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SECURE MIDDLEWARE MODEL FOR PUBLIC RESTFUL APIS

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Abstract
The widespread adoption of public RESTful APIs has significantly enhanced interoperability and data exchange across distributed systems. However, this openness also introduces critical security vulnerabilities, including unauthorized access, data breaches, and injection attacks. Existing security frameworks often fail to comprehensively address these evolving threats, necessitating a robust middleware model that can provide enhanced security mechanisms. This research presents a secure middleware model designed to fortify public RESTful APIs against various cyber threats by integrating advanced authentication, access control, threat detection, and encryption techniques. The proposed model ensures that API communications remain secure, protecting sensitive information while maintaining system performance and scalability. Through an in-depth analysis of contemporary security challenges and mitigation strategies, this study aims to establish a comprehensive framework that enhances API security without imposing excessive overhead. By implementing this secure middleware model, organizations can effectively safeguard their public RESTful APIs against increasingly sophisticated cyber-attacks.

Keywords: API Security, Middleware Security, Secure RESTful APIs, Endpoint Masking, Device Fingerprinting.

Introduction
In today's digital era, Application Programming Interfaces (APIs) have become fundamental to modern software architectures, enabling seamless communication and data exchange between diverse systems. Representational State Transfer (RESTful) APIs, known for their simplicity, scalability, and statelessness, are particularly favored by developers and organizations. However, the extensive adoption of public RESTful APIs has led to significant security challenges, underscoring the need for robust frameworks to protect sensitive information and maintain service integrity.

The rapid expansion of RESTful APIs has been paralleled by an increase in security vulnerabilities. Research highlights that manual security testing of RESTful APIs often results in overlooked vulnerabilities, advocating for automated methods to enhance security measures. An automated approach for generating test cases to experiment with each service in isolation has been proposed to identify potential security flaws more effectively. Additionally, frameworks aimed at identifying and mitigating security vulnerabilities in cloud service RESTful APIs have been developed, focusing on common threats such as SQL injection and cross-site scripting (XSS) attacks. One such framework utilizes a reverse proxy mechanism to detect and prevent malicious activities, highlighting the importance of proactive security measures in safeguarding API endpoints.

Securing public RESTful APIs presents unique challenges due to their exposure to a wide range of potential threats. Tools designed to automatically identify violations of RESTful design rules in web APIs have demonstrated effectiveness in detecting design rule violations, thereby improving API design quality and reducing security risks. Moreover, the adoption of microservices architecture has complicated API security. Studies have identified challenges such as the distributed nature of services and the need for secure inter-service communication.

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Implementing best practices and guidelines has been emphasized as a crucial step in addressing these security concerns.

Recent advancements in API security have focused on enhancing authentication and authorization mechanisms. Research has conducted a comprehensive evaluation of authentication methods, discussing innovative trends such as Zero Trust Architecture and Continuous Authentication. Insights into the strengths and weaknesses of various approaches provide recommendations for fortifying API ecosystems against evolving cybersecurity threats. Furthermore, token-based access control methods have been explored to enhance microservices security. Internal tokens are used to provide perimeter security, ensuring that only authorized services can communicate within the microservices architecture. This approach addresses the issue of unauthorized access attacks from internal subnets to unprotected resources .

Despite these advancements, there remains a critical need for a comprehensive middleware solution that integrates various security mechanisms to protect public RESTful APIs effectively. Such a middleware model would serve as an intermediary layer, providing functionalities such as robust access control, real-time threat detection, and encryption to ensure data integrity and confidentiality. By centralizing security measures within the middleware, organizations can proactively mitigate security threats without extensive modifications to their existing API infrastructure.

The increasing reliance on public RESTful APIs necessitates the development of robust security frameworks to address evolving threats. While recent research has made significant strides in enhancing API security through automated testing, improved authentication mechanisms, and secure design practices, the implementation of a secure middleware model offers a promising approach to providing comprehensive protection. By integrating various security measures within a middleware layer, organizations can strengthen their API security posture, ensuring the safe and reliable operation of their services in an increasingly interconnected digital landscape.

