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Submission ID	trn:oid:::1:3043559628
Submission Date	Oct 16, 2024, 11:15 AM GMT+5:30
Download Date	Oct 16, 2024, 11:19 AM GMT+5:30
File Name	ZeroTrust-final-report.pdf
File Size	2.3 MB

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ZERO TRUST SECURITY FOR WEB APPLICATIONS IN MICROSERVICE-BASED ENVIRONMENTS

A PROJECT REPORT

Submitted by

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in partial fulfillment for the award of the degree of

BACHELOR OF TECHNOLOGY IN COMPUTER SCIENCE AND ENGINEERING (CYBER SECURITY)

Under the guidance of

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Submitted to

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October 2024

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BONAFIDE CERTIFICATE

This is to certify that this project report entitled **"ZERO TRUST SECURITY FOR WEB APPLICATIONS IN MICROSERVICE-BASED ENVIRONMENTS"** is the bonafide work of **N. Dinesh Kumar (Reg. No CH.EN.U4CYS21014) and V. Jayaraj (Reg. No CH.EN.U4CYS21026)** who carried out the project work under my supervision.

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ABSTRACT

In the rapidly evolving landscape of cybersecurity, traditional perimeter-based security models have become insufficient to address the growing complexity and frequency of modern cyber threats. As enterprises increasingly adopt cloud-native applications and microservice-based architectures, a more robust and granular security framework is required to mitigate these risks. This paper presents the design and implementation of a Zero Trust Security Model aimed at securing web applications running in Kubernetes Clusters while extending these principles to Android applications for enhanced mobile security. For the web application, Zero Trust is implemented using JWT authentication, role-based access control (RBAC), continuous authentication, and data encryption, ensuring strict identity verification and dynamic access control across the system. Additionally, the model enforces fine-grained micro-segmentation and real-time threat detection, protecting critical resources from unauthorized access and mitigating lateral movement attacks. In the ZeroSMS Android application, the Zero Trust model is extended to mobile apps by integrating security tools like JailMonkey for detecting root access and debugging, along with code obfuscation using R8 and ProGuard for enhanced protection. These measures ensure that mobile applications are safeguarded from unauthorized use and potential exploits. The architecture further incorporates mTLS and a tool for detecting unauthorized shell command interactions to secure containerized environments, ensuring robust security at both application and infrastructure levels. Our evaluation demonstrates that this approach effectively reduces attack surfaces, enhances protection against modern threats, and provides a comprehensive security solution for both web and mobile contexts. The proposed framework offers a scalable, resilient, and adaptable security architecture, making it well-suited to the demands of modern cybersecurity challenges.

Keywords: Zero Trust Security, JWT Authentication, Mutual TLS, Cybersecurity, Web Application Security, Android App Security, Micro-segmentation, Kubernetes Clusters, Role-Based Access Control.

ACKNOWLEDGEMENT

This project work would not have been possible without the contribution of many people. It gives me immense pleasure to express my profound gratitude to our honorable Chancellor **Sri Mata Amritanandamayi Devi**, for her blessings and for being a source of inspiration. I am indebted to extend my gratitude to our Director, **Mr. I B Manikantan** Amrita School of Computing and Engineering, for facilitating us with all the facilities and extended support to gain valuable education and learning experience.

I register my special thanks to **Dr. V. Jayakumar**, Principal Amrita School of Computing and Engineering, **Dr. Sountharrajan**, Chairperson of Department of Computer Science and Engineering and **Dr. S. Udhaya Kumar**, Program Head Department of CSE(CYS) for the support given to me in the successful conduct of this project and for his inspiring guidance, personal involvement and constant encouragement during the entire course of this work.

I am grateful to the Project Coordinator, Review Panel Members and the entire faculty of the Department of Computer Science & Engineering, for their constructive criticisms and valuable suggestions which have been a rich source to improve the quality of this work.

DINESH KUMAR. N

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ZTNA	-	Zero Trust Network Access
JWT	-	JSON Web Token
SDN	-	Software Defined Networking
IoT	-	Internet of Things
API	-	Application Programming Interface
TLS	-	Transport Layer Security
ML	-	Machine Learning
AI	-	Artificial Intelligence
IDP	-	Identity Provider
SIEM	-	Security Information and Event Management
OTP	-	One-Time Password
IAM	-	Identity and Access Management
K8s	-	Kubernetes
CI/CD	-	Continuous Integration/Continuous Deployment
YAML	-	YAML Ain’t Markup Language
ACL	-	Access Control List
APK	-	Android Application Package

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

In today's digital landscape, organizations have faced an escalating number of cyber threats, which have highlighted the inadequacies of traditional perimeter-based security measures. Traditional perimeter-based security models, which rely on predefined trust zones, have struggled to keep pace with the sophistication of modern distributed cyberattacks. These models operate under the assumption that threats exist primarily outside the network, which has proven dangerously simplistic in a world where attacks often originate from within. The vulnerabilities inherent in traditional security architectures include limited visibility into network traffic, inadequate user and device verification, and the inability to monitor behaviors in real-time. A significant consequence of these vulnerabilities is the increased risk of lateral movement within a network, enabling attackers to access sensitive data once they breach the perimeter. For instance, the 2017 Equifax data breach exposed the personal information of approximately 147 million individuals, resulting in an estimated loss of $4 billion due to remediation efforts and legal settlements. Similarly, the 2020 SolarWinds cyberattack compromised numerous organizations, including U.S. government agencies, by exploiting vulnerabilities in third-party software, leading to billions in recovery costs and potential losses.

The rapid adoption of agile methodologies, cloud computing, and containerization technologies has significantly expanded the attack surface, enabling cybercriminals to exploit vulnerabilities more effectively. Traditional perimeter-based security models, which rely on predefined trust zones, have struggled to keep pace with the sophistication of modern distributed cyberattacks. Attack vectors such as phishing, ransomware, and insider threats have grown increasingly sophisticated. For example, ransomware attacks surged by 150% in 2020 alone, costing businesses an estimated $20 billion. Additionally, the Verizon 2020 Data Breach Investigations Report highlighted that 86% of breaches were financially motivated, showcasing the urgent need for more robust security measures. To counteract these evolving threats, the Zero Trust Security Model has emerged as a transformative approach, fundamentally altering the way security is implemented across networks, applications, and devices. The Zero Trust Model operates on the principle that no entity—user, device, or application—should be trusted by default, and continuous verification is mandatory for every access attempt [1].

The Zero Trust Model addresses the shortcomings of traditional security frameworks by enforcing continuous authentication and authorization, regardless of the entity's origin within or outside the network [2]. Its fundamental principle, "never trust, always verify," mandates that access be granted based on a rigorous evaluation of predefined security policies. This approach is particularly relevant in microservice environments, where data and services are distributed across multiple containers and volumes. By utilizing technologies such as JSON Web Token (JWT) authentication, mutual TLS (mTLS), and micro-segmentation, Zero Trust strengthens security postures by limiting access to only authenticated and authorized entities. Additionally, the implementation of features such as root/debug detection and code obfuscation in ZeroSMS enhances security by safeguarding against reverse engineering and unauthorized access. The deployment of tools for detecting shell command injection in Kubernetes containers further strengthens the application's resilience against attacks, ensuring that vulnerabilities can be promptly identified and mitigated. This paper aims to explore the design and implementation of a Zero Trust framework within a modern web application running in a microservice environment, addressing the limitations of traditional security models and proposing a more adaptive, resilient solution.

1.2 ANALYZING CYBERSECURITY DYNAMICS WITHIN THE ZERO TRUST FRAMEWORK

The rise of cloud computing, distributed systems, and decentralized data has transformed how organizations operate, creating new challenges for cybersecurity. Traditional perimeter-based security approaches, often referred to as "castle-and-moat" defenses, assume that threats exist primarily outside the network perimeter, with internal resources inherently trusted. However, the shift to remote work, cloud services, segmentation, and decoupling of applications and data has made these boundaries porous, leaving applications vulnerable to insider threats, compromised resources, and increasingly sophisticated cyberattacks [3].

The Zero Trust Security Model represents a paradigm shift in how security is conceptualized. Unlike traditional models, Zero Trust as shown in Fig.1.1 does not rely on network location to establish trust. Instead, it mandates that every entity—whether internal or external—be continuously authenticated and authorized before being granted access to sensitive resources. The model leverages technologies like JWT for stateless authentication of users and mTLS for secure, mutual verification of identity between containers or pods running in Kubernetes clusters, ensuring that communication remains encrypted and secure [4]. This approach aligns with the decoupled nature of modern applications, which are segmented across multiple containers in Kubernetes clusters of various cloud providers like AWS and accessed by users and devices from varied locations.

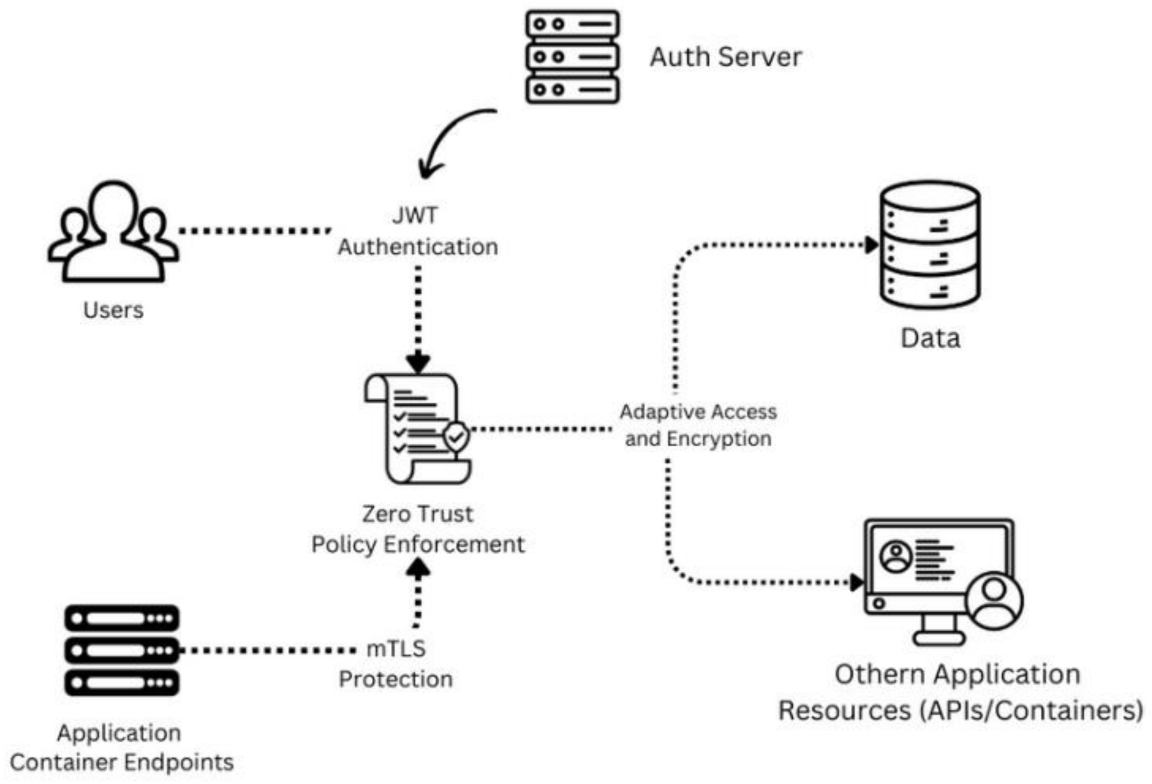

Auth Server
JWT Authentication
Users
Data
Adaptive Access and Encryption
Zero Trust Policy Enforcement
mTLS Protection
Application Container Endpoints
Othern Application Resources (APIs/Containers)

Fig. 1.1 Block diagram describing the design of ZTA and its basic architecture

1.3 PROBLEM IDENTIFICATION

The shift from perimeter-based security to Zero Trust is driven by several key challenges in securing modern microservice environments. Traditional security models often assume that threats are primarily external, leaving internal systems and data exposed once the perimeter is breached. This assumption results in several critical problems:

- Expanded Attack Surface: The adoption of agile, cloud computing, remote work, and decoupling practices has increased the usage of microservices, making it difficult to monitor and secure all potential entry points. Attackers can exploit vulnerabilities in containerized applications or user credentials to gain unauthorized access.
- Lateral Movement: Once an attacker gains access to one pod in a Kubernetes cluster, they can move laterally across other containers without encountering significant restrictions, allowing for extensive damage of other pods and data breaches, as evidenced by several high-profile incidents.

- Insufficient Identity Verification: Traditional security models grant users and devices access based on network location, with minimal continuous verification. This lack of ongoing validation leaves Kubernetes clusters vulnerable to unauthorized access.
- Distributed Systems Complexity: As an application's features and data are increasingly distributed across cloud platforms, implementing consistent security policies to restrict and manage access control becomes more challenging.
- The aforementioned challenges create a pressing need for a more robust, adaptable, and resilient security framework. The Zero Trust Security Model offers solutions by ensuring that all access requests are continuously authenticated, authorized, and validated, regardless of inter-service or external communication.

1.4 PROBLEM STATEMENT

Traditional perimeter-based security models have proven inadequate for safeguarding sensitive data and resources in modern, microservice-based environments. These environments, designed with a limited understanding of the threats facing today's decentralized networks, allow for lateral movement and insufficient identity verification, both of which leave Kubernetes clusters vulnerable to sophisticated cyberattacks. The Zero Trust Security Model addresses these challenges by implementing continuous identity verification, encrypted communication, and adaptive security policies across microservices, reducing the attack surface and preventing unauthorized access.

1.5 SIGNIFICANCE AND MOTIVATION

Adopting the Zero Trust Security Model in modern web applications based on microservice architecture has become increasingly significant. The model addresses several critical issues facing organizations as they transition to cloud-native architectures, remote work models, and globally distributed operations across various cloud providers. The motivation for implementing Zero Trust in Kubernetes clusters lies in its ability to mitigate security threats inside the clusters, enhance protection for applications, reduce lateral movement, and meet regulatory compliance requirements.

- Mitigation of Internal Threats: Zero Trust enforces strict access controls and continuously verifies user identities, minimizing the risk of communicating containers

- Cloud Application Security: Zero Trust’s dynamic approach to securing containerized environments ensures that access requests are evaluated in real time, protecting data across various platforms.
- Reduction of Lateral Movement: By using micro-segmentation and enforcing stringent access control policies, Zero Trust limits an attacker's ability to move laterally within a compromised cluster [5].
- Compliance and Regulation: As regulatory requirements intensify, Organizations must demonstrate their ability to monitor and control access to sensitive data. Zero Trust provides the framework to meet these demands by ensuring continuous authentication and authorization of all access requests.

1.6 OBJECTIVE AND SCOPE OF THE PROJECT

The primary objective of this project was to design and implement a secure microservice-based web application that integrated the Zero Trust Security Model. The application incorporates JWT authentication, mTLS, and micro-segmentation along with access control policies to provide a robust security framework. The goals were:

- Continuous Identity Verification: Implement mechanisms to authenticate users and devices with every request, using JWT for stateless, token-based authentication and mTLS for mutual verification.
- Adaptive Access Control: Develop dynamic access control policies that adjust based on user roles and request context, ensuring minimal privilege for users.
- Encrypted Communication: Secure all communications within the application using mTLS to protect against interception and tampering.
- Prevention of Lateral Movement: Implement micro-segmentation to isolate components and prevent attackers from moving laterally across the system.
- Real-Time Threat Detection: Integrate machine learning algorithms to detect anomalies in user behavior, allowing for proactive security measures [6].

The scope of this project encompasses the design and implementation of the Zero Trust Security Model within a microservice architecture, focusing on integration of advanced security features such as root/debug detection and code obfuscation to enhance application security, deployment of a tool for detecting shell command injection in Kubernetes containers to safeguard against specific vulnerabilities. And continuous evaluation and adjustment of security measures to adapt to the evolving threat landscape.

CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURE REVIEW BASED ON PREVIOUS RESEARCH PAPERS

D’Silva et al. examined the implementation of Zero Trust Architecture (ZTA) using Kubernetes [7], highlighting its significance in cloud-based environments. They emphasized how ZTA continuously verified users, devices, and applications, challenging traditional trust models. The study discussed the use of technologies such as Kubernetes, Docker and RBAC/ABAC for enhanced access control. Additionally, they critiqued traditional security frameworks, noting the inadequacies of perimeter-based models in modern cloud infrastructures. Their proposed architecture improved security through continuous verification and logging, making it adaptable to decentralized systems.

