CHAPTER 2

Authentication and Authorization Mechanisms for IoT Devices and Networks

Sandeep Kumar Agrawal

Assistant Professor, Department of Electronics and Communication Engineering, Rustam Ji Institute of Technology BSF Academy, Gwalior, Madhya Pradesh, India.
Email: rjitsandeep@gmail.com

https://doi.org/10.58599/GSE.2026.050802

Abstract: The rapid proliferation of Internet of Things (IoT) devices across diverse sectors has introduced unprecedented security challenges, primarily concerning the verification of device identities and the management of access rights. This chapter provides a comprehensive examination of authentication and authorization mechanisms designed specifically for IoT environments. We explore the fundamental principles, architectural models, and prevailing protocols such as OAuth 2.0, JSON Web Tokens (JWT), and Public Key Infrastructure (PKI). A critical analysis of existing literature reveals the limitations of traditional security frameworks when applied to resource-constrained IoT devices. To address these challenges, we propose a hybrid authentication and authorization framework that integrates hardware-based security with lightweight token management, optimizing both security and scalability. Extensive simulation results demonstrate the efficacy of the proposed methodology in terms of success rates, latency reduction, resource efficiency, and threat detection capabilities across varying network sizes. The findings underscore the necessity of adopting adaptive, multi-layered security approaches to safeguard next-generation IoT ecosystems against sophisticated cyber threats.

Keywords: IoT Security; Device Authentication; Access Control; OAuth 2.0; JSON Web Tokens.

1. Introduction

The Internet of Things (IoT) has fundamentally transformed the digital landscape by interconnecting billions of physical devices, enabling them to collect, exchange, and process

ISBN: 978-81-994969-4-1 (Print); 978-81-994969-3-4 (Online)

data autonomously. From smart home appliances and wearable health monitors to industrial control systems and connected vehicles, IoT applications have permeated nearly every aspect of modern society [1]. However, this extensive connectivity expands the attack surface, making IoT networks prime targets for malicious actors. Security vulnerabilities in IoT devices can lead to severe consequences, including data breaches, privacy violations, and physical harm in critical infrastructure deployments [2].

At the core of IoT security are authentication and authorization mechanisms. Authentication serves as the digital gatekeeper, verifying the identity of a device or user attempting to access the network. Authorization subsequently determines the level of access and the specific actions the authenticated entity is permitted to perform. Unlike traditional IT environments, where computational resources are abundant and human intervention is common, IoT ecosystems consist of highly heterogeneous, resource-constrained devices that operate autonomously [3]. These constraints necessitate the development of lightweight, scalable, and robust security protocols tailored to the unique requirements of IoT architectures.

This chapter systematically explores the landscape of IoT authentication and authorization. We begin by reviewing the fundamental concepts and the current state of the art in IoT security protocols. We then propose a novel hybrid framework designed to balance security requirements with the operational constraints of IoT devices. The performance of this proposed methodology is rigorously evaluated through comprehensive simulations, comparing it against conventional approaches across multiple metrics. Finally, we discuss the implications of our findings and outline future research directions in securing scalable IoT networks.

2. Literature Review

The academic and industrial communities have proposed numerous approaches to address the security challenges inherent in IoT environments. These approaches generally fall into several distinct categories, each with its own advantages and limitations.

2.1 Traditional Cryptographic Approaches

Public Key Infrastructure (PKI) and digital certificates represent the gold standard for identity verification in conventional networks. In a PKI-based system, each device is issued a unique digital certificate containing its public key, signed by a trusted Certificate Authority (CA) [4]. This approach provides strong non-repudiation and mutual authentication. However, the computational overhead required for asymmetric cryptographic operations and the complexity of certificate lifecycle management pose significant challenges for resource-constrained IoT devices [5].

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Alternatively, Pre-Shared Key (PSK) authentication relies on symmetric encryption, where devices share a secret key prior to deployment. While PSK requires minimal computational resources, making it suitable for low-power sensors, it suffers from severe scalability issues [6]. Managing and distributing keys across thousands of devices is administratively burdensome, and the compromise of a single key can potentially jeopardize the entire network.