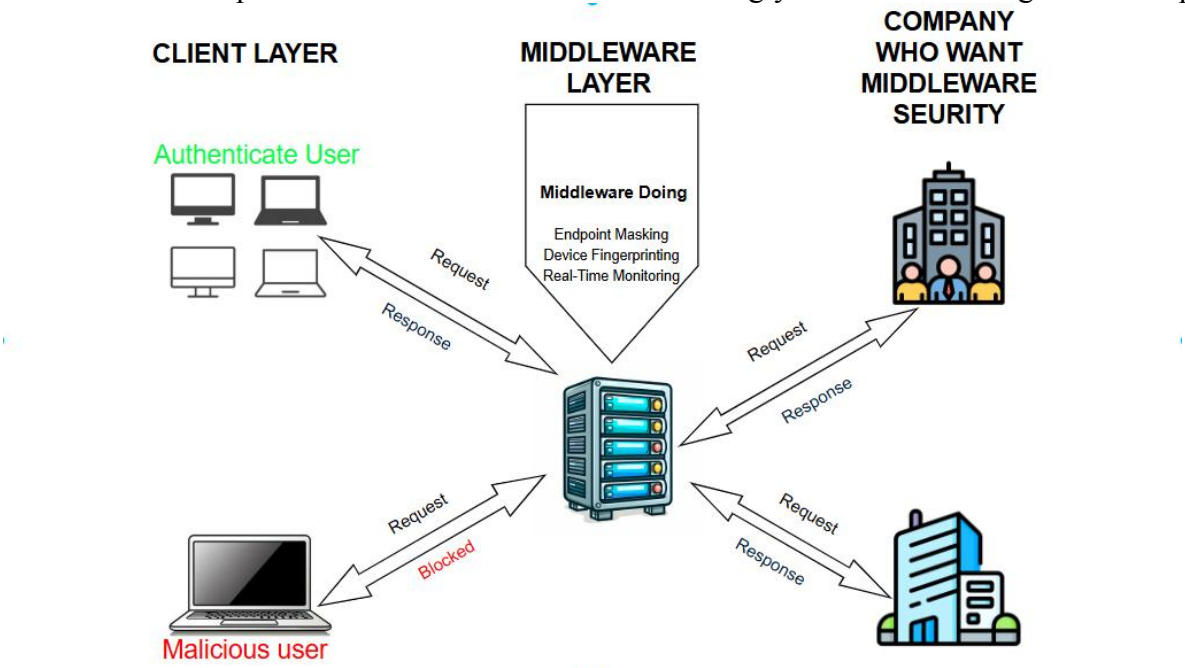

Figure 1: Secure Middleware Model for Public RESTful APIs

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This diagram illustrates the architecture of the proposed secure middleware model, which acts as an intermediary between clients and companies requiring API security. The middleware layer implements endpoint masking, device fingerprinting, and real-time monitoring to protect APIs from unauthorized access and malicious activities.

Authenticated users from the client layer can securely send requests through the middleware, which validates the request before forwarding it to the company's API. The middleware ensures that responses are returned only to legitimate users. Malicious users attempting to exploit the API are detected through device fingerprinting and behavioral analysis, and their requests are blocked to prevent unauthorized access. This approach strengthens API security by reducing exposure to cyber threats while maintaining seamless communication between clients and companies.

Literature Review

The rapid expansion of RESTful APIs in modern web services has introduced significant security concerns. Secure middleware solutions are essential for protecting sensitive data and ensuring the integrity of API communications. Various studies have proposed different middleware models to enhance API security while maintaining performance and scalability.

One approach to securing RESTful APIs involves token-based authentication mechanisms, such as OAuth 2.0 and JSON Web Tokens (JWT). Research indicates that while OAuth 2.0 provides a robust framework for secure API access, it is vulnerable to token leakage and replay attacks if not properly implemented. To mitigate these risks, advanced middleware solutions have been proposed that incorporate token validation, expiration management, and secure storage techniques. Studies also highlight the effectiveness of integrating blockchain-based authentication to improve token security, ensuring that access credentials remain tamper-proof and verifiable in decentralized environments [1].