Varalakshmi et al. [8] explored the enhancement of JSON Web Token (JWT) authentication within Software Defined Networks (SDNs). They identified vulnerabilities in traditional JWT implementations and proposed a modified authentication approach that improves security without sacrificing performance. Their analysis highlighted the importance of securing API endpoints and user sessions, ultimately enhancing the overall integrity of network communications in SDN environments.

Bucko et al. [9] examined the enhancement of JWT authentication and authorization in web applications by utilizing user behavior history. Their study analyzed how behavior-based metrics could improve the reliability of authentication processes. They proposed a dynamic authentication mechanism that adapts based on user activity, significantly reducing unauthorized access and enhancing user security in web applications.

Jánoky et al. [10] conducted an analysis of revocation mechanisms for JSON Web Tokens (JWTs). They identified the challenges associated with effectively revoking tokens without degrading system performance. Their research emphasized the need for efficient revocation strategies to ensure the security of applications relying on JWTs, contributing valuable insights into the management of token lifecycles.

Achary and Shelke [11] investigated fraud detection in banking transactions using machine learning techniques. They presented a framework that leveraged various algorithms to identify and mitigate fraudulent activities in real-time. Their findings underscored the efficacy of machine learning in enhancing the security of financial transactions, providing banks with tools to protect against fraud. The author highlighted the importance of adaptive models that can learn from evolving fraud patterns, contributing to more robust credit card security measures.

Fraudulent Transaction Detection in Credit Card by Applying Ensemble Machine Learning Techniques by Debachudamani Prusti et al. [12] explores the use of ensemble machine learning models for detecting fraudulent credit card transactions. By combining multiple machine learning algorithms, the study aims to improve accuracy, precision, and detection speed. Key findings show that ensemble methods outperform individual classifiers in identifying fraudulent transactions, reducing false positives, and increasing overall efficiency in real-time fraud detection systems.

Jaculine Priya and Saradha [13] reviewed machine learning algorithms for fraud detection and prevention. Their comprehensive analysis encompassed various techniques, assessing their strengths and weaknesses in different contexts. The paper provided a critical overview of the current state of fraud detection systems, emphasizing the potential of machine learning in enhancing predictive accuracy and operational efficiency in fraud management.

A. I. Weinberg et al. [14] studied Zero Trust Architecture (ZTA) for applications and network security, highlighting its relevance in contemporary cybersecurity frameworks. The research detailed how ZTA eliminates implicit trust and enforces strict access controls, providing a robust model for securing sensitive data in dynamic environments.

Kang et al. [15] provided a brief survey of the theory and application of Zero Trust security. They examined various implementations and discussed how Zero Trust principles could enhance overall security posture. Their findings illustrated the applicability of Zero Trust in diverse settings, emphasizing its importance in mitigating modern cybersecurity threats.

Ashfaq et al. [16] presented a comprehensive survey of the Zero Trust security paradigm. Their research analyzed existing literature, outlining key principles and strategies for implementing Zero Trust in various contexts. The authors identified gaps in current research, suggesting areas for future investigation to enhance understanding and application of Zero Trust principles.

Liu et al. [17] dissected the research landscape surrounding Zero Trust and its implementation in the Internet of Things (IoT). They identified key challenges and strategies for applying Zero Trust principles in IoT environments, emphasizing the necessity for stringent access controls and continuous verification to mitigate security risks. The authors provided a comprehensive overview of current research trends and highlighted areas requiring further investigation to enhance IoT security through Zero Trust frameworks.

Mehraj and Banday [18] proposed a Zero Trust strategy for cloud computing environments to address security challenges such as identity theft, data breaches, and trust management issues. Their model emphasizes strong access control and continuous verification due to the dynamic, shared nature of cloud services. The authors discussed how traditional security approaches are insufficient in cloud deployments and highlighted the Importance of Zero Trust in tracking and mitigating both external and insider threats.

Muddinagiri et al. [19] presented a method for deploying Kubernetes locally using Minikube to manage Docker containers before cloud or on-premise deployment. The paper focuses on containerization as a lightweight alternative to virtual machines, emphasizing the need for local Kubernetes testing. They demonstrated this with a Python-based web server application built using a DockerFile. This local Kubernetes solution is particularly beneficial for industries like finance and healthcare, which require scalable applications without compromising security by avoiding cloud-based deployments.

Pace's thesis [20] explores the implementation of Zero Trust Networks using Istio within a Kubernetes environment. Istio, an open platform, operates as a service mesh where proxies handle traffic management, observability, security, and extensibility. Key features include traffic shaping, canary deployments, strong identity verification via mutual TLS, and JWT-based authentication. Istio's modular and extensible architecture integrates seamlessly with Kubernetes, allowing dynamic configurations without modifying applications, offering a robust approach to microservices security and operational efficiency.

Kurbatov's thesis [21] presents the design and implementation of secure communication between microservices using the Istio service mesh. Istio enables secure service-to-service communication, load balancing, and traffic monitoring without altering application code. It deploys Envoy proxy sidecars to manage traffic, encryption, authentication, and authorization, ensuring robust security. Istio's architecture includes Certificate Authority

(CA) for key management, Policy Enforcement Points (PEPs), and X.509 certificates for workload identity. This approach enhances communication security across a microservice-based system, making it adaptable to deployment demands while maintaining high-level security and control.

Yang et al. (2021) discusses the security challenges in container cloud environments, identifying vulnerabilities across the kernel, container, and orchestration layers. These include container escape, resource exhaustion, and insecure configurations. Critical CVEs like CVE-2019-5736 and CVE-2020-2023 highlight how attackers exploit runtime vulnerabilities to escape containers. The paper also emphasizes weak network isolation in Kubernetes clusters, posing risks like ARP or DNS spoofing and BGP hijacking. The authors recommend robust kernel isolation mechanisms and improved configuration tools for enhanced security.

2.2 LITERATURE SUMMARY TABLE

S.NO	Author(s)	Title	Objective	Methodology	Conclusion
1	D. D'Silva, D. D. Ambawade	Building a Zero Trust Architecture Using Kubernetes [7]	To explore how Kubernetes can be used to implement a Zero Trust architecture	Discusses the use of Kubernetes for Zero Trust implementation	Zero Trust principles can be efficiently implemented using Kubernetes infrastructure
2	P. Varalakshmi, B. Guhan, P. V. Siva, T. Dhanush, K. Saktheeswaran	Improvising JSON Web Token Authentication in SDN [8]	To enhance JWT authentication in SDN environments	Uses modified JWT authentication techniques for Software-Defined Networks (SDN)	The JWT enhancements provide improved security and efficiency in SDN environments
3	A. Bucko, K. Vishi, B. Krasniqi, B. Rexha	Enhancing JWT Authentication and Authorization in Web Applications Based on User Behavior [9]	To enhance JWT authentication and authorization based on user behavior history	Applies behavior-based analysis for JWT authentication improvements	Behavior-based JWT offers better security against attacks like token theft

4	L. V. Jánoky, J. Levendovszky, P. Ekler	An Analysis on the Revoking Mechanisms for JSON Web Tokens [10]	To analyze and improve revoking mechanisms in JWT	Analyzes current JWT revocation mechanisms and suggests enhancements	Proposed mechanisms for revoking JWT improve security in token-based authentication systems
5	R. Achary, C. J. Shelke	Fraud Detection in Banking Transactions Using Machine Learning [11]	To apply machine learning algorithms for fraud detection in banking transactions	Uses machine learning models for detecting anomalous patterns in banking transactions	Machine learning proves effective in detecting fraudulent transactions in real-time
6	D. Prusti, S. K. Rath	Fraudulent Transaction Detection in Credit Card by Applying Ensemble Machine Learning Techniques [12]	To develop ensemble machine learning techniques for credit card fraud detection	Applies a combination of machine learning algorithms to detect credit card fraud	Ensemble techniques significantly improve the accuracy of fraud detection in credit card transactions
7	G. J. Priya, S. Saradha	Fraud Detection and Prevention Using Machine Learning Algorithms: A Review [13]	To review the application of machine learning algorithms in fraud detection and prevention	Provides a systematic review of various machine learning algorithms used for fraud detection	Machine learning offers innovative and efficient solutions for fraud detection and prevention
8	A. I. Weinberg, K. Cohen	Zero Trust Implementation in the Emerging Technologies Era: A Survey [14]	To survey the current trends in Zero Trust implementation across emerging technologies	Surveys recent developments and research in Zero Trust implementation for various technologies	Zero Trust is crucial for improving security in modern, emerging technology landscapes
9	H. Kang, G. Liu, Q. Wang, L. Meng, J. Liu	Theory and Application of Zero Trust Security: A Brief Survey [15]	To present a brief overview of the theoretical framework and applications of	Surveys the key theoretical aspects and applications of Zero Trust in modern IT environments	Zero Trust security is a growing necessity in securing critical infrastructure

			Zero Trust security		and IT systems
10	S. Ashfaq, S. A. Patil, S. Borde, P. Chandre, P. M. Shafi	Zero Trust Security Paradigm: A Comprehensive Survey and Research Analysis [16]	To provide a comprehensive survey of the Zero Trust security paradigm	Conducts a comprehensive survey of Zero Trust models and security practices	Zero Trust represents a paradigm shift in security, emphasizing identity verification at every access point
11	C. Liu, R. Tan, Y. Wu, Y. Feng, Z. Jin, F. Zhang, Y. Liu, Q. Liu	Dissecting Zero Trust: Research Landscape and Its Implementation in IoT [17]	To dissect the Zero Trust security model and explore its implementation in IoT environments	Provides an analysis of the research landscape and specific implementation strategies for Zero Trust in IoT	Zero Trust offers promising solutions for securing IoT environments, but challenges such as scalability remain
12	S. Mehraj, M. T. Banday	Establishing a Zero Trust Strategy in Cloud Computing Environment [18]	To establish a Zero Trust strategy tailored for cloud computing environments	Proposes a cloud-specific Zero Trust strategy and architecture	Zero Trust enhances security in cloud environments by reducing the risk of unauthorized access to cloud resources
13	R. Muddinagiri, S. Ambavane, S. Bayas	Self-Hosted Kubernetes: Deploying Docker Containers Locally with Minikube [19]	To demonstrate the process of deploying Docker containers locally using Minikube	Uses Minikube for local containerized Kubernetes deployment	Minikube allows for an efficient local setup of containerized applications for testing and development
14	M. Pace	Zero Trust Networks with Istio [20]	To explore the integration of Zero Trust principles in networks using Istio	Implements Istio for securing microservices in a Zero Trust network	Istio is a powerful tool for implementing Zero Trust in cloud-native applications

15	A. Kurbatov	Design and Implementation of Secure Communication Between Microservices [21]	To design secure communication protocols between microservices	Develops secure communication protocols using encryption and mutual authentication between microservices	Secure communication is essential for Zero Trust in microservice-based architectures
16	Y. Yang, W. Shen, B. Ruan, W. Liu, K. Ren	Security Challenges in the Container Cloud [22]	To address the security challenges specific to containerized cloud environments	Analyzes various security challenges in container-based cloud deployments	Container-based cloud environments require robust security strategies to mitigate threats such as isolation failures

Table 2.1. Literature summary table

The above Table provides a summary of the literature survey on research papers related to Zero Trust architecture, JSON Web Token (JWT) security enhancements, and fraud detection using machine learning algorithms. It highlights the objectives, methodologies, and conclusions drawn by various authors, focusing on advancements in security frameworks, especially in cloud computing, web applications, and software-defined networks. The table offers insights into the application of Zero Trust principles, JWT mechanisms, and machine learning techniques for improving authentication, authorization, and fraud prevention across different domains.

CHAPTER 3

METHODOLOGY

The proposed containerized web application is designed to provide users with a comprehensive expense tracking system that adheres to Zero Trust security principles. Built using React.js for the frontend, styled with Tailwind CSS, and supported by a MongoDB backend with a Python API, the application allows users to manage their financial transactions efficiently while ensuring secure access and data integrity at all levels. This application uses Docker for containerization, Kubernetes for container orchestration, and Helm to dynamically handle configurations of Kubernetes manifests. The complete application is then deployed to an AWS EKS cluster, which is remotely enforced with strict IAM policies and VPC.

3.1 COMMON VULNERABILITIES AND ZERO TRUST PROTECTION

In the realm of web application development, common mishandlings and vulnerabilities often lead to various attacks, including SQL injection, cross-site scripting (XSS), and unauthorized data access. These vulnerabilities can compromise the integrity, confidentiality, and availability of sensitive data, leading to severe financial and reputational repercussions for organizations.

- SQL Injection is one of the most common forms of attack, where an attacker can manipulate a SQL query by injecting malicious SQL code through input fields. This can result in unauthorized access to data, data manipulation, or even complete database compromise. Zero Trust architecture counters this vulnerability by enforcing strict input validation and sanitization processes. By employing parameterized queries and prepared statements, developers can ensure that input data is treated as data, not executable code.
- Cross-Site Scripting (XSS) attacks involve injecting malicious scripts into webpages viewed by other users. This can lead to session hijacking, defacement of web pages, or the distribution of malware. Zero Trust frameworks help mitigate XSS risks by implementing Content Security Policies (CSP) that define which sources of content are permissible. By validating and sanitizing user inputs and utilizing security headers, applications can minimize the attack surface for XSS vulnerabilities.

- Unauthorized Data Access remains a critical concern, particularly in applications handling sensitive user information. Zero Trust security frameworks address this issue through strict access controls, ensuring that users have the minimum necessary permissions to perform their tasks. By implementing Multi-Factor Authentication (MFA), organizations can add an additional layer of security, requiring users to verify their identity through multiple methods before granting access. This significantly reduces the likelihood of unauthorized access, even if credentials are compromised.

Moreover, Role-Based Access Control (RBAC) ensures that users only have access to the information and resources necessary for their role. This principle of least privilege limits the potential impact of compromised accounts and reduces the risk of insider threats.

3.2 WEB APPLICATION OVERVIEW

At the core of this application is the user interface, which enables users to perform CRUD operations (Create, Read, Update, Delete) on their financial transactions. Users can manually input their expenses, savings, and investments through a form-based system that adds each entry as a card component. Additionally, users can visualize their transaction data through graphical views implemented using react-chart-js, providing insights into spending patterns and financial health over time. A distinguishing feature of this application is its integration with the ZeroSMS mobile app. The ZeroSMS app automatically parses SMS messages related to transactions, which are often sent by banks or payment services, and synchronizes them with the web application. This functionality is especially beneficial for users who may forget to log some expenses or are too busy to manually enter transaction details. Once an SMS is parsed, the web application notifies the user, allowing them to classify and manage these transactions at their convenience. This automated process helps ensure that even small purchases or overlooked transactions are accounted for within the expense tracker.

Another key feature is the ability for users to share their transaction data with a selected list of auditors. The auditors, who are granted read-only access to user transactions, can view the data to prepare financial reports. This feature is essential for those who require external auditing services or want to maintain transparency with financial advisors. The auditor’s interface displays a list of users who have shared their transaction data, allowing them to access the data without modifying it, which aligns with Zero Trust's principle of minimal privileges for authorized users.

