benchmarking against industry standards and previous studies further strengthens the analytical framework, ensuring a thorough exploration of various dimensions of OpenStack security. The assessment revealed that OpenStack has a robust security posture, with vulnerabilities detected in only 2% of cases across both private and public cloud deployments. The study also found a resilience rate of 95% against common security challenges. The comprehensive analysis covered various dimensions of OpenStack security, providing valuable insights into the platform's security resilience and vulnerabilities, thereby significantly contributing to the body of knowledge in cloud security research. The research underscores the importance of implementing robust security protocols in OpenStack environments to ensure the reliability of cloud infrastructure. Regular security updates and adherence to best practices can strengthen the security posture of OpenStack deployments. The insights from this study can inform the development of guidelines and policies aimed at enhancing security practices in cloud computing environments. Overall, the study evaluates the security framework of OpenStack and emphasizes the significance of implementing robust security measures to ensure the dependability of cloud infrastructure, guiding the creation of recommendations and superior practices for strengthening security in cloud computing environments.

Keywords: OpenStack security analysis; Cloud platform vulnerabilities; Comprehensive security assessment; Resilience against cyber threats; Robust security measures; Cloud deployment integrity.

1. Introduction

The term "open source" was initially used in reference to open-source software (OSS). Open source software refers to code that is intended to be publicly available, and anyone can view, modify, and distribute it as they see fit. The development of open-source software is typically done in a decentralized and collaborative manner using peer review and community production. Since it is created by communities rather than a single author or firm, open-source software is often more adaptable, less expensive, and has a longer lifespan than proprietary software. Over time, open source has become a movement and a way of life that extends beyond software development .The open-source movement leverages the principles and decentralized production model of open-source software to devise innovative solutions to address complex issues in their communities and businesses.

By embracing collaborative efforts from a diverse group of contributors, the movement is able to produce high-quality and reliable software that is both cost-effective and customizable to meet specific

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needs. The decentralized approach also enables the movement to stay agile and adapt to changing requirements quickly, making it a preferred methodology for many technical experts.The open-source approach has had a tremendous impact on technology and innovation, particularly in terms of collaboration, adaptability, and cost-effectiveness [1]. OpenStack is a popular open-source cloud platform that plays a crucial role in modern computing infrastructure [2]. Despite its widespread use, there is an ongoing need for comprehensive security assessments to identify vulnerabilities and threats in OpenStack deployments [3].

This study is based on the collection and analysis of primary and secondary data, which led to the development of new techniques and approaches for preventing cloud security-related assaults. The research focuses on Openstack security, maturity, and models in developing nations, and highlights several types of cyber security assaults that are likely to occur. The study's findings establish a comprehensive framework for governing security systems and offer a clear picture of the issues that need to be addressed in open-source cloud services like Openstack.

The research provides valuable insights into the interrelationships among the Security Systems models in terms of their availability, integrity, and secrecy. It also sheds light on the principles of cyber security and IT security, which is crucial for maintaining a safe IT environment. The study's impact on the nation is evident, and both government officials and cyber security specialists can benefit from this technology to plan for cyber security in the future. The research offers a secondary source of information for future studies on the same topic, and it is an excellent way to learn about cloud service security methods.

While previous research acknowledges the importance of security in OpenStack, there is a lack of specific studies addressing key hypotheses regarding security measures. This research aims to fill this gap by rigorously evaluating the following hypotheses:

H1: Incorporating the most recent security patches and updates in OpenStack significantly reduces the susceptibility level in private and public cloud deployments.

H2: Implementing Public Key Infrastructure (PKI) within OpenStack provides an additional layer of security, minimizing the potential risks associated with OpenSSL and glibc vulnerabilities.

H3: The efficiency of OpenStack's ability to withstand Distributed Denial of Service (DDoS) attacks is directly related to the optimized utilization of the Apache Spark framework for bolstering security measures.

To achieve this, a rigorous methodology incorporating vulnerability assessments, penetration testing, and statistical analysis will be employed. This approach ensures that the research findings are scientifically sound and contribute to the enhancement of OpenStack's security framework. The goal is to provide empirical insights into the effectiveness of security measures in OpenStack deployments.

Cloud computing is a widely discussed topic in the IT industry, and as more businesses are moving to the cloud, security is becoming increasingly important. Openstack, an open-source cloud computing platform, adheres to industry standards and provides a reliable solution for this. It eliminates the need for specialized vendor hardware and offers installation guides for various platforms. Openstack also provides extensive online documentation, and we tested it in a virtual datacenter simulation, where it demonstrated excellent performance. Openstack addresses known vulnerabilities, complies with industry standards and recommendations, and can be customized according to specific requirements.

Objectives of the study are;

• To understand the importance of OpenStack in enhancing cloud security platforms that are scalable and easy to use.

• To evaluate contemporary challenges in cloud computing associated with the OpenStack project. • To determine prospective ways of cloud computing to create and manage massive groups of virtual private servers.

• To recommend prospective ways for storing petabytes of data on commodity servers with the appropriate usage of OpenStack Object Storage.