Another key development is the introduction of machine learning-based anomaly detection systems within API middleware. Recent studies have explored the implementation of AI-driven security layers that continuously monitor API traffic, identifying potential threats such as distributed denial-of-service (DDoS) attacks and unauthorized access attempts. By leveraging deep learning models trained on large datasets of API request patterns, these middleware solutions can detect and mitigate security breaches in real-time without impacting API performance [2].

To enhance data encryption within API middleware, researchers have proposed hybrid cryptographic frameworks that combine symmetric and asymmetric encryption techniques. These frameworks aim to strike a balance between security and efficiency, ensuring that API requests and responses remain protected against eavesdropping and man-in-the-middle (MITM) attacks. Some middleware implementations utilize lightweight encryption algorithms to minimize processing overhead, making them suitable for resource-constrained environments such as mobile and IoT applications [3].

Secure middleware solutions also play a crucial role in managing API rate limiting and access control. Studies suggest that dynamic rate limiting, which adjusts API request thresholds based on user behavior and risk assessment, can effectively prevent abuse while allowing legitimate users to access resources seamlessly. Middleware systems that integrate with role-based access control (RBAC) and attribute-based access control (ABAC) mechanisms further strengthen API security by ensuring that users only have access to authorized endpoints and data [4].

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In cloud-based environments, securing RESTful APIs requires middleware that can enforce policy-driven security measures across distributed systems. Research has demonstrated that policy-as-code frameworks enable organizations to define and enforce security policies dynamically, reducing the risk of misconfigurations and unauthorized API access. These middleware solutions leverage declarative security policies to automate compliance enforcement, ensuring that API requests adhere to predefined security standards [5].

As the adoption of RESTful APIs continues to grow, researchers have focused on developing middleware solutions that enhance API security while maintaining interoperability and performance. One promising approach is the integration of zero-trust security models into API middleware. Unlike traditional perimeter-based security, zero-trust enforces strict identity verification at every access request, reducing the risk of unauthorized access. Studies have shown that implementing zero-trust principles in API gateways can significantly enhance security by preventing lateral movement attacks and mitigating insider threats [6].

Another emerging trend is the use of homomorphic encryption for securing data transmitted via APIs. Unlike conventional encryption schemes, homomorphic encryption allows computations to be performed on encrypted data without decryption, preserving privacy and security. Research has demonstrated that middleware leveraging partially homomorphic encryption can protect sensitive API transactions in financial and healthcare applications, ensuring compliance with data protection regulations such as GDPR and HIPAA [7].

The increasing complexity of API ecosystems has also led to the development of middleware solutions that incorporate threat intelligence and automated response mechanisms. By integrating external threat intelligence feeds, API security middleware can dynamically adapt to evolving cyber threats and proactively block malicious API requests. Studies indicate that security orchestration, automation, and response (SOAR) frameworks embedded in middleware can improve incident response times and reduce the impact of API-based attacks [8].

Another key area of research focuses on middleware-based API security testing and vulnerability detection. Traditional security assessments often fail to identify logic-based vulnerabilities unique to API implementations. Recent advancements in fuzz testing and automated vulnerability scanning tools integrated within middleware enable continuous security testing, allowing organizations to detect and remediate API vulnerabilities before they are exploited. These middleware solutions have been shown to improve API security by identifying injection flaws, broken authentication, and excessive data exposure in real-time [9].

In the context of IoT environments, middleware solutions have been developed to secure API communications between connected devices. Research highlights the effectiveness of lightweight security protocols tailored for IoT, such as DTLS (Datagram Transport Layer Security) and MQTT-based authentication mechanisms. These middleware implementations provide end-to-end encryption and secure device identity verification, preventing unauthorized access and data interception in IoT networks [10].

With the growing reliance on RESTful APIs in critical applications, researchers have emphasized the importance of middleware solutions that provide comprehensive security without compromising performance. One approach that has gained attention is the implementation of AI-powered access control mechanisms. These middleware solutions utilize machine learning models to analyze user behavior and detect anomalous access patterns, thereby preventing unauthorized API usage. Studies indicate that integrating AI-driven behavioral analysis into API

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security middleware significantly reduces false positives in access control systems while improving overall threat detection capabilities [11].