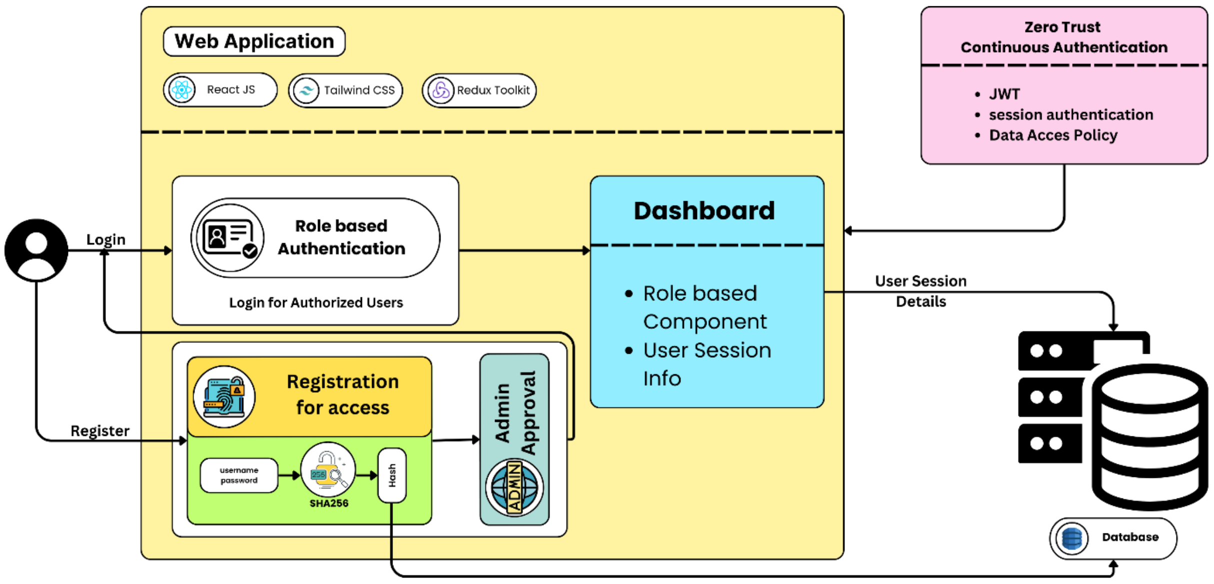


Fig. 3.1 Architecture diagram of the implementation of JWT in Web Application

3.2.1 Admin and Auditor Interfaces

The admin interface is critical for managing user roles and access within the application. New users must first register through a registration page, but their access to the system is only granted upon approval by the admin. The admin has the authority to approve or reject users,

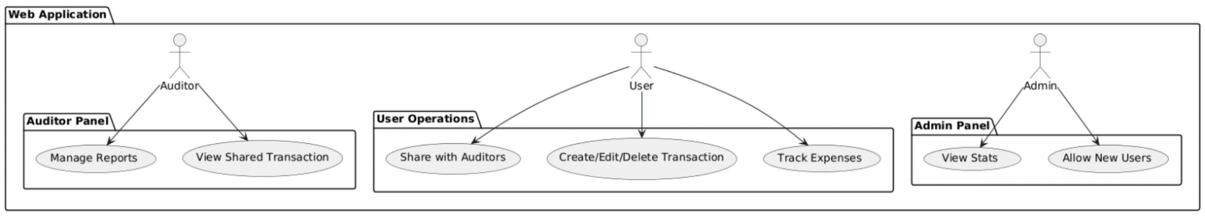


Fig 3.2. RBAC Implementation in the Web Application

as well as assign specific roles such as user, auditor, or admin. This role assignment functionality is presented as a table view, where the admin can easily manage user permissions. Role-based access control (RBAC) ensures that each user only has access to the resources necessary for their role, supporting the Zero Trust model’s principle of least privilege as illustrated in Figure 3.2. In addition to user management, the admin interface provides a user behavior analysis dashboard. This feature enables the admin to monitor important logs, such as user login and logout times, system activity, and other behaviors that may indicate suspicious activity. By continuously monitoring these behaviors, the application can detect anomalies, helping to prevent unauthorized access or potential misuse of the system. This feature reinforces Zero Trust's “never trust, always verify” approach, where users are continuously authenticated and their behavior is scrutinized to detect potential threats.

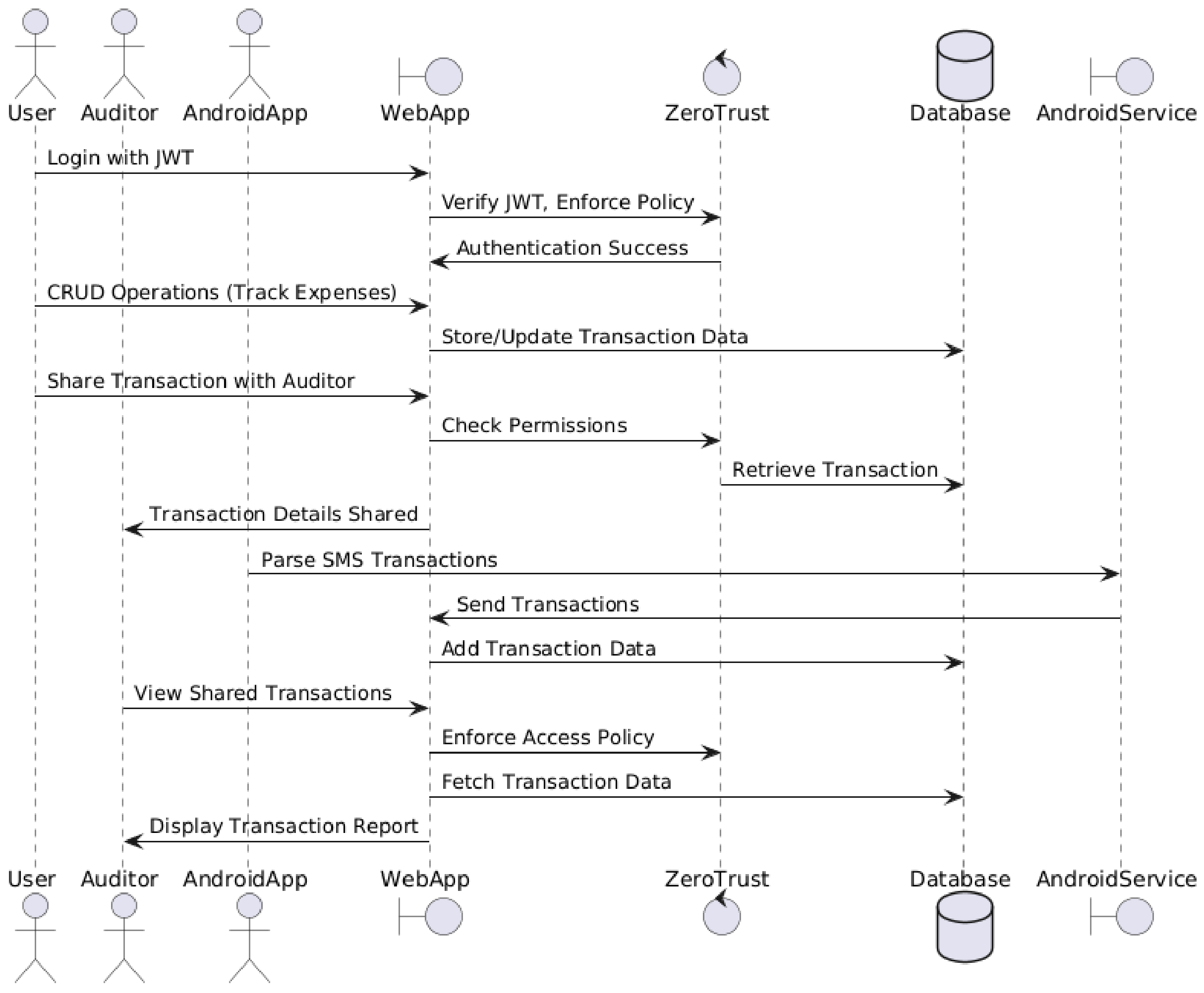


Fig. 3.3. Sequence Diagram representing the order of events taking place

3.2.2 Security and Fraud Detection

The security architecture of the application is built on the Zero Trust framework, which ensures that each user and each transaction is treated as potentially untrusted until verified. Figure 3.4 shows that each request to access sensitive data is validated through JSON Web Tokens (JWT), which provide secure, time-bound access tokens that validate the user's identity and role. If a user's JWT token is invalid or expired, access is immediately denied, ensuring that no unauthorized requests are processed. The fraud detection model is another critical component of the system. Developed using machine learning (ML) algorithms, the model analyzes transaction patterns to detect potentially fraudulent activity. It is trained on historical transaction data stored in MongoDB, leveraging algorithms such as random forest and support vector machines (SVM) to classify transactions as legitimate or suspicious.

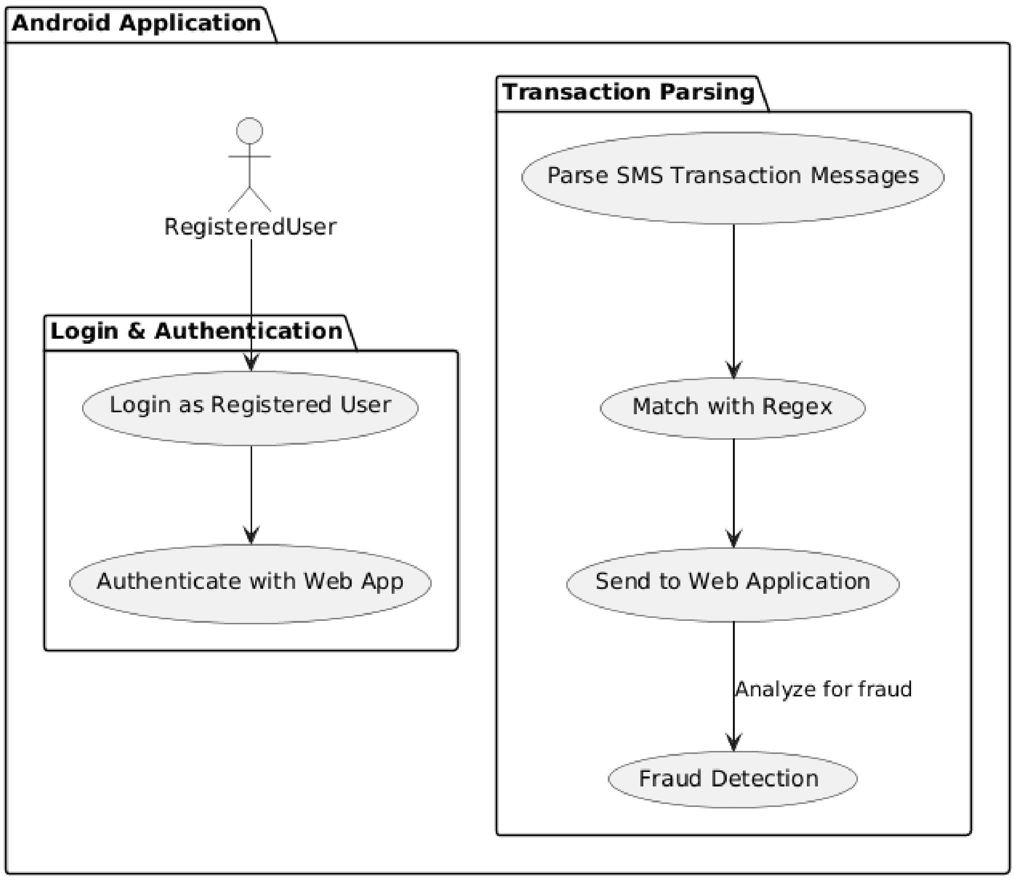


Fig. 3.4. Overview of the Android Application - ZeroSMS

This real-time analysis is particularly valuable for auditors, as they can identify anomalies or red flags that may require further investigation. The fraud detection model complements the Zero Trust approach by providing continuous monitoring and detection capabilities, ensuring that even authorized users do not engage in fraudulent behavior. The application architecture is illustrated in Figure 3.2, which shows the flow of user and admin interactions, SMS parsing through ZeroSMS, and fraud detection. Figure 3.3 illustrates the user behavior analysis dashboard, showing how logs and user activity are tracked and monitored in real time.

3.3 ACCESS TOKENS FUNCTIONALITY AND IMPLEMENTATION

In the context of Zero Trust security architecture, the utilization of Access Tokens, specifically JSON Web Tokens (JWTs), is essential for maintaining robust authentication and authorization mechanisms. JWTs are compact, URL-safe tokens that enable secure information exchange between parties. Comprising three parts—the header, which defines the signing algorithm; the payload, which contains user claims; and the signature, used to verify the token's authenticity—JWTs provide a stateless solution that enhances both scalability and security in distributed systems. The same is illustrated in Figure 3.6.

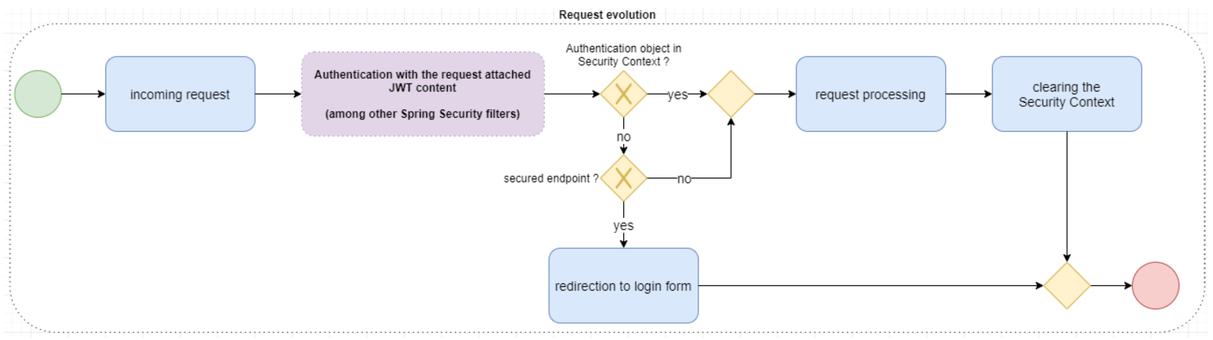

Request evolution
incoming request
Authentication with the request attached JWT content
(among other Spring Security filters)
Authentication object in Security Context ?
yes
no
secured endpoint ?
no
yes
request processing
clearing the Security Context
redirection to login form

Fig. 3.5. JWT Life Cycle

This structure allows for seamless authentication flows, where the server can validate the token without maintaining session information. As shown in Fig. 1.1, the Python APIs to generate and manage and rigorously validate JWT are containerized and built to run as a separate pod inside the Kubernetes cluster, ensuring continuous authentication of requests from the clients. Upon successful authentication, the system generates a JWT containing essential user-specific claims, such as roles and permissions, which are then transmitted to the user. For subsequent requests, the user includes this token in the authorization header, allowing the application to verify the token's integrity and validity before granting access to protected resources. This implementation not only adheres to the principle of least privilege by limiting access based on the user's current permissions but also enhances security through the use of short-lived access tokens and refresh tokens, which mitigate the risks associated with token theft or misuse. The lifecycle of JWTs, including issuance, expiration, and renewal mechanisms, is depicted in Fig. 3.5.

To fortify the security of JWT implementations, organizations can integrate additional security measures such as Multi-Factor Authentication (MFA) and continuous monitoring. By assessing user behavior, geolocation, and device health alongside JWT validation, a comprehensive security posture is achieved that aligns with the core principles of Zero Trust. Furthermore, effective revocation mechanisms for JWTs are crucial to ensure that compromised tokens are invalidated promptly. The implementation of these mechanisms, such as utilizing a token blacklist or short-lived tokens with refresh capabilities, is vital for maintaining a secure environment in Zero Trust applications.

Overall, the strategic integration of JWTs within Zero Trust frameworks not only streamlines access management but also ensures a continuous verification process that upholds the security integrity of the application.

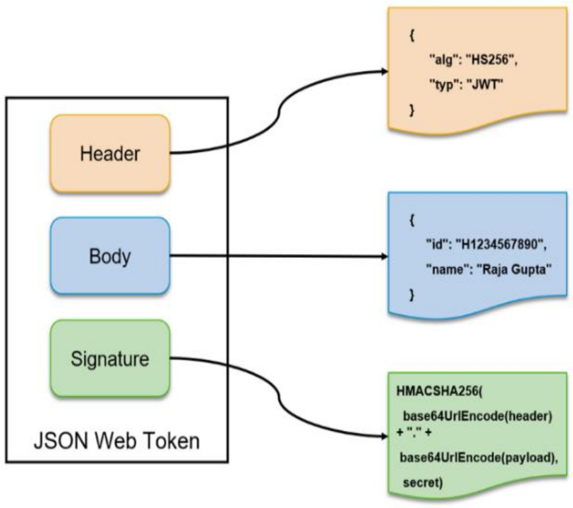


Fig. 3.6. JWT Architecture

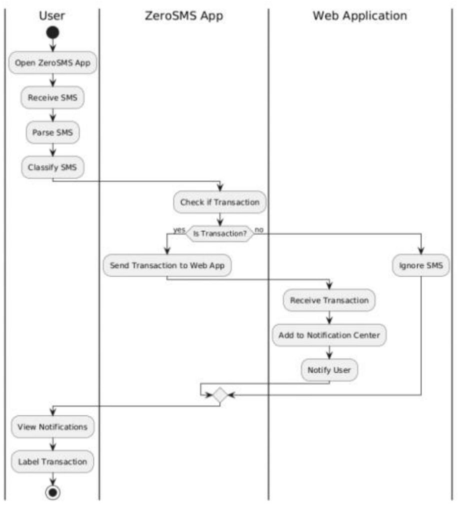


Fig. 3.7. Interaction between the Android App and Web App

3.4 SMS PARSING AND FRAUD DETECTION IN FINANCIAL TRANSACTIONS

The increasing reliance on digital financial transactions has highlighted the need for comprehensive expense management solutions that ensure users capture all transactions accurately. The ZeroSMS app addresses this challenge by parsing SMS messages related to financial transactions and classifying them as either transaction-related or non-transaction-related. This functionality not only helps users track their expenses more effectively but also mitigates the risk of overlooking minor transactions such as small purchases and pocket money. By integrating the ZeroSMS app with a web application, users can manage their finances in a centralized location while also ensuring that any missed transactions are flagged for review.