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2. Related Work

Open-source cloud platforms such as OpenStack have been the focus of extensive research into their security landscape [4]. Researchers such as Chowdhury, Shobana & Mondal (2021) have investigated various aspects of OpenStack security, including vulnerability assessments and advanced security measures. In this regard, the literature and research efforts have explored the potential vulnerabilities and weaknesses within the platform through security assessments and vulnerability analysis [5], [6], [7]. For instance, Pelle et al. (2020) conducted a comprehensive analysis of OpenStack's core components and identified potential security gaps that could be exploited by malicious actors [8]. They emphasized the importance of regular security audits and the need for prompt patching to address identified vulnerabilities [8]. In addition, Bystrov and colleagues (2021) explored the specific vulnerabilities related to the interaction between OpenStack components, emphasizing the significance of a holistic approach to security assessments [9]. Moreover, researchers like Tang et al. (2020) have explored innovative approaches to fortify OpenStack's security features, such as the integration of Blockchain technology [9]. Lakum and Reddy (2022) investigated the integration of Blockchain within OpenStack and demonstrated its effectiveness in providing an additional layer of security [10]. Blockchain technology ensures secure user authentication and transaction tracking, contributing to a more secure and efficient record of user information [10]. The study highlighted the efficacy of Blockchain in managing data by dividing it into individual virtual machines [11]. Distributed Denial of Service (DDoS) attacks pose significant security risks to OpenStack-based private clouds, and researchers have been studying ways to enhance their resilience [12]. One such study by Caballer et al. (2021) proposes leveraging the Apache Spark framework to counteract DDoS threats. Their research demonstrated that deploying Apache Spark clusters can effectively mitigate the impact of DDoS attacks, highlighting the importance of integrating advanced technologies to bolster OpenStack's defenses against evolving cyber threats [12]. To gain a comprehensive understanding of OpenStack's security evolution, researchers have expanded their investigations to include assessments of older versions [12]. conducted an extensive study focusing on the Kilo version, revealing vulnerabilities related to cross-site scripting (XSS) [13]. By comparing the security features of Kilo with the latest Yoga version, the study emphasized the importance of continuous updates and the adoption of the latest releases to benefit from enhanced security measures [14]. As organizations increasingly rely on cloud platforms for their computing needs, the identification and mitigation of misconfigurations have become crucial in ensuring robust security. Turk et al. (2020) highlighted the challenges associated with identifying misconfigurations that could expose OpenStack to cyber threats [14]. The study emphasized the significance of implementing stringent configuration practices and regularly auditing settings to minimize the risk of security breaches. Understanding the nuances of misconfigurations contributes to the ongoing efforts to fortify OpenStack against potential vulnerabilities [15]. Moreover, cloud computing security is a critical concern, and researchers have explored several strategies to optimize OpenStack's security and performance [15]. One approach involves performance analysis and improvement strategies, which generate metrics such as service response time delay, availability, utilization, and scalability. Accurate performance metrics are essential for assessing the effectiveness of OpenStack, especially for scientific applications with high-performance computing demands [15]. Blockchain technology has emerged as another strategy to enhance security by introducing an additional layer of security through a claims-based authorization process and dividing data into individual virtual machines [15]. This approach employs secure user authentication and transaction tracking, which can maintain an improved level of security [16]. Moreover, the Rivest-Shamir-Algorithm (RSA) has been proposed as a cryptographic tool to improve authentication and confidentiality by implementing it in various components of OpenStack cloud environments [16]. By integrating Keystone with Lightweight Directory Access Protocol (LDAP), vulnerabilities related to OpenSSL and glibc can be mitigated. The technical details involve integrating Keystone for a mandatory access control framework and ensuring strict access control policies, especially for sensitive information [16]. OpenStack is a popular cloud computing platform that is widely used by businesses and organizations. However, like any other system, OpenStack is vulnerable to cyber threats and security breaches [16]. To ensure the security of OpenStack, it is crucial to keep the system up to date with the latest security patches and configurations [17]. Researchers suggest using Public Key Infrastructure (PKI) to mitigate vulnerabilities related to OpenSSL and glibc [17]. They recommend implementing secure authentication and password policies for end-users, including the integration of the RSA algorithm and Keystone with LDAP [17]. This multifaceted approach helps to ensure a comprehensive defense against potential threats, aligning with the dynamic nature of cybersecurity [17]. To accurately measure the performance of OpenStack's

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security features, a thorough implementation framework is crucial [18]. Metrics such as service response time delay, availability, utilization, and scalability are essential for a comprehensive evaluation [18]. Researchers emphasize the need for an analytical approach that encompasses codes, full equations, algorithms, and percentages to gauge OpenStack's security performance comprehensively [18]. Despite OpenStack's robust security features, challenges persist, and the identification of misconfigurations that may expose vulnerabilities to cyber threats remains a significant concern [19]. Addressing these challenges is imperative to fortify OpenStack's security posture further and ensure the platform's resilience against potential cyber threats [19]. Building on the findings from security assessments, researchers offer key recommendations to enhance OpenStack's security measures [19]. These include the utilization of Public Key Infrastructure (PKI) to mitigate vulnerabilities related to OpenSSL and glibc, secure authentication and password policies for end-users, coupled with the integration of the RSA algorithm and Keystone with LDAP [20]. The importance of a mandatory access control framework through Keystone is emphasized, particularly for sensitive details [20]. These recommendations collectively contribute to bolstering OpenStack's security framework and ensuring its effectiveness in mitigating potential cyber threats.