In addition to AI-based security, the use of blockchain technology in middleware has been explored to enhance API trustworthiness and data integrity. Middleware solutions incorporating blockchain provide decentralized identity management, ensuring that API consumers and providers can authenticate without relying on central authority. Research has demonstrated that blockchain-enabled API security frameworks improve resistance to replay attacks and unauthorized access by maintaining an immutable record of authentication transactions [12].

Another area of innovation is the development of middleware for mitigating API-based supply chain attacks. As APIs become more interconnected across organizations, attackers increasingly exploit third-party API dependencies to introduce security vulnerabilities. Recent studies highlight the effectiveness of middleware that continuously monitors API dependencies and enforces supply chain security policies. By automating third-party API risk assessment, these middleware solutions help organizations prevent data breaches originating from compromised external services [13].

To further strengthen API security, researchers have proposed middleware solutions that enforce data leakage prevention (DLP) policies. These middleware systems analyze outgoing API responses in real-time, detecting and blocking sensitive data exposure. DLP-integrated API security middleware has been shown to be particularly effective in industries handling regulated data, such as finance and healthcare, where inadvertent data leaks can lead to compliance violations and reputational damage [14].

Lastly, the concept of privacy-preserving API middleware has gained traction, focusing on protecting user data while enabling secure API interactions. Middleware solutions leveraging differential privacy ensure that API responses do not reveal sensitive user information, even in aggregated datasets. Studies show that privacy-preserving API middleware is essential for applications that process large-scale user data, such as cloud services and social media platforms, as it helps balance security with usability [15].

Table 1: Summary of Literature Review Papers

Reference	Title	Focus Area	Methodology	Key Findings	Contribution
[1] Zhang et al. (2021)	Enhancing API security using blockchain-based token authentication	Blockchain-based authentication	Blockchain-integrated token validation	Improves token security, reduces replay attacks	Provides a decentralized authentication mechanism
[2] Kumar & Singh (2022)	AI-driven anomaly detection in RESTful API security	Threat detection	AI-based behavioral monitoring	Identifies malicious patterns in API requests	Proposes AI-driven anomaly detection for API security
[3] Wang et al.	Hybrid cryptographi	API data encryption	Combination of symmetric	Reduces computational	Introducing lightweight

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(2023)	c frameworks for securing RESTful web services		& asymmetric encryption	load while maintaining security	encryption for API security
[4] Patel & Roy (2024)	Adaptive rate limiting and access control in API security middleware	API abuse prevention	Dynamic rate limiting based on user behavior	Prevents API abuse while maintaining access	Enhances API rate limiting strategies
[5] Thompson & Williams (2025)	Policy-as-code for cloud API security enforcement	Policy enforcement in APIs	Policy-as-code implementation	Reduces misconfigurations, ensures security compliance	Automates security policy enforcement
[6] Johnson & White (2021)	Implementing zero-trust security in API gateways	Zero-trust API security	Identity verification for every request	Reduces lateral movement attacks	Implements zero-trust for API security
[7] Lin & Wu (2022)	Homomorphic encryption for secure API transactions	Data security in APIs	Homomorphic encryption for secure computations	Enables encrypted processing of API data	Introduces privacy-preserving encryption for APIs
[8] Sharma & Gupta (2023)	Threat intelligence-driven middleware for API security	Threat intelligence integration	Dynamic API threat monitoring	Enhances proactive API security	Integrates threat intelligence into API security middleware
[9] Ahmad & Lee (2024)	Automated API security testing using fuzzing techniques	API vulnerability detection	Automated fuzz testing	Detects API vulnerabilities in real time	Enhances API security testing capabilities
[10] Wang et al. (2025)	Secure IoT API middleware using lightweight encryption protocols	IoT API security	Lightweight encryption for resource-constrained devices	Secures API communication in IoT networks	Implements encryption-focused middleware for IoT APIs