Once the SMS messages are parsed, the app identifies those that pertain to transactions and sends them to the web application, where they appear in a notification center. Users can then revisit these notifications to categorize the transactions as expenses, savings, or investments, and to provide additional information as needed. This approach enhances the accuracy of expense tracking and ensures that all relevant financial activities are recorded. As illustrated in Fig. 3.7, the workflow demonstrates how SMS parsing feeds into the user's expense management process, emphasizing the seamless integration between the mobile and web platforms.

3.4.1 ML Model for SMS Spam Detection

To further enhance the functionality of the ZeroSMS app, a Machine Learning (ML) model was developed to detect fraudulent transactions. The model was built using a combination of supervised learning techniques and ensemble methods, specifically leveraging algorithms such as Random Forest, Gradient Boosting, and Support Vector Machines (SVM). A diverse dataset comprising historical transaction data, including both legitimate and fraudulent transactions, was utilized to train the model. Feature engineering played a critical role in this process, where features such as transaction amount, frequency, and user behavior patterns were extracted from the data to improve classification accuracy.

Classifier Model	Accuracy
Naive Bayes	0.9784688995215312
Support Vector Machine (SVM)	0.9772727272727273
Logistic Regression	0.9778708133971292
Random Forest	0.9742822966507177
Gradient Boosting	0.9694976076555024

Table 3.1. Comparisons of Different classifiers based on Accuracy

The ML model underwent several phases of development, including data preprocessing, model training, and validation. During preprocessing, the data was cleaned and normalized, addressing any inconsistencies or missing values. A cross-validation technique was employed to evaluate the model's performance, ensuring that it generalized well to unseen data. After extensive testing, the model achieved an accuracy of over 96%, demonstrating its effectiveness in identifying potential fraud. As shown in Table 3.1, the performance metrics highlight the accuracy of different classifier models used, emphasizing its capability to minimize false positives and negatives in fraud detection.

The integration of this ML model within the ZeroSMS app allows for real-time monitoring of transactions, alerting users to any suspicious activities based on predefined thresholds and user behavior patterns. By continuously learning from new data, the model can adapt to evolving fraudulent strategies, ensuring that users are protected against financial fraud. Ultimately, the ZeroSMS app not only aids in managing expenses but also provides a robust layer of security against fraudulent transactions, enhancing users' overall financial management experience.

3.4.2 Enhancing App Security in React Native

To bolster the security of the React Native application, several libraries and techniques have been integrated. The JailMonkey and RootBeer libraries were utilized to detect if the application is running on a jailbroken or rooted device, which could pose security risks. Additionally, code obfuscation techniques were employed using obfuscator-io-metro-plugin and R8/ProGuard to make reverse engineering of the application more difficult. This obfuscation process modifies the application code to protect it from unauthorized access and manipulation, enhancing overall security.

3.5 POLICY ENFORCEMENT POINT FOR ROLE BASED ACCESS CONTROL

A Policy Enforcement Point (PEP) is a crucial component in enforcing security within web applications, especially in the context of a Zero Trust Architecture (ZTA). The PEP acts as a gatekeeper that intercepts all incoming requests before they reach the application's core services, ensuring that only authorized users or services gain access. When implemented in microservice based web applications, the PEP evaluates each request based on predefined security policies. These policies determine who can access which service and resources, at what time, and under what conditions. The PEP typically works alongside a Policy Decision Point (PDP), which makes the decision regarding access based on rules such as role-based access control (RBAC) or attribute-based access control (ABAC). Once a decision is made by the PDP, the PEP either grants or denies access.

In practical terms, the PEP is embedded at critical points within the microservice architecture, such as API gateways or middleware layers. Every incoming request to the service of application containers passes through the PEP, where it is authenticated, and authorization policies are applied. If the user or service is unauthorized or violates policies, the PEP blocks access. For an instance, in our application a, the PEP ensures that an auditor is allowed to access only the transactions and data related to their client. Also, the routes behind the services are restricted and are specific to the entities (user, admin, auditor) to access. It could also enforce least privilege access, allowing users or services to only perform the actions necessary for their role. Additionally, PEPs can be deployed as sidecar containers in microservices, ensuring that access controls are enforced at each service endpoint. This is especially important when services communicate internally within distributed environments. Overall, PEP strengthens security by ensuring consistent policy enforcement, providing granular access control, and mitigating potential attack vectors.

3.6 SECURE COMMUNICATION WITHIN THE KUBERNETES CLUSTERS USING mTLS

Mutual TLS (mTLS) is a foundational security mechanism in implementing Zero Trust Architecture (ZTA) for microservices. It provides robust authentication and encrypted communication between microservices by requiring both the client and server to present valid certificates, ensuring mutual trust before communication occurs. This mutual verification process is key to the “never trust, always verify” principle of ZTA.

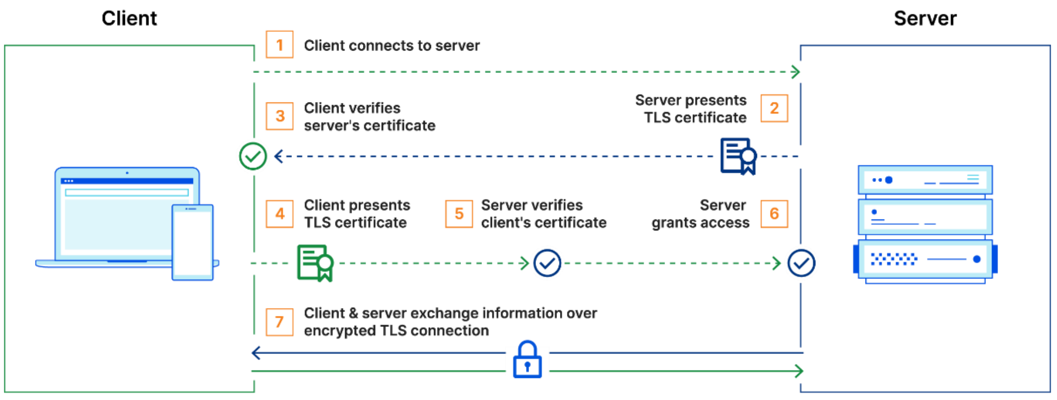

Client
Server
1 Client connects to server
2 Server presents TLS certificate
3 Client verifies server's certificate
4 Client presents TLS certificate
5 Server verifies client's certificate
6 Server grants access
7 Client & server exchange information over encrypted TLS connection

Fig. 3.8. Mutual Transport Layer Security (mTLS) Architecture

In mTLS, each pod in the cluster is assigned a unique cryptographic certificate issued by a trusted Certificate Authority (CA). When two services communicate, both sides (client and server) present their certificates during the handshake process. Each service verifies the other’s certificate against the CA’s public key to ensure authenticity. Once both certificates are validated, an encrypted communication channel is established using TLS (Transport Layer Security). This ensures that data exchanged between services is not only authenticated but also protected from eavesdropping and tampering. The architecture of mTLS is illustrated in Figure 3.8. mTLS is integrated into our application service meshes using a tool named Istio which automate certificate management and enforce mTLS at the network layer. In these environments, mTLS is applied transparently to microservices, without requiring each service to implement its own TLS logic. The service mesh handles certificate issuance, renewal, and rotation, ensuring seamless mTLS enforcement. Unlike traditional systems that assume trust once inside the network, mTLS requires that every interaction between services involves identity verification. This eliminates the risk of unauthorized services accessing resources, as only those with valid certificates are allowed to communicate. When combined with Policy Enforcement Points (PEPs), mTLS strengthens the overall ZTA. The PEP verifies that requests originate from authorized services with valid certificates before granting access to resources.

CHAPTER 4

SYSTEM DESIGN

In this section, we transition from theoretical concepts to practical implementation, detailing the system requirements, tools, and technical infrastructure used to develop, and deploy the web and mobile applications. Additionally, we outline the deployment process in both local and cloud environments using Docker and Kubernetes. This section highlights the real-world applicability of the project by focusing on development environments and deployment strategies.

4.1 SYSTEM REQUIREMENTS FOR DEVELOPMENT

This section outlines the software and hardware requirements necessary for building and running the web application frontend, Python backend API, and React Native mobile application. The application was developed on Windows 11 with the following system specifications:

- OS: Windows 11 10.0.22631 (64 bit)
- Processor: 11th Gen Intel(R) Core(TM) i7-11370H @ 3.30GHz
- Cores/Threads: 4 Cores, 8 Logical Processors
- Memory: minimum 8GB RAM
- Secondary Storage: minimum 128GB SSD or HDD

4.1.1 Web Application Frontend (React.js)

The frontend of the application is built using React.js, a popular JavaScript library for building user interfaces.

- Node.js Version: v20.11.0
- NPM Version: 10.8.1 or Yarn Version: 1.22.21
- React Version: 18.3.1

Other necessary tools for the frontend development include Webpack for bundling and Babel for transpiling JavaScript code.

4.1.2 Python Backend API

The backend API, which provides the necessary server-side logic for the application, is developed using Python.

- Python Version: 3.10.6 (> 3.10 preferred)

4.1.3 React Native Mobile Application

The mobile application is developed using React Native, enabling cross-platform compatibility for iOS and Android.

- React Native Version: 0.75.3
- Java Version: 17.0.8 (LTS)
- Gradle Version: 8.8
- Kotlin Version: 1.9.22
- Groovy Version: 3.0.21
- Ant Version: 1.10.13
- JVM: 17.0.8 (Oracle Corporation 17.0.8+9-LTS-211)

4.1.4 Tools Used

- Visual Studio Community 2022: Version 17.11.35327.3 for code editing and debugging
- Android Studio: Android Studio Koala Feature Drop | 2024.1.2 for mobile development and Android emulation

4.2 SYSTEM REQUIREMENTS FOR DEPLOYMENT IN DOCKER AND KUBERNETES

This section details the deployment strategy for the application in both local and cloud environments using Docker and Kubernetes. The hardware and software requirements for each environment, as well as the cloud services used for deployment are mentioned below:

4.2.1 Local Environment

For local development and testing, the system can be containerized using Docker and deployed with Minikube for Kubernetes orchestration. Below are the system requirements for local deployment.

- Operating System Requirements:

1. Windows: 8 and above (64-bit)
2. Linux: Debian or RedHat-based distributions
3. MacOS: Sequoia or later

- Software Requirements:
    1. Docker: Containerization platform
    2. Minikube: For Kubernetes local cluster
    3. Helm: Kubernetes package manager for managing applications
    4. K9s: Terminal-based UI to interact with Kubernetes clusters
- Hardware Requirements:
    1. Processor: Intel® Core™ i7-1165G7 (2.8 GHz up to 3.9 GHz) or AMD equivalent
    2. Memory: Minimum 8GB RAM
    3. Storage: Minimum 128GB SSD or HDD
    4. Network: 10-100 Mbps for downloading dependencies and containers

4.2.2 Cloud Environment

The cloud deployment leverages Amazon Web Services (AWS) to deploy the containerized application with Elastic Kubernetes Service (EKS) and other cloud-native services.

- Software Requirements for the Deployment System:
    1. AWS CLI: For interacting with AWS services
    2. Terraform: Infrastructure-as-code (IaC) tool for provisioning AWS resources
    3. Helm: To deploy Kubernetes resources on EKS
    4. K9s: For Kubernetes cluster management
- AWS Services Used:
    1. Elastic Compute Cloud (EC2): Virtual machines for running services
    2. Elastic Kubernetes Service (EKS): Managed Kubernetes service
    3. Virtual Private Cloud (VPC): For network isolation
    4. Identity and Access Management (IAM): For securing access to AWS services
    5. Elastic Load Balancing (ELB): For balancing incoming traffic across instances
    6. Lambda: For running serverless functions, if required
- Requirements for EKS Nodegroups:
    1. Operating System: Amazon Linux 2 or Ubuntu
    2. EC2 Instance Type: t3.large (2 vCPUs, 8GB RAM, 5 Gbps bandwidth)
    3. Storage: Minimum 50GB Elastic Block Store (EBS)

4.3 ARCHITECTURE OF THE DESIGN

The architecture of the system illustrated in the Fig 4.1 represents a secure transaction tracking and monitoring platform, integrating multiple components such as a mobile Android app, a web application, and a security module leveraging Zero Trust principles.

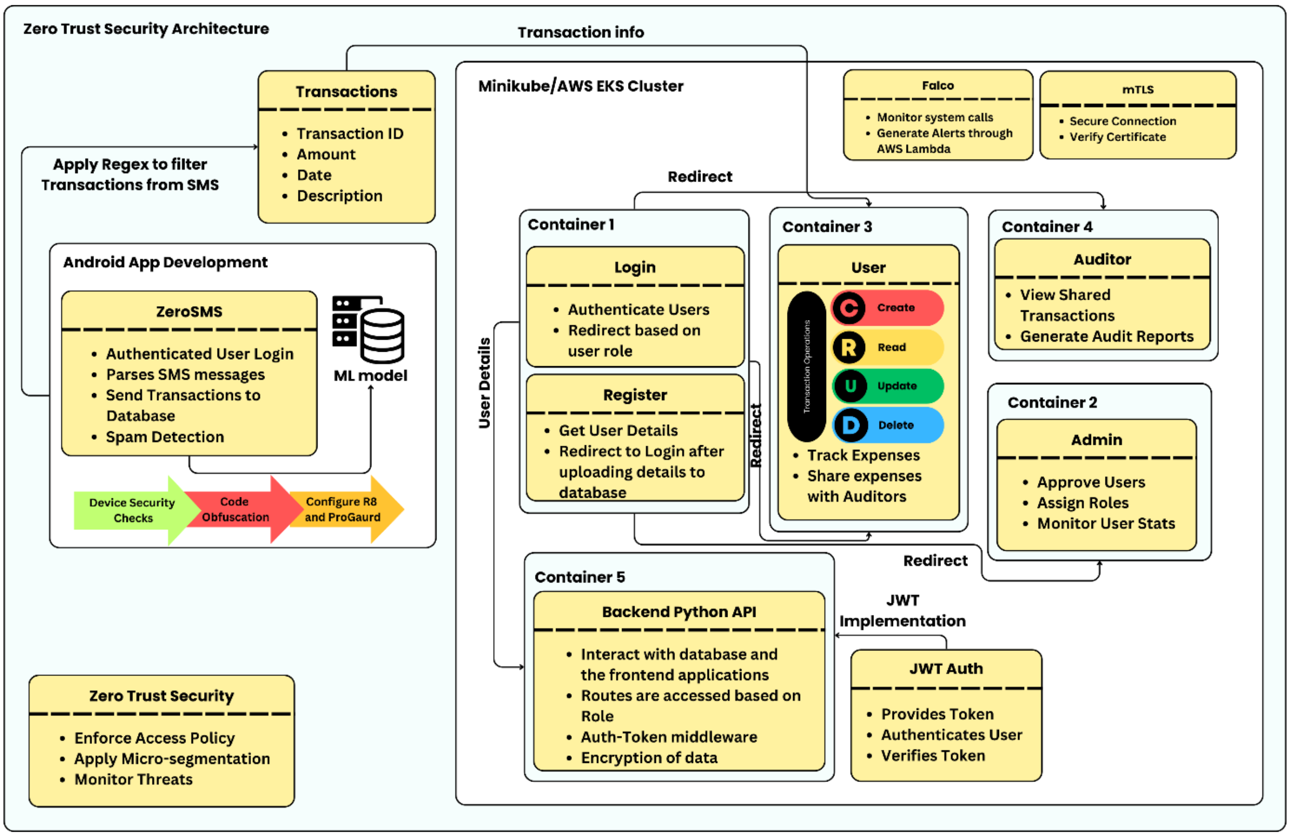


Fig. 4.1 Architecture design of the developed system

1. Android App: The AndroidApp class parses SMS data to extract transaction information, which is then sent to the WebApp for further processing. It also includes methods for user login and spam detection.
2. Web Application: The WebApp class acts as the central hub, managing users, transactions, and applying Zero Trust security policies. The app is responsible for adding transactions, retrieving transaction details for specific users, and applying security policies for authentication.
3. Authentication Layer: JWTAuth (JSON Web Token Authentication) is used to authenticate users and validate tokens during login and transaction operations. The authenticate() and verifyToken() methods ensure that only authorized users access the system.