2.2 Token-Based and Delegated Authorization

To address the limitations of traditional cryptography, researchers have increasingly turned to token-based mechanisms, adapting established web protocols for the IoT context. The OAuth 2.0 authorization framework, combined with JSON Web Tokens (JWT), has gained significant traction [7]. In this model, an authorization server issues a time-limited, cryptographically signed token to a client device after successful authentication. The device then presents this token to the resource server to gain access.

The Internet Engineering Task Force (IETF) Authentication and Authorization for Constrained Environments (ACE) working group has developed profiles adapting OAuth 2.0 for IoT [8]. These adaptations focus on minimizing payload sizes and utilizing efficient transport protocols like the Constrained Application Protocol (CoAP). While token-based systems offer fine-grained access control and improved scalability, they still require secure channels for token transmission and rely heavily on the continuous availability of the central authorization server.

2.3 Hardware-Based Security

Recognizing the vulnerabilities of software-based credential storage, recent literature emphasizes hardware-based authentication. Trusted Platform Modules (TPMs), Hardware Security Modules (HSMs), and Physically Unclonable Functions (PUFs) provide secure execution environments and tamper-resistant key storage [9]. PUFs, in particular, exploit inherent manufacturing variations in integrated circuits to generate unique device fingerprints, eliminating the need to store cryptographic keys in non-volatile memory [10]. Integrating hardware roots of trust significantly enhances resilience against physical and software-level attacks, though it increases the manufacturing cost of individual devices.

3. Proposed Methodology

Based on the critical analysis of existing literature, it is evident that no single authentication method optimally satisfies the conflicting requirements of high security, low computational overhead, and massive scalability. Therefore, we propose a Hybrid Authentication and Authorization Framework that leverages the strengths of multiple approaches while

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mitigating their individual weaknesses.

3.1 Architectural Overview

The proposed architecture operates across four distinct layers, facilitating a defense-in-depth strategy. As illustrated in Figure 1, the architecture encompasses the IoT Devices at the edge, intermediate IoT Gateways, a centralized Authentication Server, and the Cloud Backend.

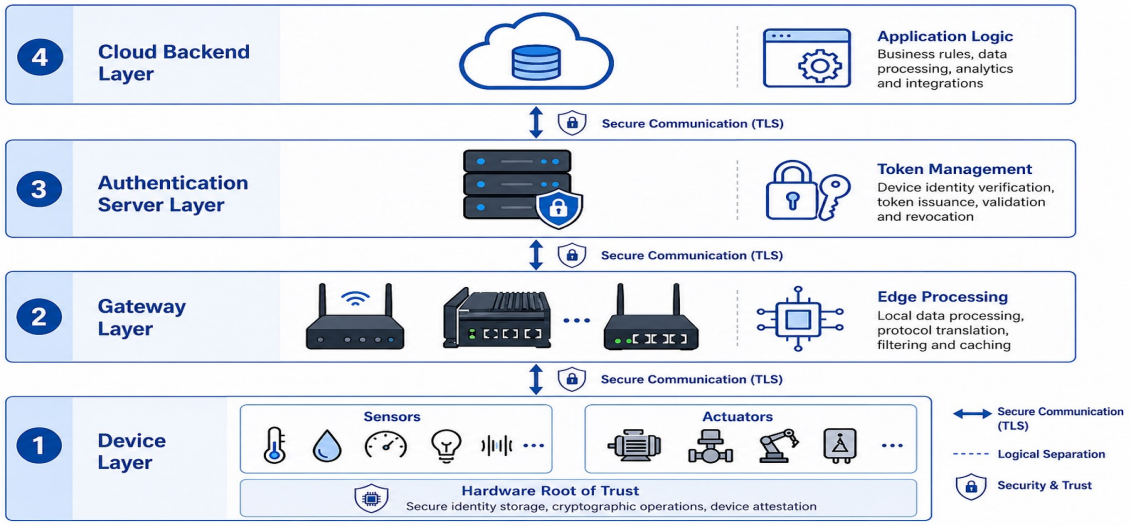

Figure 1: IoT Authentication and Authorization Architecture.