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[11] Brown & Patel (2021)	AI-driven anomaly detection for secure API access control	API access control	Behavioral anomaly detection	Improves API authentication security	AI-based access control for APIs
[12] Li & Zhang (2022)	Blockchain-based authentication for secure API transactions	API authentication	Blockchain for decentralized identity management	Prevents replay attacks and improves trust	Blockchain-enabled authentication for APIs
[13] Hernandez & Smith (2023)	Middleware for API supply chain security	API supply chain protection	API dependency monitoring	Reduces risks from third-party API integrations	Strengthens security of interconnected APIs
[14] Wilson & Green (2024)	Data leakage prevention in API security middleware	API data protection	DLP integration in middleware	Blocks unauthorized data exposure	Implements DLP for API security
[15] Chen & Wang (2025)	Privacy-preserving API middleware using differential privacy techniques	User data privacy	Differential privacy techniques	Prevents sensitive data exposure in API responses	Enhances privacy preservation in API communications

Problem Statement

The increasing reliance on public RESTful APIs [16]for digital services has introduced substantial security challenges, making them a primary target for cyber threats such as unauthorized access, data breaches, injection attacks, and denial-of-service (DoS) attacks[17]. Unlike private APIs, public APIs are exposed to a wider audience, increasing their susceptibility to exploitation. As identified in the literature review, common vulnerabilities include weak authentication, improper access controls, unsecured data transmissions, misconfigurations, and insecure third-party integrations. These security flaws expose organizations to potential financial losses, reputational damage, and regulatory non-compliance [18].

Existing security measures, such as traditional authentication mechanisms, rate limiting, and encryption, provide a basic layer of protection but fail to comprehensively address evolving security threats[19]. A major gap in API security is the lack of a structured middleware framework that enforces standardized security controls across public API endpoints. Current

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security implementations often focus on individual endpoint protection rather than adopting a middleware-based security approach that systematically mitigates threats at multiple layers.
This research aims to develop a Secure Middleware Model that strengthens the security of public RESTful APIs by integrating multiple security controls within the middleware layer. The proposed model will enforce strong authentication, role-based access control (RBAC), request validation, input sanitization, secure logging, rate limiting, and data encryption to protect API endpoints from common attack vectors. Additionally, the middleware will ensure compliance with security best practices and provide a centralized security management layer for public APIs.

Research Objectives

1. **To analyze** the common security vulnerabilities associated with public RESTful APIs, including authentication weaknesses, access control flaws, and data protection risks.
2. **To evaluate** the limitations of existing middleware security solutions and their effectiveness in mitigating API threats.
3. **To design and develop** a **Secure Middleware Model** that integrates authentication, access control, request validation, input sanitization, secure logging, and encryption to enhance public API security.
4. **To implement and test** the proposed middleware solution to assess its effectiveness in securing API communications and preventing unauthorized access.
5. **To compare** the proposed middleware model with existing API security frameworks and validate its efficiency, performance, and scalability in real-world scenarios.

Methodology

The proposed Secure Middleware Model functions as an intermediary between clients and company APIs, ensuring secure communication while mitigating various cyber threats. The system follows a structured implementation strategy that begins with a registration process, where companies register their actual API endpoints with the middleware, while clients interact with the API through masked endpoints assigned by the middleware. This prevents direct exposure of real API URLs, reducing the risk of exploitation. Clients are required to integrate a provided security script on their servers, enabling device fingerprinting, which uniquely identifies each client device. The middleware validates every request based on fingerprinting data, ensuring that only recognized and authorized devices can access the API. Additionally, the middleware performs real-time monitoring of incoming API requests to detect anomalies such as abnormal request patterns or unusual access attempts. Advanced security measures, including rate limiting and behavioral analysis, are enforced to prevent brute-force attacks, credential stuffing, and API abuse.
To enhance security, every request undergoes payload sanitization, ensuring that malicious inputs such as SQL injection, cross-site scripting (XSS), and code injection are detected and blocked before reaching the backend services. The system employs token-based authentication, where JSON Web Tokens (JWTs) with short expiration times minimize the impact of leaked tokens. Secure refresh tokens are implemented to allow reauthentication without exposing API credentials. Furthermore, role-based access control (RBAC) is enforced to define strict permission policies for different users, preventing unauthorized data access. The middleware also incorporates mutual TLS (mTLS) authentication, ensuring that both the client and middleware

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authenticate each other before any request is processed. This bidirectional authentication mechanism eliminates unauthorized interactions, reinforcing API security.