4. mTLS (Mutual Transport Layer Security): Provides secure communication between the Android app, web app, and users by verifying certificates and securing connections. This ensures that data is encrypted and transmitted over secure channels.
5. Zero Trust Security: The ZeroTrustSecurity class continuously enforces security policies. This includes:
   - enforceAccessPolicy(): Ensures that only authorized users have access to sensitive data.
   - applyMicrosegmentation(): Implements microsegmentation to control network traffic and reduce lateral movement in case of a security breach.
   - monitorThreats(): Monitors potential security threats.
6. Admin, Auditor, and User Roles:
   - Admin: Manages users, approves new users, and views system statistics.
   - Auditor: Generates reports and views detailed transaction reports.
   - User: Can log in to the system, track expenses, and share transaction details with auditors if needed.

4.4 ATTRIBUTES OF THE INPUT DATA

The input data for this system primarily revolves around transaction details and user authentication. Here are the key attributes:

1. Transaction Data (Transaction Class):
   - transactionID (int): A unique identifier for each transaction.
   - amount (float): The monetary value of the transaction.
   - date (Date): The date when the transaction took place.
   - description (string): A brief description or note about the transaction.

Methods like getTransactionDetails() are used to retrieve transaction-specific information, essential for tracking and reporting purposes.

2. User Data (User Class):
   - userID (int): A unique identifier assigned to each user.
   - name (string): The full name of the user.
   - email (string): The email address used for authentication and communication.

The user class has methods like login() for accessing the system and trackExpenses() for viewing and managing personal transactions.

3. Authentication Tokens (JWTAuth Class):
    - token (string): A JWT token generated upon successful authentication. This token is used for session management and verifying the user’s identity across multiple requests.
4. Parsed SMS Data (AndroidApp Class):
    - transactionData (string): SMS content is parsed by the Android app to extract transaction information, which is then sent to the web application for processing.

4.5 ALGORITHM FOR ZERO TRUST ARCHITECTURE BEST PRACTICES

```
1: ZeroTrustArchitecture main
2: Initialize ()
3: if UserLogin then
4: user ← AuthenticateUser()
5: if user.authorized then EnforceLeastPrivilege(user)
6: else DenyAccess()
7: end if
8: end if
9: if RequestAccessToResource then
10:
11: if VerifyAccess(user) then LogAccess(user)
12: else DenyAccess()
13: end if
14: end if
15: if ManageContainers then
16: InitializeAndSecureKubernetes()
17: DeployContainersWithmTLS()
18: end if
19: if DockerizeApp then BuildDeployAndSecureApp()
20: end if
21: if MonitorActivity then AuditAndDetectThreats(user)
22: end if
23: end procedure
24: procedure AuthenticateUser
25: return ValidateCredentialsAndAssignRole()
26: end procedure
27: procedure VerifyAccess(user)
28: return ValidateTokenAndAccess(user)
29: end procedure
```

4.6 PROTOCOLS AND STANDARDS

The system incorporates several security protocols and standards to ensure the integrity, confidentiality, and authenticity of data exchanged within the application. By adopting well-established security measures, the system can defend against common cyber threats such as data breaches, man-in-the-middle attacks, and unauthorized access. These protocols are essential to maintaining a Zero Trust environment, where no entity is inherently trusted, and every access request must be verified.

4.6.1 JWT (JSON Web Tokens)

Used for authentication and token-based session management. JWT is a compact, URL-safe means of representing claims between two parties and is widely used for securing APIs and web applications. authenticate(user) and verifyToken(token) methods ensure secure, token-based access to the system, preventing unauthorized users from accessing sensitive transaction data.

4.6.2 mTLS (Mutual Transport Layer Security)

In a microservices architecture, mTLS is employed to ensure secure interservice communication. Since microservices communicate over APIs and can potentially expose sensitive data, mTLS adds an essential layer of encryption and mutual authentication, ensuring that only authorized services interact with each other. To implement mTLS, each microservice must possess a unique certificate issued by a trusted certificate authority (CA), which is verified during service communication. The process involves:

- Certificate Authority (CA): A central authority that issues certificates to each service, which can be internal or external.
- Service Meshes: Tools like Istio or Linkerd that simplify mTLS management in large microservices environments by handling certificate issuance, renewal, and validation.

Istio enhances security by integrating mTLS, ensuring encrypted and authenticated communication between services. Both client and server authenticate each other, protecting against threats like impersonation. Istiod, Istio's control plane, automates certificate management, issuing unique identities to each service, ensuring all traffic is encrypted and verified. Istio supports permissive and strict mTLS modes for gradual adoption. This approach aligns with Zero Trust principles, where no service is trusted by default. By using sidecar proxies like Envoy, Istio simplifies secure communication without requiring application-level changes. It also automates certificate rotation and revocation, providing effective encryption, authentication, and access controls in distributed microservices environments.

4.6.3 Policy Enforcement Point (PEP)

A Policy Enforcement Point (PEP) is a security component responsible for making real-time access control decisions. It evaluates whether an entity (user, device, or service) should be granted access to a resource based on predefined policies. PEPs intercept each request and validate it against a set of security policies, ensuring that only authorized entities can access protected resources. In microservices architectures, PEPs are crucial for controlling service-to-service interactions and external requests. PEPs enforce access policies at multiple levels, including API gateways, service meshes, and individual services, to ensure that only verified and authorized requests are processed.

4.6.4 Falco: Real-Time Security Monitoring

Falco is an open-source runtime security tool designed for microservices and containerized environments. It monitors system calls in real-time to detect abnormal behavior or potential threats. By intercepting system calls using eBPF, Falco analyzes actions like file access and process creation against a set of predefined security rules. When a rule is violated, it generates alerts and can trigger responses, such as blocking processes or notifying security teams. In microservices, Falco enhances security by continuously monitoring for unauthorized access, unexpected process launches, and unusual network activity, thus providing vital insights into runtime behavior and security posture.

4.6.5 Code Obfuscation

Code obfuscation is a crucial practice in protecting the intellectual property of an application, especially in mobile and web environments where the application code can be reverse-engineered. By obfuscating the code, the original source is transformed into a more complex, less understandable version, making it harder for attackers to reverse-engineer or exploit vulnerabilities.

- Proguard: Proguard is a popular open-source tool for Java and Android applications that performs a variety of optimization tasks, including shrinking, optimizing, and obfuscating the code. Proguard renames classes, fields, and methods with obscure names, making it difficult for attackers to understand the structure of the application.

- R8: R8 is the more modern successor to Proguard, specifically designed for Android development. R8 integrates more tightly with Android build systems and improves both obfuscation and performance optimization. In addition to shrinking and renaming, R8 removes unused code, making it leaner while providing more advanced optimization features than Proguard. One key advantage of R8 is its faster compilation times and more aggressive code shrinking, making it a preferred choice for Android developers today.

4.6.6 Root, Debug, and Developer Options Detection

To further enhance security, the system implements mechanisms to detect rooted devices, active debugging sessions, and whether developer options are enabled. These checks are essential for preventing attacks that rely on modifying the operating system or analyzing the application in a controlled debugging environment. Rooted devices allow users to bypass certain security controls, making it easier for attackers to access sensitive application data. JailMonkey is an open-source library used primarily in React Native applications to detect if a device has been rooted or compromised in other ways.

By leveraging these standards and protocols, the system ensures secure, authenticated, and reliable management of financial transactions, maintaining robust security through the Zero Trust framework.

CHAPTER 5

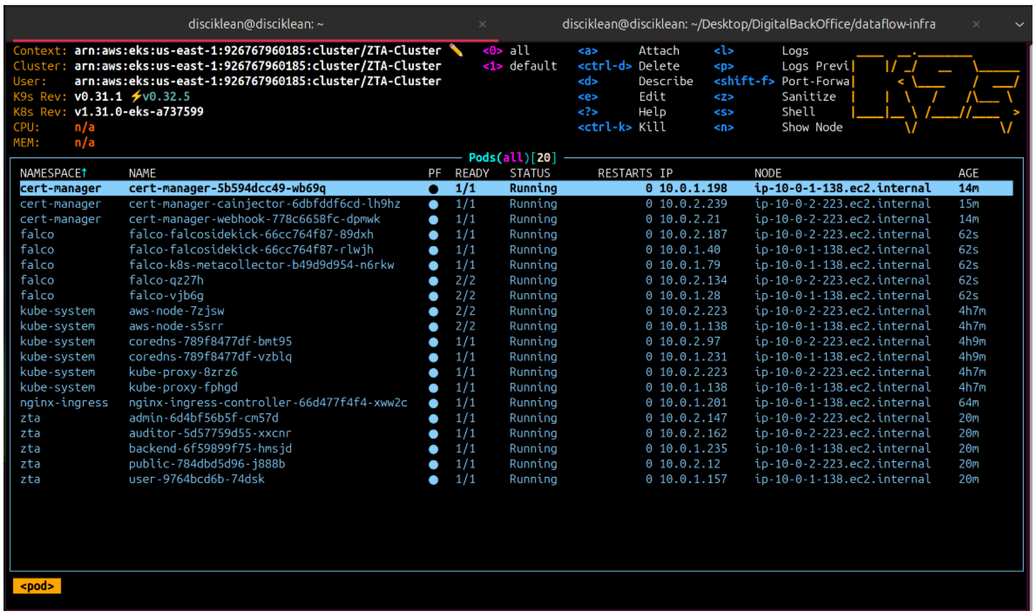
IMPLEMENTATION AND RESULT ANALYSIS

This chapter presents the real-time implementation and deployment of the web and Android applications, centered around Zero Trust security practices. It outlines the deployment of the web application on a Minikube cluster and subsequently on AWS EKS, along with the secure implementation of the Android app. Key security measures, including user access controls and data integrity protocols, are discussed to highlight the effectiveness of the proposed solutions in maintaining a secure environment.

5.1 REAL-TIME IMPLEMENTATION OF THE PROTOTYPE

5.1.1 Preparation of Environment in AWS

To prepare the environment for deploying the Zero Trust Architecture, Terraform was used as the Infrastructure as Code (IaC) tool to ensure consistent and automated provisioning of AWS resources. A dedicated Virtual Private Cloud (VPC) was created to host the Amazon EKS (Elastic Kubernetes Service) cluster with high availability and scalability. Similarly, AWS Lambda is configured with AWS CloudWatch to capture alerts from Falco and produce the logs. A Network Load Balancer is deployed along with Nginx-Ingress Controller to route internet traffic to the cluster. Identity, and Access Management (IAM) roles were defined was all the above configurations to enable secure communication and management of resources.



```
disciklean@disciklean: ~                    disciklean@disciklean: ~/Desktop/DigitalBackOffice/dataflow-infra

Context: arn:aws:eks:us-east-1:926767960185:cluster/ZTA-Cluster ✏️  <0> all      <a>      Attach    <l>       Logs        ____  __.________
Cluster: arn:aws:eks:us-east-1:926767960185:cluster/ZTA-Cluster     <1> default  <ctrl-d> Delete    <p>       Logs Previ|    |/ _/   __   \______
User:    arn:aws:eks:us-east-1:926767960185:cluster/ZTA-Cluster                  <d>      Describe  <shift-f> Port-Forwa|      < \____    /  ___/
K9s Rev: v0.31.1 ⚡v0.32.5                                                       <e>      Edit      <z>       Sanitize  |    |  \   /    /\___ \
K8s Rev: v1.31.0-eks-a737599                                                     <?>      Help      <s>       Shell     |____|__ \ /____//____  >
CPU:     n/a                                                                     <ctrl-k> Kill      <n>       Show Node         \/            \/
MEM:     n/a
                                                          Pods(all)[20]
 NAMESPACE↑     NAME                                      PF  READY  STATUS      RESTARTS IP           NODE                          AGE
 cert-manager   cert-manager-5b594dcc49-wb69q             ●   1/1    Running            0 10.0.1.198   ip-10-0-1-138.ec2.internal    14m
 cert-manager   cert-manager-cainjector-6dbfddf6cd-lh9hz  ●   1/1    Running            0 10.0.2.239   ip-10-0-2-223.ec2.internal    15m
 cert-manager   cert-manager-webhook-778c6658fc-dpmwk     ●   1/1    Running            0 10.0.2.21    ip-10-0-2-223.ec2.internal    14m
 falco          falco-falcosidekick-66cc764f87-89dxh      ●   1/1    Running            0 10.0.2.187   ip-10-0-2-223.ec2.internal    62s
 falco          falco-falcosidekick-66cc764f87-rlwjh      ●   1/1    Running            0 10.0.1.40    ip-10-0-1-138.ec2.internal    62s
 falco          falco-k8s-metacollector-b49d9d954-n6rkw   ●   1/1    Running            0 10.0.1.79    ip-10-0-1-138.ec2.internal    62s
 falco          falco-qz27h                               ●   2/2    Running            0 10.0.2.134   ip-10-0-2-223.ec2.internal    62s
 falco          falco-vjb6g                               ●   2/2    Running            0 10.0.1.28    ip-10-0-1-138.ec2.internal    62s
 kube-system    aws-node-7zjsw                            ●   2/2    Running            0 10.0.2.223   ip-10-0-2-223.ec2.internal    4h7m
 kube-system    aws-node-s5srr                            ●   2/2    Running            0 10.0.1.138   ip-10-0-1-138.ec2.internal    4h7m
 kube-system    coredns-789f8477df-bmt95                  ●   1/1    Running            0 10.0.2.97    ip-10-0-2-223.ec2.internal    4h9m
 kube-system    coredns-789f8477df-vzblq                  ●   1/1    Running            0 10.0.1.231   ip-10-0-1-138.ec2.internal    4h9m
 kube-system    kube-proxy-8zrz6                          ●   1/1    Running            0 10.0.2.223   ip-10-0-2-223.ec2.internal    4h7m
 kube-system    kube-proxy-fphgd                          ●   1/1    Running            0 10.0.1.138   ip-10-0-1-138.ec2.internal    4h7m
 nginx-ingress  nginx-ingress-controller-66d477f4f4-xww2c ●   1/1    Running            0 10.0.1.201   ip-10-0-1-138.ec2.internal    64m
 zta            admin-6d4bf56b5f-cm57d                    ●   1/1    Running            0 10.0.2.147   ip-10-0-2-223.ec2.internal    20m
 zta            auditor-5d57759d55-xxcnr                  ●   1/1    Running            0 10.0.2.162   ip-10-0-2-223.ec2.internal    20m
 zta            backend-6f59899f75-hmsjd                  ●   1/1    Running            0 10.0.1.235   ip-10-0-1-138.ec2.internal    20m
 zta            public-784dbd5d96-j888b                   ●   1/1    Running            0 10.0.2.12    ip-10-0-2-223.ec2.internal    20m
 zta            user-9764bcd6b-74dsk                      ●   1/1    Running            0 10.0.1.157   ip-10-0-1-138.ec2.internal    20m

<pod>
```

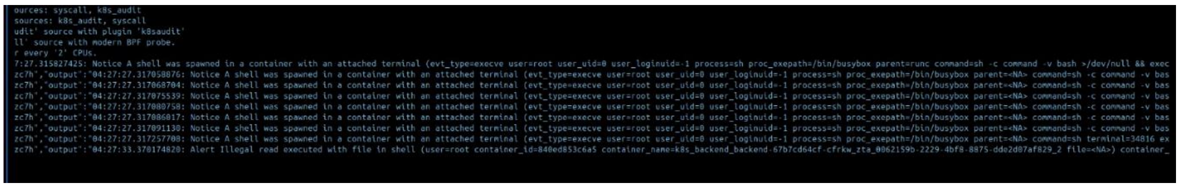
Fig 5.1. List of pods running in the EKS cluster

5.1.2 Deployment of Web Application to EKS Cluster

The web application was containerized and deployed using Kubernetes manifests and a Helm chart. Docker images were created for each component of the application, defining the necessary environment and dependencies. Helm chart was used to manage the deployment of the web application to the EKS cluster. Each component of the application was deployed under their own prefix which is seamlessly managed by ingress controller deployed along with the application. HTTPS protocol was enforced to ensure secure communication between the users and application. Figure 5.1. showcases the pods of Web Application and Falco tool running in EKS cluster.