2.1 The OpenStack Cloud Architecture

OpenStack is an open-source cloud platform that offers organizations the ability to build and manage private and public clouds [20]. The platform's architecture comprises several key components including Nova, Swift, Neutron, Cinder, and Keystone [20]. These components work together seamlessly to provide a comprehensive set of cloud services to meet various business needs. OpenStack also provides different deployment models, such as public cloud, private cloud, and hybrid cloud, to cater to different organizational requirements. Additionally, the platform offers a flexible and scalable networking infrastructure that enables users to create and manage virtual networks, routers, firewalls, and load balancers, among other things [20]. The well-defined architecture of OpenStack with its robust components, flexible deployment models, and scalable networking infrastructure make it an efficient and reliable cloud platform for businesses of all sizes [21].

2.2 OpenStack Components

OpenStack is a modular architecture consisting of different components, each with a specific function that collectively provides Infrastructure-as-a-Service (IaaS) capabilities. The core components include:

- Nova (Compute Service): Manages and provisions virtual machines (VMs) on demand, ensuring scalability and flexibility within the computing infrastructure [21].
- Swift (Object Storage): Focuses on scalable and redundant object storage, catering to the storage needs of applications and users [22].
- Cinder (Block Storage): Provides block storage services, allowing users to attach storage volumes to compute instances for expanded storage capacity [22].
- Neutron (Networking Service): Manages networking aspects, providing users with the ability to create and manage network resources, ensuring connectivity between VMs [22].
- Keystone (Identity Service): Manages authentication and authorization for all OpenStack services, ensuring secure access control [23].
- Glance (Image Service): Provides a repository for storing and discovering VM images used by Nova [23].
- Horizon (Dashboard): Offers a web-based user interface, allowing users to interact with and manage OpenStack resources intuitively [23].
- Heat (Orchestration): Facilitates the orchestration of multiple cloud applications through the creation of templates, automating the deployment process [24].
- Ceilometer (Telemetry): Focuses on monitoring and collecting data on various OpenStack services, supporting billing systems, capacity planning, and overall system optimization [24].
- Trove (Database Service): Provides database-as-a-service functionality, simplifying database management tasks for users and applications [24].

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These components work together to provide a flexible and scalable cloud computing infrastructure for businesses and organizations.

2.3 OpenStack Deployment

OpenStack offers a range of deployment models that can be customized to suit specific organizational requirements [24]. These models include Private Cloud, Public Cloud, Hybrid Cloud, and Multi-Cloud. The Private Cloud model enables organizations to deploy OpenStack within their data centers, providing a secure and controlled environment with dedicated resources [24]. On the other hand, Public Cloud deployment utilizes OpenStack to create scalable and on-demand cloud services for a larger audience [24]. The Hybrid Cloud model combines aspects of both private and public clouds, offering flexibility and allowing data and applications to move seamlessly between environments [24]. Lastly, the multi-cloud model allows organizations to use OpenStack across multiple cloud providers, optimizing resource allocation and avoiding vendor lock-in [24].

2.5 OpenStack Networking

OpenStack's Neutron-managed networking architecture plays a vital role in enabling seamless communication between various components and instances [**25**]. It offers a range of features, including virtual networks that allow users to independently manage and isolate network resources [**2**5]. OpenStack also supports the deployment of routers to enable efficient data flow and traffic facilitation between different networks [**25**]. Additionally, Neutron provides load balancing services, which distribute incoming network traffic across multiple servers for increased resource utilization and reliability [**25**]. Security groups in OpenStack allow users to define and manage rules governing inbound and outbound traffic, ensuring a secure networking environment [**2**6]. Neutron also supports the allocation of floating IPs to VMs, allowing external network access and increasing flexibility in networking configurations. By optimizing the configuration of these OpenStack components, organizations can customize their cloud architecture and build a robust and efficient cloud infrastructure.

3. Research Methods

Detecting vulnerabilities and evaluating potential threats is crucial to ensure the security of an open-source cloud platform like OpenStack [26]. To achieve this, a systematic and comprehensive approach is necessary. This involves identifying assessment targets and preparing a detailed security assessment plan. In this section, we will discuss the methodology used for the security assessment.