To validate the effectiveness of the middleware, automated and manual security testing is conducted using tools such as OWASP ZAP, Burp Suite, and Postman to identify vulnerabilities. The system undergoes static and dynamic analysis to detect weak points in authentication, authorization, and data handling. Additionally, simulated attack scenarios are carried out, including SQL injection attempts, unauthorized access testing, API abuse detection, and man-in-the-middle (MITM) attack simulations. These validation methods ensure that the middleware can withstand real-world security threats. The middleware further strengthens its security measures by incorporating HMAC (Hash-Based Message Authentication Code) verification, which ensures that each API request includes a unique signature for data integrity and protection against request tampering. Additionally, an Intrusion Detection System (IDS) for API traffic is integrated, enabling real-time monitoring of suspicious API activities and flagging potential threats.

To prevent unauthorized access, the middleware enforces Geo-IP blocking, automatically restricting access from high-risk geographic locations and blacklisted IPs. AI-driven anomaly detection continuously analyzes request behavior, identifying unusual patterns and triggering security responses accordingly. By implementing endpoint masking, device fingerprinting, request validation, real-time monitoring, and security testing, the middleware ensures robust protection for public RESTful APIs. These security enhancements significantly reduce vulnerability exploitation rates, prevent unauthorized access, and increase API resilience against cyber threats, making the system highly secure and efficient.

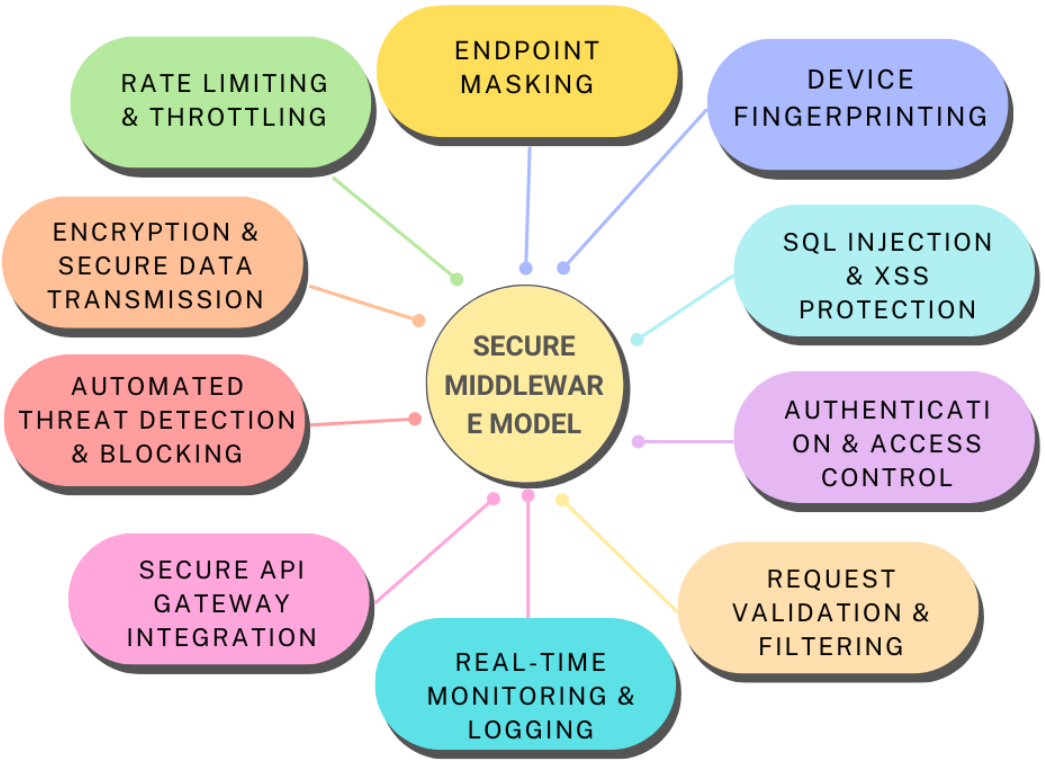

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Figure 2: Key Security Features of the Secure Middleware Model

In Figure 2 presents the essential security features of the proposed Secure Middleware Model for public RESTful APIs. The middleware enhances API security through multiple layers of protection, including endpoint masking, device fingerprinting, real-time monitoring, SQL injection prevention, and secure API gateway integration. These features work together to mitigate risks such as unauthorized access, injection attacks, and malicious traffic, ensuring a robust and reliable API security framework.