5.1.3 Deployment of Falco to EKS Cluster

Falco, a cloud-native runtime security tool, was deployed to monitor container activity and detect any anomalous behavior. It was deployed as a DaemonSet in Kubernetes, ensuring that each node in the EKS cluster had Falco instance running for comprehensive monitoring. Custom policy rules were defined to restrict the expected behavior of the containers. Any deviation from these policies. As illustrated in the Figure 5.2. the logs will be given as standard output and also will be exported to AWS cloud watch when any rules defined in Falco gets violated which improves the Zero trust of resources deployed in the cluster.

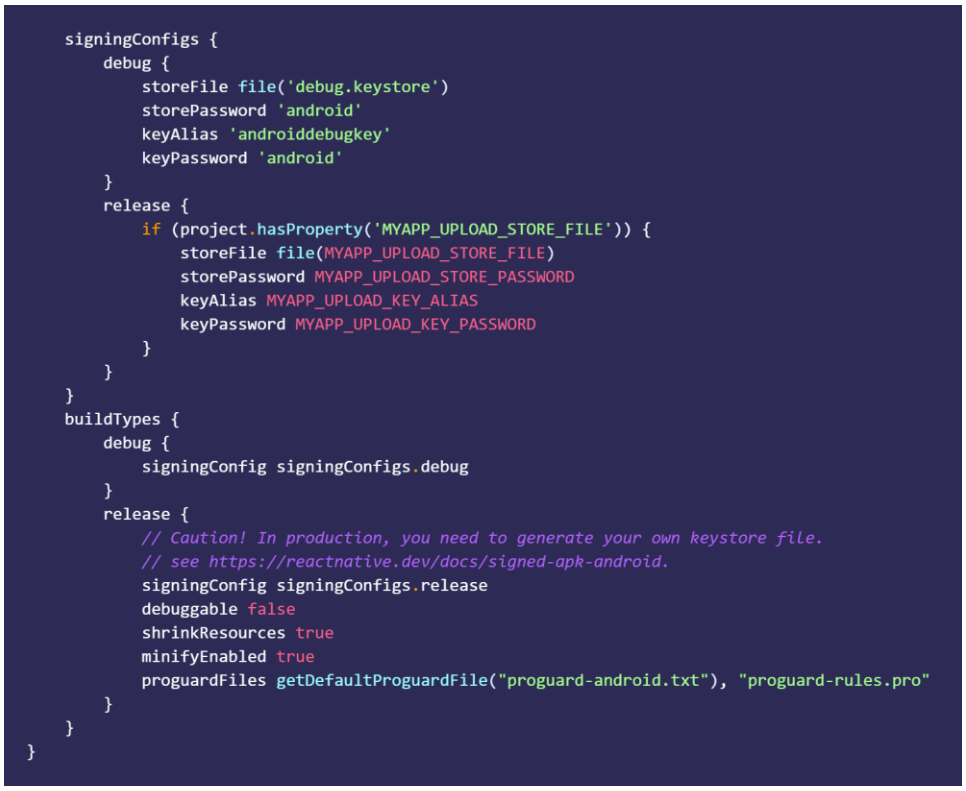


```
ources: syscall, k8s_audit
sources: k8s_audit, syscall
udit' source with plugin 'k8saudit'
ll' source with modern BPF probe.
r every '2' CPUs.
7:27.315827425: Notice A shell was spawned in a container with an attached terminal (evt_type=execve user=root user_uid=0 user_loginuid=-1 process=sh proc_exepath=/bin/busybox parent=runc command=sh -c command -v bash >/dev/null && exec
zc7h","output":"04:27:27.317058876: Notice A shell was spawned in a container with an attached terminal (evt_type=execve user=root user_uid=0 user_loginuid=-1 process=sh proc_exepath=/bin/busybox parent=<NA> command=sh -c command -v bas
zc7h","output":"04:27:27.317068704: Notice A shell was spawned in a container with an attached terminal (evt_type=execve user=root user_uid=0 user_loginuid=-1 process=sh proc_exepath=/bin/busybox parent=<NA> command=sh -c command -v bas
zc7h","output":"04:27:27.317075539: Notice A shell was spawned in a container with an attached terminal (evt_type=execve user=root user_uid=0 user_loginuid=-1 process=sh proc_exepath=/bin/busybox parent=<NA> command=sh -c command -v bas
zc7h","output":"04:27:27.317080758: Notice A shell was spawned in a container with an attached terminal (evt_type=execve user=root user_uid=0 user_loginuid=-1 process=sh proc_exepath=/bin/busybox parent=<NA> command=sh -c command -v bas
zc7h","output":"04:27:27.317086017: Notice A shell was spawned in a container with an attached terminal (evt_type=execve user=root user_uid=0 user_loginuid=-1 process=sh proc_exepath=/bin/busybox parent=<NA> command=sh -c command -v bas
zc7h","output":"04:27:27.317091130: Notice A shell was spawned in a container with an attached terminal (evt_type=execve user=root user_uid=0 user_loginuid=-1 process=sh proc_exepath=/bin/busybox parent=<NA> command=sh -c command -v bas
zc7h","output":"04:27:27.317257708: Notice A shell was spawned in a container with an attached terminal (evt_type=execve user=root user_uid=0 user_loginuid=-1 process=sh proc_exepath=/bin/busybox parent=<NA> command=sh terminal=34816 ex
zc7h","output":"04:27:33.370174820: Alert Illegal read executed with file in shell (user=root container_id=840ed853c6a5 container_name=k8s_backend_backend-67b7cd64cf-cfrkw_zta_0062159b-2229-4bf8-8875-dde2d07af829_2 file=<NA>) container_
```

Fig 5.2. Logs as given by Flaco when shell is accessed inside a container

5.2 IMPLEMENTING PRODUCTION BUILD FOR THE ANDROID APP

The zeroSMS app is designed as a robust security application focused on protecting sensitive information through secure messaging. Its development process involves implementing effective measures to detect rooting and developer options, particularly using JailMonkey, a library that helps identify whether the device is compromised or running in an unsafe environment. By leveraging JailMonkey's capabilities, the app can ensure that it operates only on secure devices, providing users with confidence in the integrity of their communications.



```
    signingConfigs {
        debug {
            storeFile file('debug.keystore')
            storePassword 'android'
            keyAlias 'androiddebugkey'
            keyPassword 'android'
        }
        release {
            if (project.hasProperty('MYAPP_UPLOAD_STORE_FILE')) {
                storeFile file(MYAPP_UPLOAD_STORE_FILE)
                storePassword MYAPP_UPLOAD_STORE_PASSWORD
                keyAlias MYAPP_UPLOAD_KEY_ALIAS
                keyPassword MYAPP_UPLOAD_KEY_PASSWORD
            }
        }
    }
    buildTypes {
        debug {
            signingConfig signingConfigs.debug
        }
        release {
            // Caution! In production, you need to generate your own keystore file.
            // see https://reactnative.dev/docs/signed-apk-android.
            signingConfig signingConfigs.release
            debuggable false
            shrinkResources true
            minifyEnabled true
            proguardFiles getDefaultProguardFile("proguard-android.txt"), "proguard-rules.pro"
        }
    }
}
```

Fig 5.3. Configuring production release with keystore for secure signing and code obfuscation

To prepare the zeroSMS app for production release, enabling code optimization and obfuscation is essential. This is achieved by configuring the R8 and ProGuard tools within the Android build system. As shown in figure 5.3, By setting minifyEnabled to true in the build.gradle file, R8 is instructed to remove unused code, resources, and perform obfuscation, thereby enhancing the app’s performance and security. Additionally, the app is configured to use a secure keystore for signing the APK, ensuring that only authorized releases are distributed. This involves generating a private signing key with the keytool command and placing the keystore file in the appropriate directory. Finally, the command “./gradlew assembleRelease” is executed to build the APK, applying all the specified configurations, thus resulting in a secure and optimized release version of the zeroSMS app.

5.3 ML MODEL FOR SPAM DETECTION

The zeroSMS app is designed to streamline SMS management, particularly for transaction-related messages that help users track their finances. It automatically sends important transaction notifications to a secure database for easy reference. However, spam messages can clutter the inbox, making it difficult for users to identify essential information. To address this issue, incorporating spam detection capabilities became crucial, ensuring that users can focus on legitimate messages and enhancing the app's overall usability.

5.3.1 Dataset

The SMS Spam Collection dataset, accessible on Kaggle, consists of 5,574 tagged SMS messages in English, providing a robust foundation for SMS spam detection research. Each entry in the dataset is structured with two columns: the first column (v1) indicates the label, categorizing the message as either "ham" (legitimate) or "spam," while the second column (v2) contains the raw text of the message. This dataset is compiled from various reputable sources, including 425 spam messages manually extracted from the Grumbletext website, a UK forum dedicated to reporting SMS spam. Additionally, it includes 3,375 randomly selected ham messages from the NUS SMS Corpus, which were collected from volunteers at the National University of Singapore. Other contributions to the dataset consist of 450 ham messages from a PhD thesis and 1,002 ham messages along with 322 spam messages from the SMS Spam Corpus v.0.1 Big. Dataset for reference: https://rb.gy/7vbfxx

5.3.2 Preprocessing

The preprocessing stage is crucial for preparing the SMS messages for effective spam detection. Initially, the dataset is imported using the Pandas library and loaded into a DataFrame. Unnecessary columns are then dropped to streamline the dataset, retaining only the relevant columns: 'category' and 'msg.' Subsequently, the 'category' column is transformed into a binary format, creating a new column 'spam,' where messages categorized as "spam" are assigned a value of 1, and "ham" messages are assigned a value of 0.

To facilitate the conversion of text messages into a format suitable for machine learning models, the CountVectorizer from the Scikit-learn library is employed. This tool transforms the text data into a matrix of token counts. The features (X) and labels (y) are extracted from the DataFrame, with X representing the transformed message data and y representing the corresponding binary labels. Finally, the dataset is split into training and testing sets using the train_test_split function, with 70% of the data allocated for training and 30% for testing. This structured approach ensures that the model is trained on a representative sample of the data, allowing for effective evaluation and performance assessment.

5.4 MODELS USED FOR TRAINING

Various machine learning models were employed to enhance the performance of the spam detection system. These models, including Naive Bayes, Support Vector Machine (SVM), Logistic Regression, Random Forest, and Gradient Boosting, were chosen for their diverse strengths in handling classification tasks, particularly with high-dimensional and complex datasets. By leveraging both simple and advanced algorithms, the models offer a balance between computational efficiency and predictive accuracy, making them well-suited for the spam detection problem. Each model's unique characteristics are explored in the following sections.

5.4.1 Naive Bayes

The Naive Bayes classifier, specifically the Multinomial Naive Bayes variant, is a probabilistic model based on Bayes' theorem. It is particularly effective for text classification tasks, such as spam detection, due to its assumption of feature independence given the class label. This model computes the probability of each class based on the features extracted from the SMS messages, making it computationally efficient and easy to implement. Its simplicity and effectiveness in handling high-dimensional data contribute to its popularity in natural language processing tasks.

5.4.2 Support Vector Machine (SVM)

The Support Vector Machine (SVM) algorithm is a powerful supervised learning model used for classification and regression tasks. By finding the optimal hyperplane that maximizes the margin between different classes, SVM effectively classifies data points. In this project, the SVM is configured with probability=True to enable probability estimates, which are essential for calculating metrics like the ROC AUC score. SVM's ability to handle non-linear relationships through the use of kernel functions makes it a versatile choice for various datasets, including text data.

5.4.3 Logistic Regression

Logistic Regression is a linear model used for binary classification tasks. It estimates the probability that a given input belongs to a specific class based on the logistic function. In this project, the model is configured with a maximum of 1000 iterations to ensure convergence. Despite its simplicity, logistic regression can perform surprisingly well on text classification tasks, especially when the relationship between the features and the target variable is approximately linear. Its interpretability and ease of use make it a common choice for classification problems.

5.4.4 Random Forest

Random Forest is an ensemble learning method that constructs multiple decision trees during training and merges their outputs for improved accuracy and robustness. This model mitigates the risk of overfitting, which is a common issue in decision tree algorithms. By averaging the predictions of various trees, Random Forest enhances classification performance and provides a more generalized solution. Its ability to handle large datasets with numerous features makes it particularly suitable for spam detection tasks, where the input space can be quite extensive.

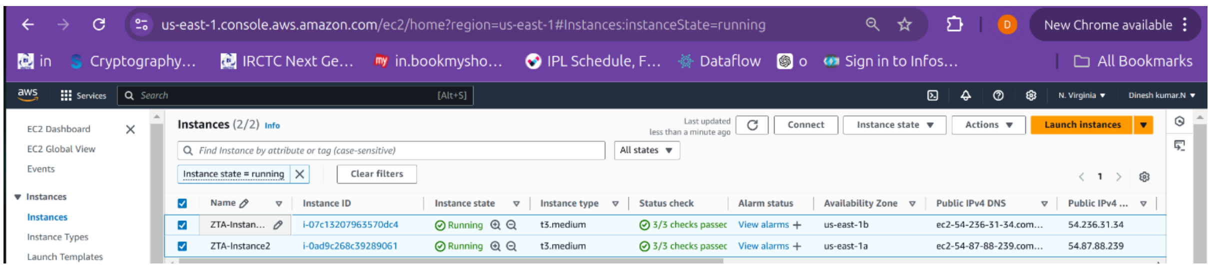
5.4.5 Gradient Boosting

Gradient Boosting is another ensemble learning technique that builds models sequentially, where each new model corrects the errors made by the previous ones. This method creates a strong predictive model by combining multiple weak learners, usually decision trees. The Gradient Boosting Classifier in this project leverages this approach to improve accuracy and handle complex relationships within the data. It is particularly effective for tasks like spam detection, as it can capture intricate patterns in the dataset, leading to enhanced classification performance.

5.5 RESULT ANALYSIS

This section highlights the effectiveness of the security measures pertaining to code obfuscation, permission management, and real-time threat detection deployed across both platforms. For the web application, the analysis focuses on the successful deployment within an EKS cluster, featuring AWS EC2 instances for both the frontend and backend. Performance metrics such as session logs and security alerts triggered by AWS Lambda with Falco showcase the system's robustness and resilience against vulnerabilities.