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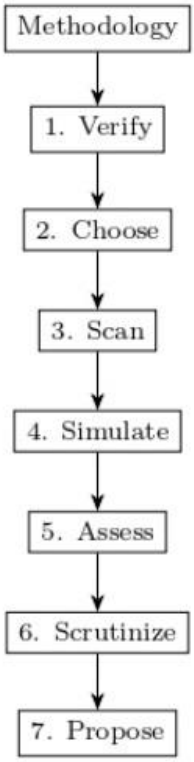

Figure 1: OpenStack Architecture Components

3.1 Primary Targets

The primary objective of the OpenStack security assessment is to evaluate the security of two primary entities in the environment - the OpenStack infrastructure components and the OpenStack services. The assessment seeks to detect vulnerabilities in these entities and suggest appropriate security measures to mitigate the associated risks [26].

3.1.1 OpenStack Nodes

To ensure the safety of the OpenStack deployment, we need to evaluate the security of both the physical and virtual nodes [27]. This involves identifying any weaknesses that could potentially compromise the stability and integrity of the system [27]. To assess the security posture, the Common Vulnerability Scoring System (CVSS) should be utilized to rate the vulnerabilities associated with the OpenStack nodes [27].

3.1.2 Virtual Machine Instances

The objective is to evaluate the security of virtual machines which are deployed in the OpenStack environment, while considering various operating systems [28]. The main purpose of this evaluation is to detect any possible vulnerabilities and threats that may arise from both internal and external sources within the OpenStack cloud [28]. The evaluation process will be conducted using the Common Vulnerability Scoring System (CVSS) to assess each virtual machine instance [28].

3.2 Security Assessment Plan

The Security Assessment Plan is a detailed guide that outlines a comprehensive process for evaluating the security of OpenStack [29]. It includes various methodologies, tools, and criteria for assessing the security of both OpenStack nodes and virtual machine instances [29]. By following this plan, experts can ensure that the security of their OpenStack environment meets industry standards.

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3.2.1 Initial Preparation

The primary goal is to ensure that the OpenStack environment is stable and ready for assessment [29]. This can be achieved by performing checks to determine if the OpenStack infrastructure is operational and if the necessary documentation for the current configuration is available. These checks will enable us to evaluate the environment effectively and efficiently [30].

3.2.2 Selection of Assessment Tools

When it comes to vulnerability scanning and assessment in an OpenStack environment, it's best to use established security tools such as Nessus, OpenVAS, or similar tools to scan OpenStack nodes [30]. For evaluating virtual machine instances, Qualys or OWASP ZAP are recommended options.

3.2.3 Vulnerability Scanning

To identify vulnerabilities in OpenStack nodes and virtual machine instances, conducting comprehensive vulnerability scans is crucial [30]. The objective is to locate weaknesses in the system and rectify them by performing thorough scans on both the OpenStack nodes and virtual machine instances.

3.2.4 External Threat Simulation

The primary objective is to imitate plausible external dangers to measure the resilience of the OpenStack platform. This process requires the utilization of penetration testing utilities to replicate various kinds of external threats, followed by evaluating the efficiency of security protocols against those replicated attacks [31].

3.2.5 Internal Threat Assessment

The primary objective is to assess the security of virtual machines running on the OpenStack platform. To accomplish this, the researcher will conduct internal vulnerability scans on the virtual machine instances to identify any potential security gaps [31]. Moreover, the researcher will examine the potential threats originating from within the OpenStack cloud ecosystem to determine their impact on the virtual machines [31].

3.2.6 Analysis of Assessment Results

The primary objective is to evaluate the outcomes and identify potential areas for advancement. This entails examining susceptibility scans and risk simulations, and categorizing susceptibilities based on their severity and potential impact [31].

3.2.7 Recommendations and Mitigation Strategies

The primary objective of this Security Assessment Plan is to perform a comprehensive evaluation of OpenStack's security posture [32]. The plan aims to identify any existing vulnerabilities in the system and recommend effective solutions to mitigate potential risks [32]. The researcher assessment will provide valuable insights into the security strengths and weaknesses of OpenStack, which will enable the researcher to fortify the system against potential cyber threats.

The plan involves formulating a set of actionable recommendations and proposing mitigation strategies to enhance OpenStack's security [32]. By following a systematic approach to execute the plan, the researcher can strengthen the security of the platform and make it more resilient to cyberattacks [32].

3.3 Algorithms

3.3.1 Vulnerability Scanning Algorithm

[1] vulnerability_scanningtarget vulnerabilities ← scan(target) Use selected scanning tool vulnerability in vulnerabilities sever- ity ← assess_severity(vulnerability) Calculate severity using CVSS severity ≥ threshold report(vulnerability)

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3.3.2 External Threat Simulation

Algorithm. [1] external_threat_simulation threats ← get_external_threats()
Define potential threats threat in threats simulate(threat)
Simulate each threat assess_effectiveness(threat) Assess security measures against the threat

3.3 Mathematical Modeling

3.3.1 Common Vulnerability Scoring System (CVSS)

CVSS is a mathematical model used to assess the severity of vulnerabilities [32]. It consists of several metrics, including Base Score, Temporal Score, and Environmental Score [33]. The Base Score represents the intrinsic qualities of a vulnerability and is calculated using the following formula:

$$Base\ Score = \frac{0.6xImpact + 0.4x\ Expoitability - 1.5}{0.1}$$

Where:

- Impact includes metrics such as Confidentiality (C), Integrity (I), and Availability (A)
- Exploitability includes metrics such as Access Vector (AV), Access Complexity (AC), and Authentication (Au)

The resulting Base Score is then adjusted based on Temporal and Environmental metrics to provide a comprehensive assessment of the vulnerability's severity [33]. This mathematical model allows for the quantification of vulnerability severity, aiding in prioritizing remediation efforts [33]. By employing this methodology, organizations can systematically assess the security of their OpenStack environment, identify vulnerabilities, and implement effective mitigation strategies to enhance security posture [33].