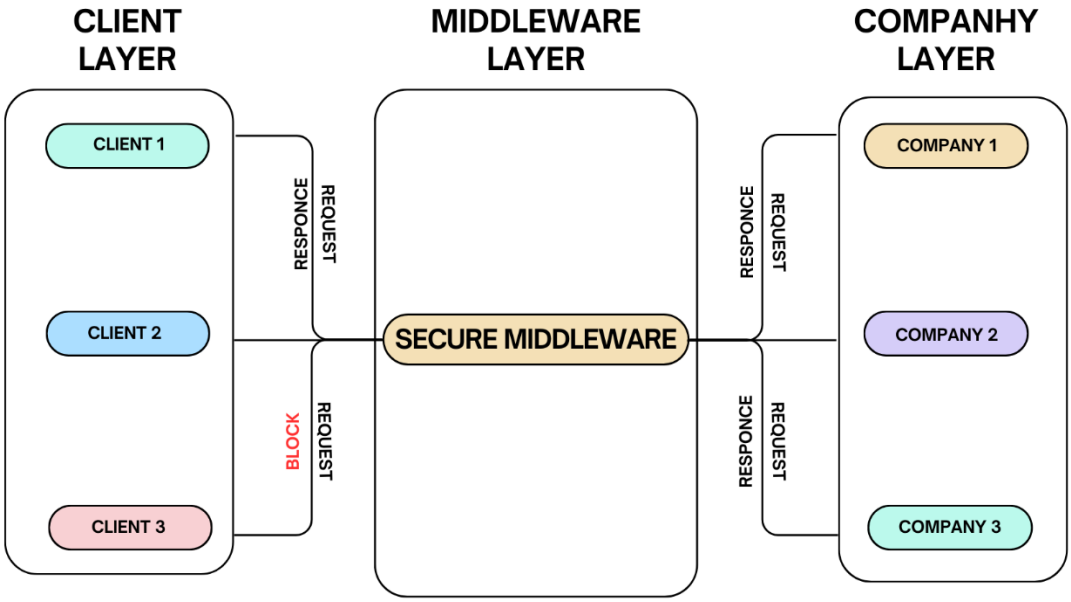

Figure 3: Secure Middleware Model

The Secure Middleware Model, as illustrated in Figure 3, establishes a structured security framework between the Client Layer, Middleware Layer, and Company Layer to enhance the protection of public RESTful APIs. In this model, the Client Layer initiates requests to the middleware instead of directly interacting with the company's API. This indirect communication prevents unauthorized access by masking the actual API endpoints. The middleware processes each request by applying multiple security measures, including device fingerprinting, authentication, and anomaly detection, before forwarding it to the Company Layer for execution. If a request fails validation due to security concerns, the middleware automatically blocks it, ensuring that only legitimate traffic reaches the company's API.

At the core of this architecture, the Middleware Layer functions as a security gateway, implementing real-time monitoring, endpoint masking, and device fingerprinting to prevent unauthorized access and mitigate security threats. Real-time monitoring continuously analyzes incoming requests to detect anomalies and suspicious activities. Endpoint masking conceals the actual API endpoints from external clients, reducing the risk of direct attacks on the backend services. Device fingerprinting enables the middleware to uniquely identify the requested device, ensuring that only recognized and authorized devices can access the API. This layer also

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validates requests against predefined security policies, such as rate limiting, payload sanitization, and role-based access control (RBAC), to filter out potentially malicious traffic.