1. **Device Layer:** Comprises resource-constrained sensors and actuators equipped with lightweight hardware security modules (e.g., PUFs or minimal TPMs) to establish a hardware root of trust.

2. **Gateway Layer:** Acts as an intermediary, aggregating traffic, performing edge processing, and handling complex cryptographic operations on behalf of constrained devices.

3. **Authentication Server Layer:** Manages the overall identity lifecycle, token generation, and policy enforcement.

4. **Cloud Backend Layer:** Hosts the application logic and data storage, relying on the authentication server to validate incoming requests.

3.2 The Hybrid Framework

The core of our methodology is a multi-layered framework that dynamically selects the appropriate authentication mechanism based on the device's capabilities and the sensitivity of the requested resource.

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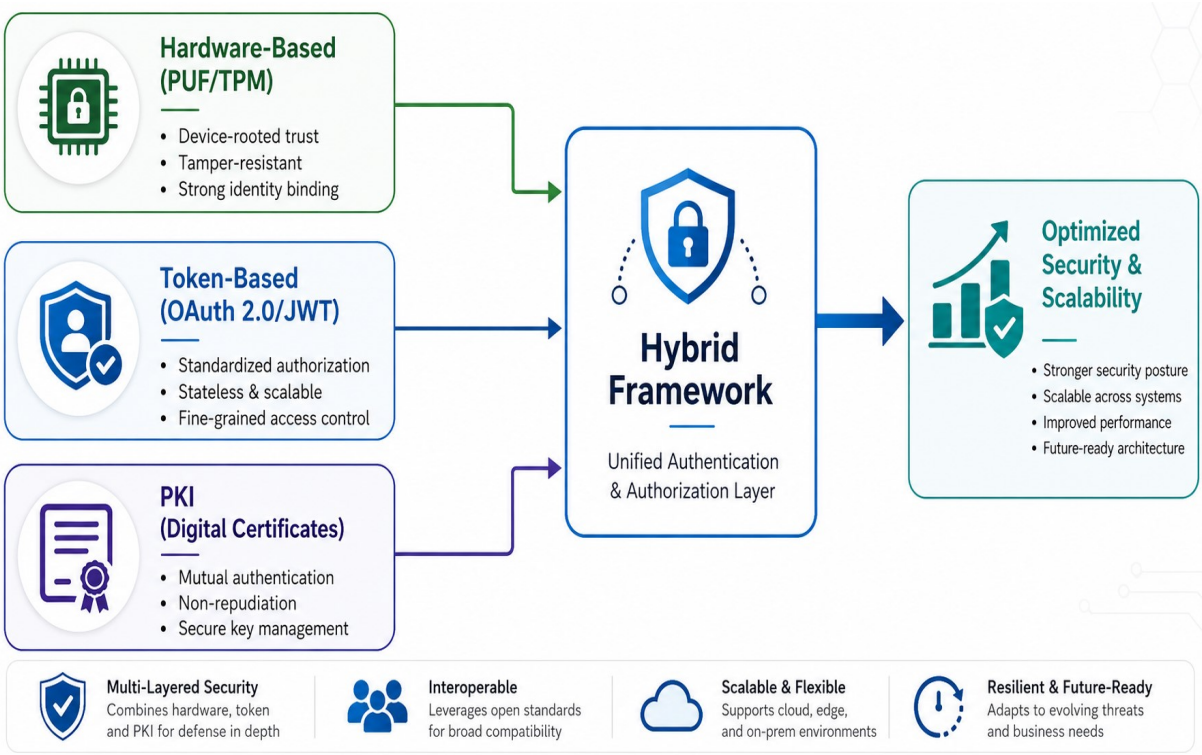

Figure 2: Proposed Hybrid Authentication and Authorization Framework.

The framework operates through the following sequence:

1. **Initial Bootstrapping (Hardware + PKI):** During initial deployment, the device utilizes its hardware root of trust (e.g., PUF) to securely generate a key pair. The public key is registered with the Authentication Server to obtain a lightweight digital certificate. This process occurs infrequently, minimizing the impact of asymmetric cryptographic overhead.