5.5.1 Web Application Deployment in EKS Cluster


us-east-1.console.aws.amazon.com/ec2/home?region=us-east-1#Instances:instanceState=running

Instances (2/2) Info

Last updated less than a minute ago

Find Instance by attribute or tag (case-sensitive)

All states

Instance state = running

Name	Instance ID	Instance state	Instance type	Status check	Alarm status	Availability Zone	Public IPv4 DNS	Public IPv4 ...
ZTA-Instan...	i-07c13207963570dc4	Running	t3.medium	3/3 checks passec	View alarms	us-east-1b	ec2-54-236-31-34.com...	54.236.31.34
ZTA-Instance2	i-0ad9c268c39289061	Running	t3.medium	3/3 checks passec	View alarms	us-east-1a	ec2-54-87-88-239.com...	54.87.88.239

Fig 5.4. Node Groups of EKS Cluster deployed as EC2 instances

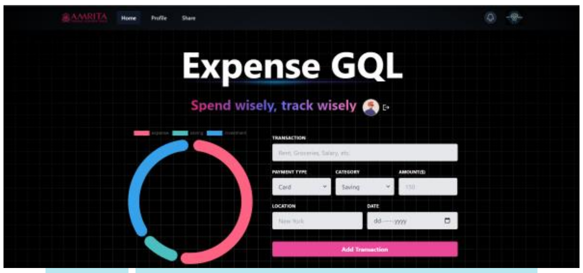
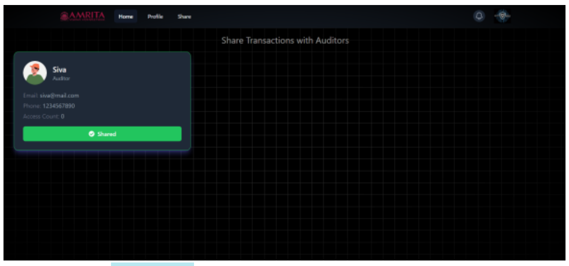


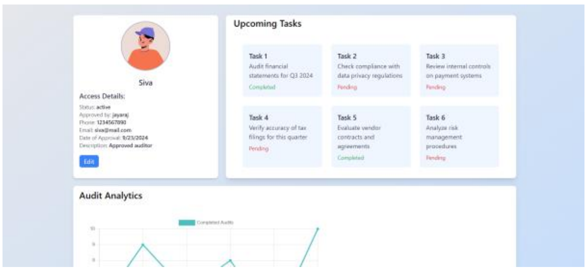
Fig 5.5. User dashboard for CRUD operations



Share Transactions with Auditors

Siva
Auditor
Email: siva@mail.com
Phone: 1234567890
Access Count: 0

Fig 5.6. Share data with auditors



Siva

Access Details:
Status: active
Approved by: jayaraj
Phone: 1234567890
Email: siva@mail.com
Date of Approval: 9/23/2024
Description: Approved auditor

Upcoming Tasks

Task 1
Audit financial statements for Q3 2024
Completed

Task 2
Check compliance with data privacy regulations
Pending

Task 3
Review internal controls on payment systems
Pending

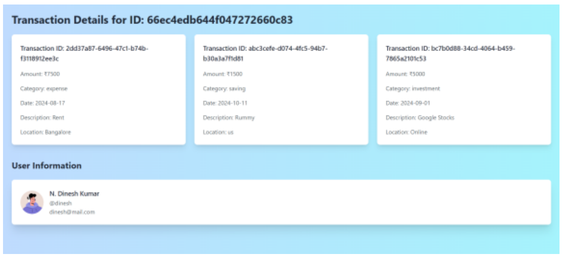
Task 4
Verify accuracy of tax filings for this quarter
Pending

Task 5
Evaluate vendor contracts and agreements
Completed

Task 6
Analyze risk management procedures
Pending

Audit Analytics

Fig 5.7. Auditor dashboard with tasks



Transaction Details for ID: 66ec4edb644f047272660c83

Transaction ID: 2dd37a87-6496-47c1-b74b-f3118912ee3c
Amount: ₹7500
Category: expense
Date: 2024-08-17
Description: Rent
Location: Bangalore

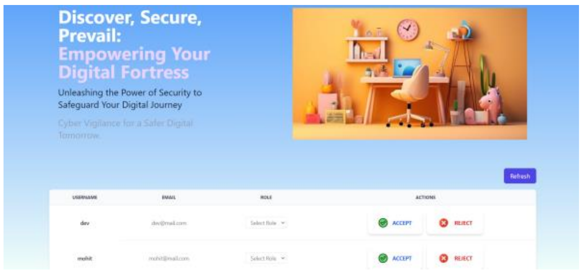
Transaction ID: abc3cefe-d074-4fc5-94b7-b30a3a7f1d81
Amount: ₹1500
Category: saving
Date: 2024-10-11
Description: Rummy
Location: us

Transaction ID: bc7b0d88-34cd-4064-b459-7865a2101c53
Amount: ₹5000
Category: investment
Date: 2024-09-01
Description: Google Stocks
Location: Online

User Information

N. Dinesh Kumar
@dinesh
dinesh@mail.com

Fig 5.8. Auditor's read-only view of transactions


Discover, Secure, Prevail:
Empowering Your Digital Fortress
Unleashing the Power of Security to Safeguard Your Digital Journey
Cyber Vigilance for a Safer Digital Tomorrow.
Refresh

USERNAME	EMAIL	ROLE	ACTIONS
dev	dev@mail.com	Select Role	ACCEPT REJECT
mohit	mohit@mail.com	Select Role	ACCEPT REJECT

Fig 5.9. Admin dashboard for assigning roles

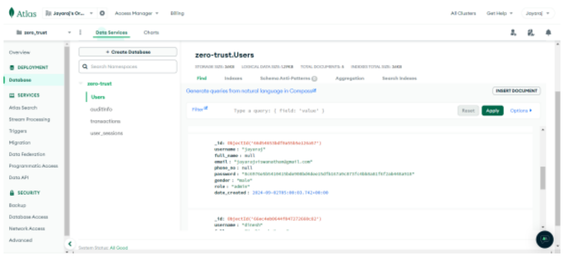
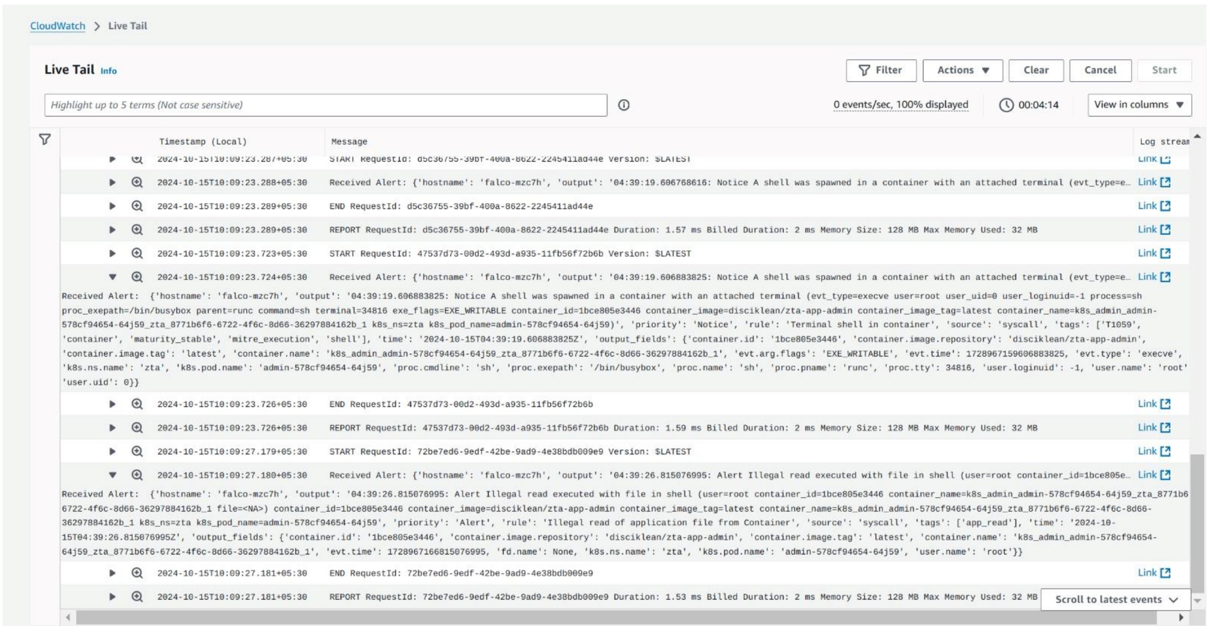


Fig 5.10. Database Collections

The web application was deployed in an EKS cluster, utilizing node groups belonging to the EKS Cluster. As illustrated in Figure 5.4, the architecture ensures scalability and fault tolerance, with seamless communication between services for a smooth user experience. The user dashboard enables CRUD operations, allowing users to manage data securely, as illustrated in Figure 5.5. Data sharing with auditors is seamlessly integrated, ensuring selective access to sensitive information, as shown in Figure 5.6. The auditor dashboard provides a clear overview of tasks, and auditors have read-only access to transactions, as depicted in Figures 5.7 and 5.8. The admin dashboard facilitates dynamic role assignment and access control, as illustrated in Figure 5.9. Additionally, the database collections efficiently store role-based access and transaction data, as shown in Figure 5.10.

Security within the application is strengthened through AWS Lambda and the Falco tool, which monitors the cluster for anomalies and triggers alerts for real-time threat detection, as illustrated in Figure 5.11. Fig. 5.11 showcases the alerts from Lambda as logs captured in AWS Cloudwatch. These logs contain valuable information such as the violated rule, container name, container ID, pod name, and namespace where the attack occurred, along with the system call used to perform the attack. This collective data emphasizes the implementation of the Zero Trust strategy and aids in identifying the root cause of suspicious activity. Additionally, session logs provide a thorough audit trail, tracking user activities and identifying suspicious behavior, as shown in Table 5.1. These logs ensure compliance with Zero Trust principles by ensuring all user actions are continuously monitored and recorded.



```
Timestamp (Local)              Message                                                                                                                                  Log stream
2024-10-15T10:09:23.287+05:30  START RequestId: d5c36755-39bf-400a-8622-2245411ad44e Version: $LATEST                                                                   Link
2024-10-15T10:09:23.288+05:30  Received Alert: {'hostname': 'falco-mzc7h', 'output': '04:39:19.606768616: Notice A shell was spawned in a container with an attached terminal (evt_type=e…  Link
2024-10-15T10:09:23.289+05:30  END RequestId: d5c36755-39bf-400a-8622-2245411ad44e                                                                                      Link
2024-10-15T10:09:23.289+05:30  REPORT RequestId: d5c36755-39bf-400a-8622-2245411ad44e Duration: 1.57 ms Billed Duration: 2 ms Memory Size: 128 MB Max Memory Used: 32 MB  Link
2024-10-15T10:09:23.723+05:30  START RequestId: 47537d73-00d2-493d-a935-11fb56f72b6b Version: $LATEST                                                                   Link
2024-10-15T10:09:23.724+05:30  Received Alert: {'hostname': 'falco-mzc7h', 'output': '04:39:19.606883825: Notice A shell was spawned in a container with an attached terminal (evt_type=e…  Link
Received Alert:  {'hostname': 'falco-mzc7h', 'output': '04:39:19.606883825: Notice A shell was spawned in a container with an attached terminal (evt_type=execve user=root user_uid=0 user_loginuid=-1 process=sh
proc_exepath=/bin/busybox parent=runc command=sh terminal=34816 exe_flags=EXE_WRITABLE container_id=1bce805e3446 container_image=disciklean/zta-app-admin container_image_tag=latest container_name=k8s_admin_admin-
578cf94654-64j59_zta_8771b6f6-6722-4f6c-8d66-36297884162b_1 k8s_ns=zta k8s_pod_name=admin-578cf94654-64j59)', 'priority': 'Notice', 'rule': 'Terminal shell in container', 'source': 'syscall', 'tags': ['T1059',
'container', 'maturity_stable', 'mitre_execution', 'shell'], 'time': '2024-10-15T04:39:19.606883825Z', 'output_fields': {'container.id': '1bce805e3446', 'container.image.repository': 'disciklean/zta-app-admin',
'container.image.tag': 'latest', 'container.name': 'k8s_admin_admin-578cf94654-64j59_zta_8771b6f6-6722-4f6c-8d66-36297884162b_1', 'evt.arg.flags': 'EXE_WRITABLE', 'evt.time': 1728967159606883825, 'evt.type': 'execve',
'k8s.ns.name': 'zta', 'k8s.pod.name': 'admin-578cf94654-64j59', 'proc.cmdline': 'sh', 'proc.exepath': '/bin/busybox', 'proc.name': 'sh', 'proc.pname': 'runc', 'proc.tty': 34816, 'user.loginuid': -1, 'user.name': 'root'
'user.uid': 0}}
2024-10-15T10:09:23.726+05:30  END RequestId: 47537d73-00d2-493d-a935-11fb56f72b6b                                                                                      Link
2024-10-15T10:09:23.726+05:30  REPORT RequestId: 47537d73-00d2-493d-a935-11fb56f72b6b Duration: 1.59 ms Billed Duration: 2 ms Memory Size: 128 MB Max Memory Used: 32 MB  Link
2024-10-15T10:09:27.179+05:30  START RequestId: 72be7ed6-9edf-42be-9ad9-4e38bdb009e9 Version: $LATEST                                                                   Link
2024-10-15T10:09:27.180+05:30  Received Alert: {'hostname': 'falco-mzc7h', 'output': '04:39:26.815076995: Alert Illegal read executed with file in shell (user=root container_id=1bce805e…  Link
Received Alert:  {'hostname': 'falco-mzc7h', 'output': '04:39:26.815076995: Alert Illegal read executed with file in shell (user=root container_id=1bce805e3446 container_name=k8s_admin_admin-578cf94654-64j59_zta_8771b6
6722-4f6c-8d66-36297884162b_1 file=<NA>) container_id=1bce805e3446 container_image=disciklean/zta-app-admin container_image_tag=latest container_name=k8s_admin_admin-578cf94654-64j59_zta_8771b6f6-6722-4f6c-8d66-
36297884162b_1 k8s_ns=zta k8s_pod_name=admin-578cf94654-64j59', 'priority': 'Alert', 'rule': 'Illegal read of application file from Container', 'source': 'syscall', 'tags': ['app_read'], 'time': '2024-10-
15T04:39:26.815076995Z', 'output_fields': {'container.id': '1bce805e3446', 'container.image.repository': 'disciklean/zta-app-admin', 'container.image.tag': 'latest', 'container.name': 'k8s_admin_admin-578cf94654-
64j59_zta_8771b6f6-6722-4f6c-8d66-36297884162b_1', 'evt.time': 1728967166815076995, 'fd.name': None, 'k8s.ns.name': 'zta', 'k8s.pod.name': 'admin-578cf94654-64j59', 'user.name': 'root'}}
2024-10-15T10:09:27.181+05:30  END RequestId: 72be7ed6-9edf-42be-9ad9-4e38bdb009e9                                                                                      Link
2024-10-15T10:09:27.181+05:30  REPORT RequestId: 72be7ed6-9edf-42be-9ad9-4e38bdb009e9 Duration: 1.53 ms Billed Duration: 2 ms Memory Size: 128 MB Max Memory Used: 32 MB
```

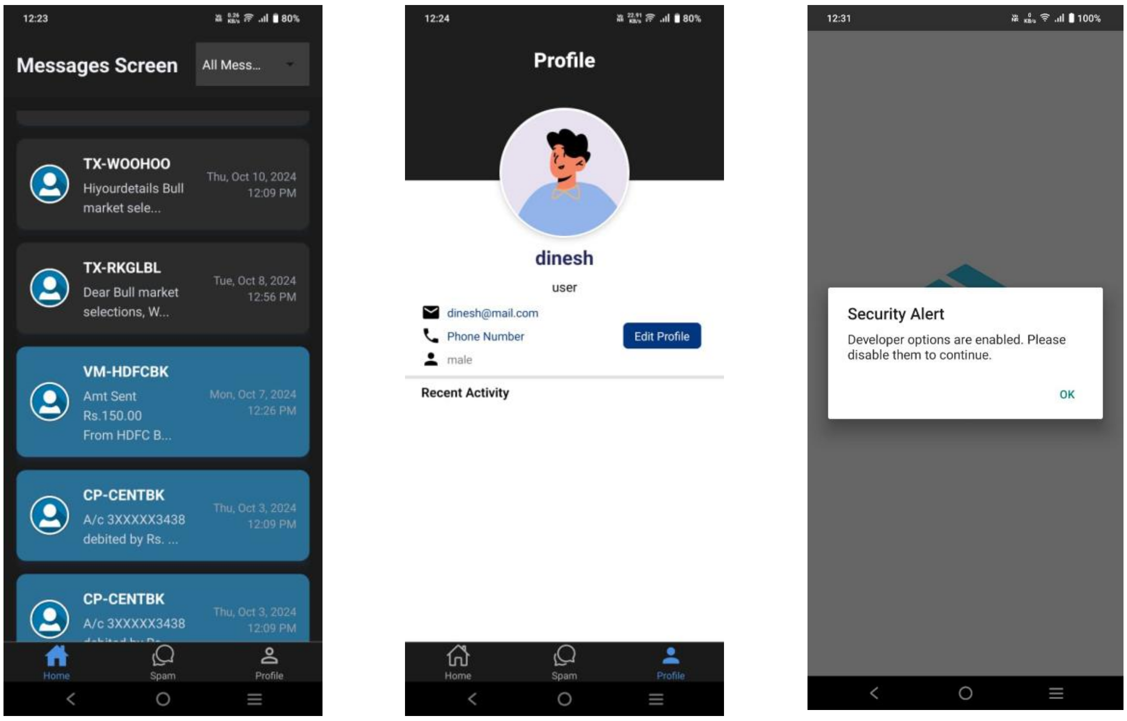
Fig 5.11. AWS Lambda Alerts triggered by Falco tool deployed in the cluster

Field	**User 1**	**User 2**	**User 3**
_id	66e9072851dcced0a150dbe0	66e936584582a105b70ee0a9	66f1340bafc75d1c676baebe
user_id	66d54653bdf0a55b5e126a57	66e934f44582a105b70ee0a8	66f133e9afc75d1c676baebb
username	jayaraj	dinesh	siva
role	admin	user	auditor
sessions	1	1	1
Date	17-09-24	03-10-24	23-09-24
Login Time	2024-09-17T04:35:52.286+00:00	2024-10-03T07:57:12.037+00:00	2024-09-23T09:25:30.920+00:00

Table 5.1 Session logs for logged in users

5.5.2 Android Application Production Build Results

The Android application was developed with comprehensive security measures in place, as illustrated in Figure 5.3, which shows an alert dialog indicating that developer options are enabled. Additionally, the application includes safeguards to prevent screenshots during the login process, further enhancing its security protocols.