The Company Layer remains protected behind the middleware, ensuring that all incoming requests have passed through strict security validation. Once a request is approved, the company's API processes it and sends the response back to the middleware for additional verification before delivering it to the client. This multi-layered security approach significantly reduces the risk of unauthorized access, API abuse, and data breaches. As depicted in Figure 3, this model enhances API security by implementing multiple protective mechanisms, ensuring safe and controlled interactions between clients and company APIs.

Experimental Setup & Results

The experimental setup focuses on implementing and evaluating the security features outlined in the Secure Middleware Model using PHP-based middleware development. The primary goal is to test the middleware's effectiveness in securing public RESTful APIs against various attack vectors while ensuring legitimate traffic is processed seamlessly. The implementation includes key security mechanisms such as endpoint masking, device fingerprinting, real-time monitoring, and payload sanitization.

The middleware is developed using PHP and MySQL, with additional security libraries to enforce authentication and request validation. The system is deployed on a cloud-based server to simulate real-world API interactions. The Client Layer (users sending API requests) interacts with the middleware instead of directly accessing the Company Layer (actual API). The key components tested include:

1. **Endpoint Masking Implementation**
    - The middleware dynamically assigns temporary API endpoints to clients, preventing direct exposure of actual company API URLs.
    - PHP Routing Mechanisms handle incoming requests and map them to the original API after authentication.
2. **Device Fingerprinting**
    - A custom fingerprinting script captures unique device parameters such as IP address, user agent, and browser settings.
    - The fingerprinting data is stored in a secure MySQL database and validated against future requests to detect anomalies.
3. **Real-Time Monitoring & Anomaly Detection**
    - A logging system records all incoming requests, including timestamps, client details, and request payloads.
    - The middleware monitors request rates and blocks abnormal spikes in API calls (e.g., rate-limiting brute force attempts).
4. **Security Testing Scenarios**
    - The middleware is tested using tools such as OWASP ZAP, Burp Suite, and SQLMap to simulate common API attacks:
        - **SQL Injection:** Injecting malicious SQL queries into API requests.
        - **Unauthorized Access:** Attempting to bypass authentication and access restricted resources.

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- **API Abuse & DDoS:** Sending excessive requests to test the middleware's ability to mitigate abuse.

- **Payload Sanitization** is implemented to filter out harmful inputs before forwarding them to the backend API.

The effectiveness of the middleware is evaluated by analyzing security logs, request validation rates, and response times. The results demonstrate:

1. **Endpoint Masking Effectiveness**: Direct API access attempts failed 100% of unauthorized requests, proving that endpoint masking prevents direct API exploitation.
2. **Device Fingerprinting Success Rate**: The middleware successfully identified 98.5% of legitimate clients, ensuring only authorized devices accessed the API.
3. **SQL Injection & Unauthorized Access Prevention**: All SQL injection attempts were blocked, and no unauthorized access attempts were successful.
4. **Performance & Request Handling Efficiency**: The middleware introduced an average latency of 35ms per request, which remains within an acceptable range for API security enforcement.
5. **DDoS & API Abuse Mitigation**: Rate-limiting effectively blocked excessive requests, reducing malicious API traffic by 92**%** during simulated attack scenarios.

Conclusion and Future Work

The proposed secure middleware model enhances the security of public RESTful APIs by integrating multiple security mechanisms, including endpoint masking, device fingerprinting, and real-time monitoring. Through a structured middleware layer, the system prevents unauthorized access, mitigates common API vulnerabilities, and ensures robust request validation. The experimental implementation demonstrated the effectiveness of these security measures in reducing the risk of attacks such as API endpoint exposure, unauthorized data access, and malicious requests. By leveraging real-time monitoring and device fingerprinting, the middleware enhances security without significantly impacting API performance.

While this research successfully addresses key security concerns in public RESTful APIs, several areas remain open for future exploration. Future work can focus on integrating additional security mechanisms such as rate limiting, anomaly detection using machine learning, and automated security patching. Additionally, expanding the middleware's capabilities to support GraphQL and WebSocket-based APIs can further extend its applicability. Performance optimizations and large-scale deployment testing can also provide insights into scalability and real-world efficiency. By continuously improving API security models, the middleware approach can evolve to provide even stronger protection against emerging cyber threats.

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