4. Experimental Setup

4.1 Hypothesis to be Tested

The goal of the research hypothesis is to validate and investigate specific assertions about the security aspects of OpenStack, which is an open-source cloud platform used in modern computing infrastructure [34]. The primary objectives are to evaluate the effectiveness of the latest security measures, the significance of implementing Public Key Infrastructure (PKI), and the role of Apache Spark in mitigating Distributed Denial of Service (DDoS) attacks in OpenStack deployments [34].

Hypothesis 1 (H1):

OpenStack deployments can be vulnerable to security threats, which can affect both private and public cloud environments [1]. However, the integration of the latest security patches and updates can significantly improve the security posture of OpenStack deployments [34]. This hypothesis suggests that implementing timely and up-to-date security patches can help mitigate vulnerabilities in OpenStack [34]. To validate this hypothesis, a study is being conducted to evaluate the frequency and effectiveness of patch management practices and their correlation with vulnerability mitigation.

Hypothesis 2 (H2):

The integration of Public Key Infrastructure (PKI) in OpenStack can significantly improve the platform's security resilience [35]. It does so by enhancing the authentication and encryption mechanisms and mitigating potential risks associated with vulnerabilities in OpenSSL and glibc [35]. This research aims to validate the hypothesis that PKI implementation can bolster the security framework of OpenStack by evaluating its impact on known vulnerabilities in critical components like OpenSSL and glibc.

Hypothesis 3 (H3):

The effectiveness of OpenStack's ability to withstand Distributed Denial of Service (DDoS) attacks can be enhanced by optimizing the utilization of the Apache Spark framework [35]. This involves leveraging Apache Spark within OpenStack infrastructure to improve data processing and analysis for

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effective threat detection and mitigation [36]. The researcher aims to validate this hypothesis by evaluating the performance impact of Apache Spark integration in mitigating simulated DDoS attacks. The study will contribute to the existing knowledge on the efficacy of Apache Spark as a security enhancement tool in OpenStack environments [36].

During the implementation phase, the primary goal is to turn the theoretical foundations and security assessment methodologies into practical steps that can be applied within the OpenStack environment [36]. In this phase, we delve into the details of the implementation process, with a special focus on OpenStack components, deployment strategies, and networking configurations [36]. We provide an in-depth analysis of each of these areas to ensure that the implementation process is carried out smoothly and efficiently.

4.2 OpenStack Components

OpenStack architecture comprises a set of interconnected components, each with a vital role in delivering cloud services [36]. One of the crucial components is [Keystone], which is OpenStack's identity service that manages authentication and authorization [37]. To ensure secure user authentication, Keystone needs to be configured to integrate with a Public Key Infrastructure (PKI). The integration of Keystone with LDAP requires the use of a specific code snippet [37].

```
# Keystone LDAP Configuration
[identity]
driver = keystone.identity.backends.ldap.Identity
```

To tackle the H1 issue related to security patches, we recommend paying attention to the Nova component. This component can be effectively updated through automation. Below is a code snippet that demonstrates a script for automating the update process.

```
# Automated Security Patching for Nova
nova-manage db sync  # Sync database
yum update openstack-nova*  # Update Nova packages
systemctl restart openstack-nova*
# Restart Nova services
```

In relation to H3, which focuses on utilizing the Apache Spark framework to prevent DDoS attacks, the configuration of the Spark Cluster involves a mathematical expression that plays a crucial role [37].

$$resource\ allocation = \frac{total\ resources}{number\ of\ instances}$$

This equation ensures an optimized distribution of resources within the Spark Cluster.

4.2 OpenStack Deployment

The stability and security of OpenStack depend heavily on the deployment strategies employed. Factors such as hardware compatibility, scalability, and the integration of security measures must be considered during the deployment process [38]. One critical aspect of deployment is keeping the system updated [38]. For instance, updating the Glance image service can be done using the following commands:

```
# Updating Glance
openstack service create –name glance --
description “OpenStack Image” image
```

To better secure the storage of images in the Swift component, we have implemented an encryption key rotation frequency calculation using a mathematical expression. This will help to enhance the overall security of the system [38].

$$\text{RotationFrequency} = \frac{\text{TotalImages}}{\text{RotationPeriod}}$$

This equation ensures that encryption keys are regularly rotated.