TX-WOOHOO
Hiyourdetails Bull market sele...
Thu, Oct 10, 2024 12:09 PM

TX-RKGLBL
Dear Bull market selections, W...
Tue, Oct 8, 2024 12:56 PM

VM-HDFCBK
Amt Sent Rs.150.00 From HDFC B...
Mon, Oct 7, 2024 12:26 PM

CP-CENTBK
A/c 3XXXXX3438 debited by Rs. ...
Thu, Oct 3, 2024 12:09 PM

CP-CENTBK
A/c 3XXXXX3438
Thu, Oct 3, 2024 12:09 PM

dinesh
user
dinesh@mail.com
Phone Number
male

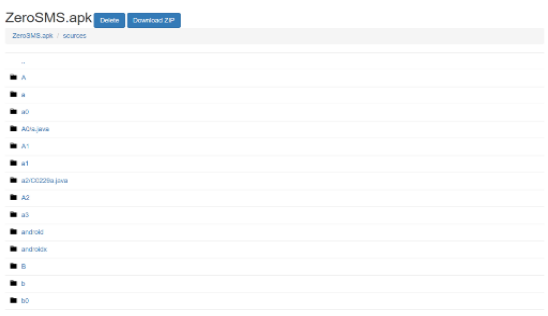
Security Alert
Developer options are enabled. Please disable them to continue.

Fig 5.12. ZeroSMS in production release with security features

5.5.3 Comparing and Testing ZeroSMS Apks with Other Normal Apks

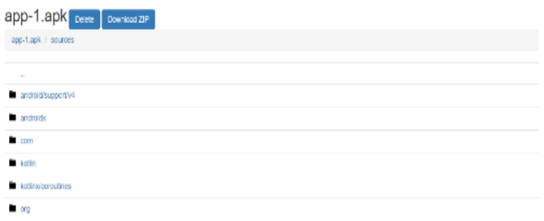
Due to the implementation of code obfuscation tools, the reverse engineering of the ZeroSMS APK significantly differs from that of standard APK files, as depicted in Figures 5.4 and 5.5. The class names within the application have been obfuscated, complicating an attacker's ability to navigate through the folders and files. The utilization of R8 and ProGuard further enhanced the obfuscation process, as illustrated in Figure 5.6. In contrast, Figure 5.7 presents a typical APK where the code remains clearly visible and easily understandable.

Figure 5.8 presents a comparison of the MobSF scans for both the ZeroSMS APK and a standard APK. The security score for ZeroSMS is 57, earning a ‘B’ grade, while the normal APK scores 31, receiving a ‘C’ grade. It is important to note that ZeroSMS has SMS read and write permissions enabled, and “http” traffic is permitted in its AndroidManifest.xml file through the script: *android:usesCleartextTraffic="true"*. This configuration was necessary for connecting to the backend service and significantly influenced the security score as android application by default connects only to ‘https’. In contrast, the normal APK is merely a "Hello World" application built in Android Studio, lacking any additional privileges. Despite this, ZeroSMS achieved a security score that is 83.87% higher than that of the standard APK.



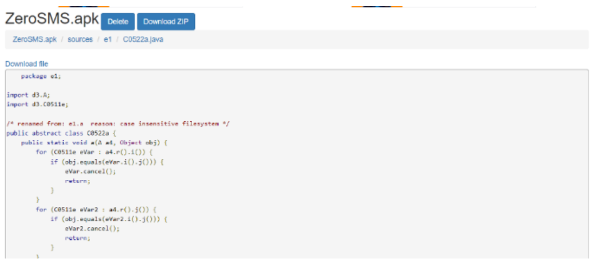
```
..
A
a
a0
A0/a.java
A1
a1
a2/C0229a.java
A2
a3
android
androidx
B
b
b0
```

Fig 5.13. ZeroSMS class name Obfuscation



```
..
android/support/v4
androidx
com
kotlin
kotlinx/coroutines
org
```

Fig 5.14. Reverse engineered file names

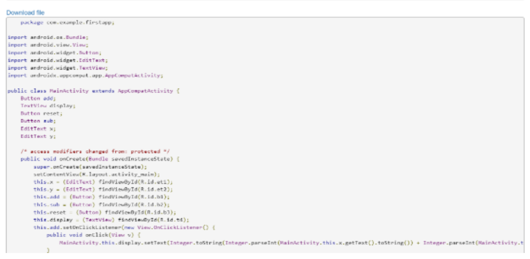


```
    package e1;

import d3.A;
import d3.C0511e;

/* renamed from: e1.a  reason: case insensitive filesystem */
public abstract class C0522a {
    public static void a(A a4, Object obj) {
        for (C0511e eVar : a4.r().i()) {
            if (obj.equals(eVar.i().j())) {
                eVar.cancel();
                return;
            }
        }
        for (C0511e eVar2 : a4.r().j()) {
            if (obj.equals(eVar2.i().j())) {
                eVar2.cancel();
                return;
            }
        }
```

Fig 5.15. ZeroSMS code Obfuscation



```
    package com.example.firstapp;

import android.os.Bundle;
import android.view.View;
import android.widget.Button;
import android.widget.EditText;
import android.widget.TextView;
import androidx.appcompat.app.AppCompatActivity;

public class MainActivity extends AppCompatActivity {
    Button add;
    TextView display;
    Button reset;
    Button sub;
    EditText x;
    EditText y;

    /* access modifiers changed from: protected */
    public void onCreate(Bundle savedInstanceState) {
        super.onCreate(savedInstanceState);
        setContentView(R.layout.activity_main);
        this.x = (EditText) findViewById(R.id.et1);
        this.y = (EditText) findViewById(R.id.et2);
        this.add = (Button) findViewById(R.id.b1);
        this.sub = (Button) findViewById(R.id.b2);
        this.reset = (Button) findViewById(R.id.b3);
        this.display = (TextView) findViewById(R.id.td);
        this.add.setOnClickListener(new View.OnClickListener() {
            public void onClick(View v) {
                MainActivity.this.display.setText(Integer.toString(Integer.parseInt(MainActivity.this.x.getText().toString()) + Integer.parseInt(MainActivity.t
            }
```

Fig 5.16. Normal Apk’s reverse engineered code

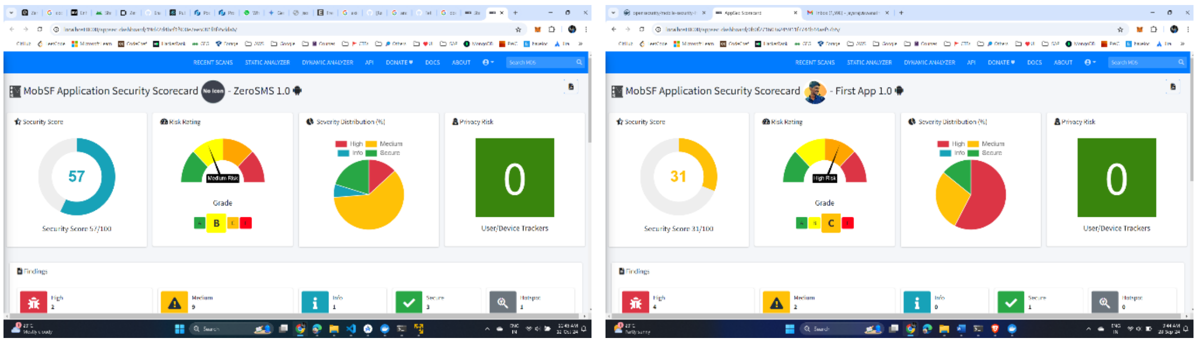


Fig 5.17. Comparison between MobSF scans of ZeroSMS and Normal Apk file

5.5.3 Comparing Various ML models for Spam Detection

In evaluating the performance of the classifiers employed in this project, several key metrics were analyzed as in Table 5.3 to determine the most effective model for the given dataset. Naive Bayes emerged as the best-performing model, achieving a high F1 score of 0.918, which indicates a well-balanced measure of precision and recall. The recall rate for Naive Bayes stood at 0.918, signifying its robust capability in correctly identifying a substantial proportion of actual positive cases. Moreover, the model demonstrated an impressive accuracy of 0.978 see fig 5.8, underscoring its predictive reliability. The mean squared error (MSE) for Naive Bayes was 0.022, indicating minimal deviation between predicted and actual values.

Additionally, the ROC AUC score was calculated at 0.975, reflecting the model's strong discriminative power between the positive and negative classes. The mean absolute error (MAE) also corroborated these findings with a value of 0.022. Support Vector Machine (SVM), while exhibiting a perfect precision score of 1.000, recorded an F1 score of 0.905 due to a slight decrease in recall at 0.826. The accuracy of the SVM model was 0.977, and it achieved the highest ROC AUC score of 0.984, indicating its superior ability to discriminate between classes.

Model	**F1 Score**	**Recall**	**Precision**	**Accuracy**	**Mean Squared Error**	**ROC AUC Score**	**Mean Absolute Error**	**Specificity**
Naive Bayes	0.918	0.918	0.918	0.978	0.022	0.975	0.022	0.988
SVM	0.9505	0.826	1.0	0.977	0.023	0.984	0.023	1.0
Logistic Regression	0.909	0.845	0.984	0.978	0.022	0.983	0.022	0.998
Random Forest	0.905	0.826	1.0	0.977	0.023	0.981	0.023	1.0
Gradient Boosting	0.87	0.781	0.983	0.969	0.031	0.973	0.031	0.998

Table 5.2. Comparison of Model Performance Metrics

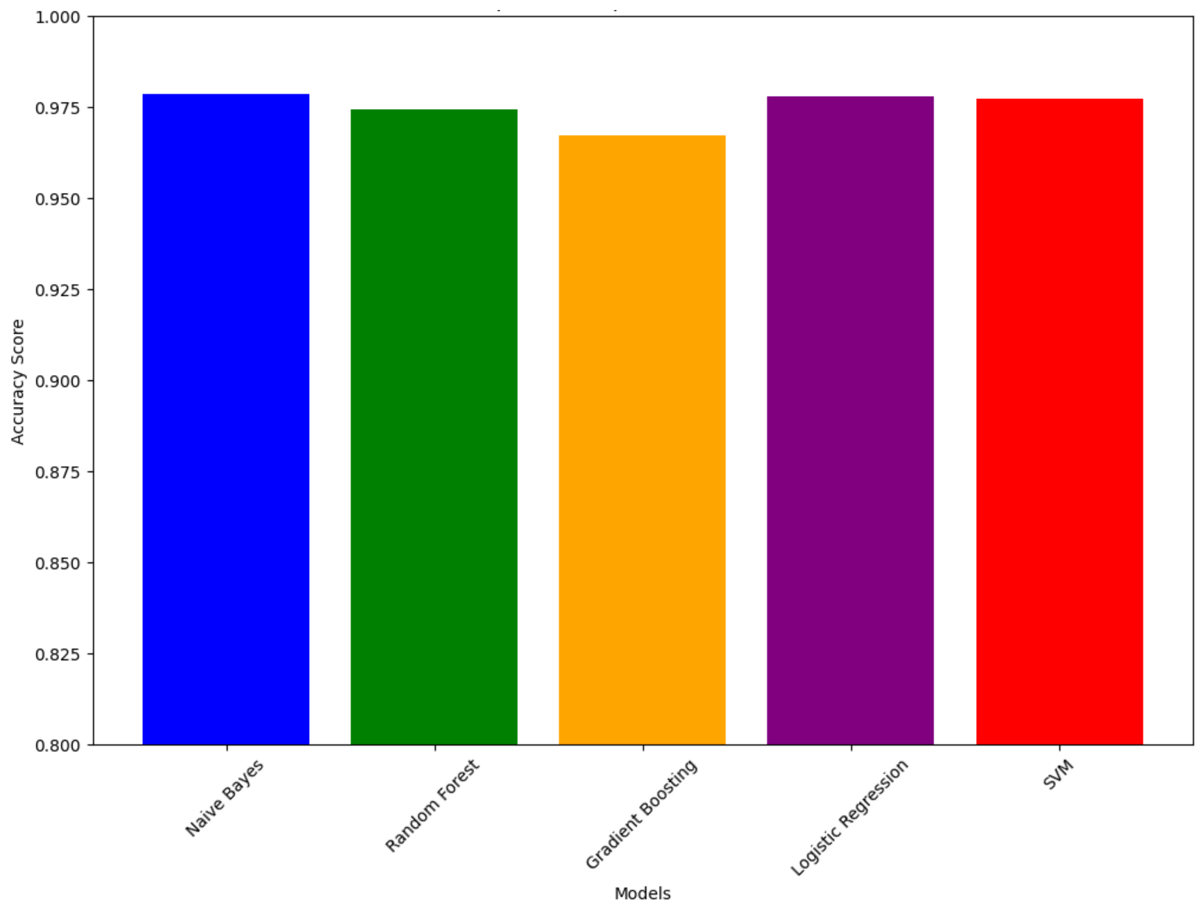


Fig 5.18. Comparison between Spam Detection Models

The MSE for SVM was 0.023, and the MAE was 0.023. Logistic Regression followed closely behind, with an F1 score of 0.909, recall of 0.845, and an accuracy of 0.978. The model's MSE was recorded at 0.022, with a ROC AUC score of 0.983, reinforcing its effectiveness in classification tasks. Random Forest exhibited a slightly lower performance, with an F1 score of 0.891, a recall of 0.804, and an accuracy of 0.974. Its MSE was 0.026, while the ROC AUC score was 0.981. The specificity for Random Forest was perfect at 1.000, indicating its efficacy in identifying true negatives. Gradient Boosting presented the lowest overall performance among the models evaluated, achieving an F1 score of 0.870, recall of 0.781, and an accuracy of 0.969. Its MSE was 0.031, and the ROC AUC score was 0.974, suggesting some limitations in predictive capabilities compared to the other models.

CHAPTER 6

CONCLUSION AND FUTURE WORK

In an era where cyber threats are increasingly sophisticated, ensuring the security of containerized environments is paramount. This project has explored various strategies and best practices to enhance security through the implementation of the Zero Trust model. By developing a proof of concept (PoC) that includes a secure web application, a Python API, and an Android application, we have demonstrated how to adopt Zero Trust principles effectively. Key strategies such as JWT authentication, continuous monitoring, code obfuscation, root detection, mutual TLS (mTLS) within containers, and robust policy enforcement for Role-Based Access Control (RBAC) have been applied throughout the development process. The outcomes of this project underscore the importance of adopting a proactive approach to security in containerized environments. By prioritizing trust verification at every layer and consistently monitoring for potential vulnerabilities, organizations can significantly mitigate risks.

Looking ahead, there are several avenues for further exploration and enhancement of security in containerized environments. Future work could involve implementing advanced threat detection mechanisms utilizing machine learning algorithms to analyze patterns and detect anomalies in containerized applications, thereby enhancing the continuous monitoring process. Automating security auditing processes can provide continuous assessments of the security posture of containerized applications, allowing for timely vulnerability scanning and compliance checks against industry standards. Integrating security practices into CI/CD pipelines will ensure that security measures are considered and implemented from the earliest stages of application development. Furthermore, providing resources and training for developers and operators to understand Zero Trust principles will foster a security-first mindset across development teams. Conducting real-world deployments of the developed applications within various organizational contexts would also enable the gathering of data on security performance and user experiences, facilitating ongoing improvements and adaptations of the proposed strategies. By advancing these areas, organizations can strengthen their security frameworks and effectively protect their containerized environments against evolving threats, all while adhering to the Zero Trust model.

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