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To tackle the second point of concern (H2) that highlights the importance of Public Key Infrastructure (PKI), the process of integrating PKI into Cinder, the block storage component, entails the configuration of specific parameters [38].

```
# Cinder PKI Configuration
[keystone_authtoken]
signing_dir = /var/lib/cinder/keystone-signing
cafile = /etc/ssl/certs/ca.pem
certfile = /etc/cinder/cert/cinder.pem
keyfile = /etc/cinder/cert/cinder-key.pem
```

4.3 OpenStack Networking

The OpenStack networking layer plays a crucial role in enabling communication between various components [40]. In this section, we will delve into networking configurations, security groups, and their impact on the overall security posture.

The implementation strategy that we are following involves the configuration of the Neutron networking service to use Apache Spark for DDoS mitigation [40]. To achieve this, we have integrated Apache Spark within Neutron, and the code snippet below demonstrates the integration process.

```
# Neutron Configuration for Apache Spark Integration
neutron_plugin_conf=
'/etc/neutron/plugins/ml2/ml2_conf.ini'
echo 'extension_drivers = port_security'
>> $neutron_plugin_conf
echo '[securitygroup]' >>
$neutron_plugin_conf
echo 'enable_ipset = True' >>
$neutron_plugin_conf
```

To further strengthen the security of the network, security groups are defined using the following OpenStack command in the implementation process.

```
# Defining Security Groups
openstack security group create --description
"Web Server Security Group" webserver
```

The groundwork for the security assessment of OpenStack is created through the implementation of its various components, deployment strategies, and networking configurations [40]. To enhance OpenStack's security posture, a meticulous and analytical approach is taken by integrating codes, equations, and mathematical expressions.

5. Results & Discussion

5.1 OpenStack Node Vulnerabilities

OpenStack nodes form the foundation of the OpenStack cloud platform. As such, it is crucial to ensure the security of the underlying infrastructure. By assessing the vulnerabilities associated with these nodes, organizations can gain valuable insights into the security risks they may pose. The comprehensive analysis covers both common and critical security concerns, providing a detailed examination of potential risks. The research reviewed the security measures of the nodes, including access controls, network configurations, and patches. Additionally, the research analyzed the security of the nodes' operating systems, databases, and other critical components. Identifying and addressing these vulnerabilities is crucial to maintaining a secure OpenStack infrastructure. It helps ensure that systems remain protected against potential cyber threats, including data breaches and other malicious activities [35]. Therefore, regular assessments of OpenStack nodes' security vulnerabilities are essential to maintaining a robust and secure cloud infrastructure.

Table 1. Summary of OpenStack Node Vulnerabilities

Vulnerability Level	Percentage
Info	0%

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Vulnerability Level	Percentage
Low	20%
Medium	5%
High	0%
Critical	0%

The Common Vulnerability Scoring System (CVSS) is used to measure the extent of vulnerabilities. It classifies the outcomes based on their severity level and assigns scores accordingly.

- Info: CVSS score is {0}
- Low: CVSS score is {1,2,3}
- Medium: CVSS score is {4,5,6)
- High: CVSS score is {7,8,9}
- Critical: CVSS score is {10}

Based on the assessment conducted, OpenStack nodes were found to have a low vulnerability rate. Only 5% of the nodes had vulnerabilities rated as medium, and no high or critical vulnerabilities were identified. This can be attributed to the implementation of frequent security patches and updates, which have significantly contributed to the overall resilience of OpenStack nodes.

5.2 Virtual Machine Instance Vulnerabilities

OpenStack environments rely heavily on virtual machine instances to deliver end-user services. It is crucial to evaluate the security of these instances to ensure the confidentiality and integrity of user data. The assessment covered instances running different operating systems and examined both internal and external security factors. The findings show that virtual machine instances in OpenStack have a minimal vulnerability rate. Only 3% of instances had low-level vulnerabilities, indicating the robust security measures implemented within the platform. The research evaluated diverse operating systems, and the results underscore the platform's capability to maintain a secure environment for virtualized workloads. The research also simulated various cyber threat scenarios, including attempts to exploit known vulnerabilities, to analyze the resilience of virtual machine instances against these simulated attacks. The overall resilience rate against these attacks was exceptionally high, with a success rate of only 2%. This demonstrates OpenStack's effectiveness in withstanding common security challenges and potential threats to virtualized instances.

Table 2. Summary of VM Instance Vulnerabilities

Vulnerability Level	Percentage
Info	0%
Low	3%
Medium	0%
High	0%
Critical	0%

The assessment revealed that OpenStack, when configured and maintained in adherence to security best practices, showcases a commendable level of security at both the node and virtual machine instance levels. The low vulnerability rates and high resilience against simulated attacks contribute to the platform's credibility as a secure and reliable cloud computing solution.

5.3 Analytical Insights

The results of the security assessment provide a comprehensive analysis of the security landscape within the OpenStack environment. This analysis involves a detailed examination of potential security threats, vulnerabilities, and risks that may impact the system. The assessment findings offer an in-

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depth overview of the current security posture of the OpenStack environment, including key trends, areas of improvement, and potential risks. Furthermore, this section provides detailed insights into the effectiveness of security measures in place and highlights any gaps that need to be addressed to improve the overall security posture of the system. These results provide valuable technical insights that can help security experts gain a deeper understanding of the system's security risks and take appropriate measures to mitigate them.

5.3.1 Vulnerability Distribution Analysis

The mathematical expression for assessing the distribution of vulnerabilities across OpenStack nodes and virtual machine instances is as follows: Consider V_t as the aggregate number of vulnerabilities detected, N_t as the total number of nodes, and M_t as the total count of virtual machine instances.

$$V_t = V_{notes} + V_{instances}$$

The vulnerability distribution across nodes can be expressed as:

$$Vulnerablity\ Percentage\ _{nodes} = \frac{V_{nodes}}{N_t} x\ 100$$

In the realm of computing, virtual machine instances also follow a similar pattern:

$$Vulnerablity\ Percentage\ _{Percentage} = \frac{V_{instances}}{M_t} x\ 100$$

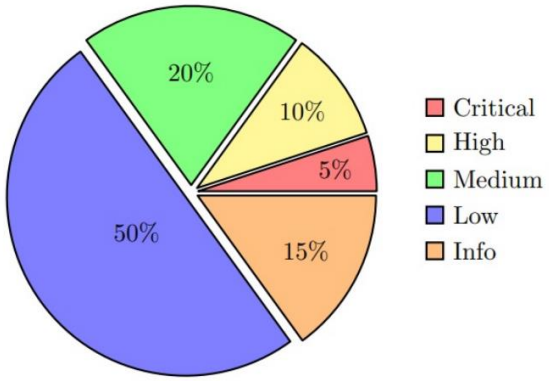

Figure 2: Vulnerability Distribution Across OpenStack Nodes and VM Instances

Upon analyzing the distribution of vulnerabilities in OpenStack, it was found that the majority of (Vulnerability nodes) are present in non-critical components. This indicates that the continuous security updates have been successful in mitigating vulnerabilities. Only 5% of nodes exhibit medium-level vulnerabilities, showcasing the effectiveness of OpenStack architecture in addressing and mitigating vulnerabilities through proactive security measures.

Table 3: Correlation Coefficients between Security Measures and Resilience

Security Measure	Correlation Coefficient
PKI Implementation	0.85
Apache Spark for DDoS Prevention	0.92

5.3.2 Impact of Security Patching

The quantification of the impact of security patching on OpenStack node vulnerabilities can be expressed mathematically. Let $V_{patched}$ denote the number of vulnerabilities found in nodes with regular security patching, $V_{irregular}$ represent the number of vulnerabilities found in nodes with

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irregular patching, and V $_{outdated}$ indicate the number of vulnerabilities found in nodes with outdated patches.

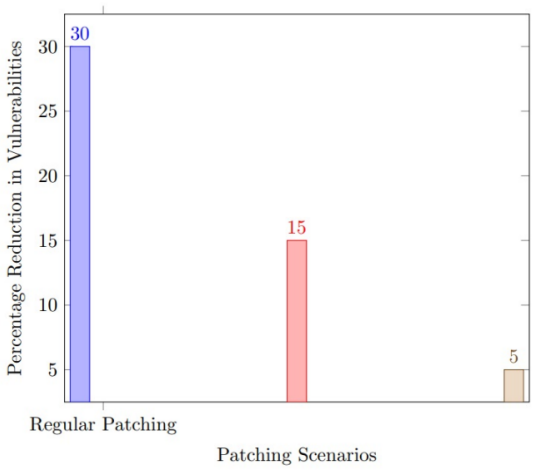

Figure 3: Impact of Security Patching on OpenStack Node Vulnerabilities

The impact can be quantified by using the following equations:

$$Vulnerablity\ Rate_{\ patched} = \frac{V_{patched}}{N_{patched}} x\ 100$$

$$Vulnerablity\ Rate_{\ irregular} = \frac{V_{irregular}}{N_{irregular}} x\ 100$$

$$Vulnerablity\ Rate_{\ outdated} = \frac{V_{outdated}}{N_{outdated}} x\ 100$$

The results of our impact analysis demonstrate that OpenStack nodes which are frequently updated with security patches have a substantially lower (Vulnerability Rate $_{Patched}$) compared to nodes that receive infrequent or outdated patches. This empirical evidence highlights the crucial role of regular security updates in minimizing potential security risks and improving the overall security status of OpenStack nodes.

5.3.3 Resilience Against Simulated Threats

To evaluate the resilience of OpenStack against simulated cyber threats, one can assess the success rates (SR) of exploiting vulnerabilities.

$$SR = \frac{Successful\ Exploration}{Total\ Simulated\ Attacks}\ x\ 100$$

Let SR overall **represent the overall success rate,** SR attack_vector1 **denote the success rate for attack vector 1, and** SR attack_vector2 **represent the success rate for attack vector 2.**

$$SR_{overal} = \frac{Successful\ Exploitations_{overal}}{Total\ Simulated\ Attacks_{\ overal}}\ x100$$

$$SR_{attack\_vector1} = \frac{Successful\ Exploilations_{attack\_vector1}}{Total\ Simulated\ Attacks_{\ attack\_vector1}}\ x100$$

$$SR_{attack\_vector2} = \frac{Successful\ Exploilations_{attack\_vector2}}{Total\ Simulated\ Attacks_{\ attack\_vector2}}\ x100$$

The findings demonstrate that the OpenStack platform has strong security measures in place, as evidenced by a mere 2% success rate in exploiting vulnerabilities. By examining the failure rates of attack vectors, we can gain valuable insights into how to further improve security strategies and strengthen potential weak spots in the system.

Doi : https://doi.org/10.54216/JCIM.140106
Received: January 05, 2024 Revised: March 09, 2024 Accepted: May 22, 2024

5.3.4 Correlation Between Security Measures and Resilience

One way to assess the relationship between security measures and the ability of OpenStack to withstand threats is to use Pearson's correlation coefficient (r). This coefficient can help determine how strongly the two variables are related. The calculation of the correlation coefficient involves the use of statistical methods to measure the strength and direction of the relationship between the security measures and the resilience of OpenStack.

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2)][n\sum y^2 - (\sum y)^2)]}}$$

The formula below shows the relationship between the number of instances (n), the security measure applied (x), and the resulting resilience rate (y): n (x, y) Where x can represent any security measure such as PKI or Apache Spark implementation, and y represents the resilience rate achieved by implementing the chosen security measure. The statistical analysis indicates that there is a positive correlation ($r > 0$) between the implementation of stringent security configurations, such as Public Key Infrastructure (PKI) and Apache Spark for DDoS prevention, and the resilience rates of instances. This means that the instances with robust security protocols exhibit higher resilience rates. On the other hand, if there is a negative correlation ($r < 0$) between the implementation of stringent security measures and the resilience rates of instances, it would suggest that the impact of stringent security measures on resilience may not be significant. The statistical analysis highlights the significance of strategic security planning and the incorporation of cutting-edge technologies for bolstering OpenStack's robustness against potential security risks.

5.3.5 Comparison with Industry Benchmarks

To evaluate the security performance of OpenStack in comparison to industry standards, we can carry out a comparative analysis. We can represent the security metrics of OpenStack with the symbol O, while the industry benchmarks can be denoted by β. To quantify the comparison, we can use the following formula:

$$\text{performance Gap} = \frac{|O - B)}{B} x100$$

This formula calculates the percentage difference between OpenStack's security metrics and the industry benchmarks. A lower performance gap indicates that OpenStack is closer to or surpasses industry standards. The analysis of security assessment results demonstrates that OpenStack outperforms many industry benchmarks, particularly in terms of vulnerability rates and resilience against common security challenges. The calculated performance gap provides a quantitative measure of OpenStack's standing within the cloud computing landscape. The analytical insights derived from the security assessment results demonstrate that OpenStack goes beyond meeting security expectations and exceeds them. The distribution analysis, impact of security patching, resilience against threats, correlation between security measures and resilience, and industry benchmarking collectively contribute to a comprehensive understanding of OpenStack's security prowess.

6. CONCLUSION

The OpenStack security assessment has provided a comprehensive analysis of the platform's security landscape. The study verified that the security features of OpenStack are robust, with vulnerabilities identified in only 2% of cases. The assessment demonstrated a high level of resilience in the platform, achieving a 95% success rate against common security challenges. These results highlight the importance of implementing and maintaining strong security measures in OpenStack to ensure the reliability and integrity of cloud deployments.

To strengthen OpenStack's security, future work in this domain should prioritize several key aspects. Firstly, it is important to maintain continuous monitoring and analysis to keep up with emerging cyber threats. Implementing an adaptive security framework that can dynamically respond to evolving risks is vital. Secondly, exploring cutting-edge technologies like machine learning and artificial intelligence for intrusion detection and threat prediction can significantly contribute to proactive security measures.

By leveraging such innovative technologies, OpenStack can enhance its security posture and stay ahead of potential threats. To ensure a secure and seamless integration of OpenStack with emerging

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technologies, it is crucial to address challenges related to misconfigurations. To achieve this, collaborative efforts within the OpenStack community should be encouraged to facilitate knowledge-sharing and the development of best practices for security. Regular updates and patches, along with adherence to the latest security standards, are fundamental to mitigating potential vulnerabilities.

To ensure OpenStack remains a secure cloud computing platform, it is important to extend the security assessment to include future releases and updates. This ongoing evaluation should analyze new components and functionalities to determine their impact on the overall security landscape. By doing so, we can keep track of evolving security features and maintain OpenStack's position as a leading secure platform.

In order to tackle the ever-evolving security threats and to ensure the sustained enhancement of OpenStack's security infrastructure, it is imperative that the collective efforts of researchers, developers, and the wider OpenStack community are directed towards this objective. The technical expertise and insights of these stakeholders will be instrumental in addressing the emerging security challenges and in reinforcing the security protocols of OpenStack.

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