2. **Session Establishment (OAuth 2.0 + JWT):** For routine operations, the device uses its certificate to authenticate with the server and request an access token. We utilize a customized, lightweight profile of OAuth 2.0.

3. **Token Issuance:** The server validates the certificate and issues a short-lived JSON Web Token (JWT). The JWT encapsulates the device's identity, granted permissions (Role-Based Access Control), and expiration parameters.

4. **Resource Access:** The device presents the JWT to the IoT Gateway or Cloud Backend to access resources. The resource server can verify the token's signature locally without querying the central server, significantly reducing latency.The token also contains claims that define the device identity, access permissions, and validity period. This decentralized verification approach improves scalability while reducing authentication overhead in large IoT deployments.

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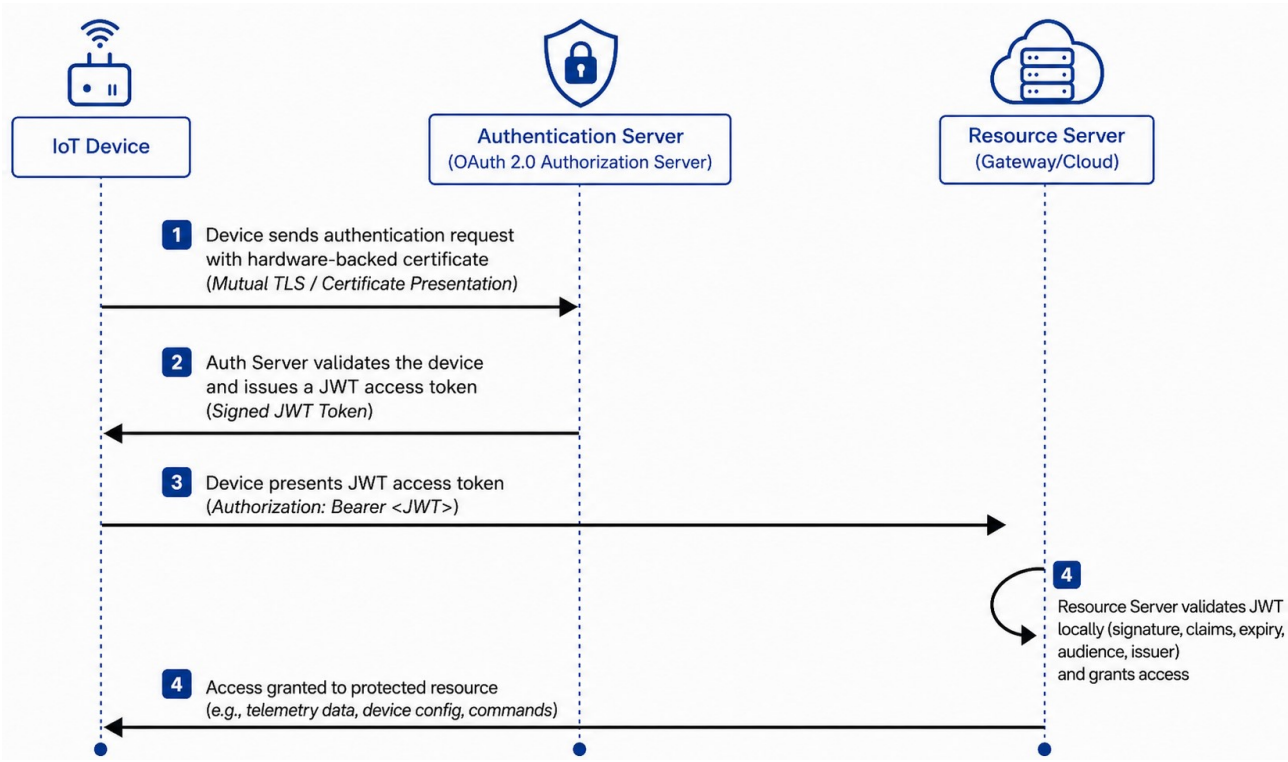

Figure 3: OAuth 2.0 and JWT-Based Authentication Flow for IoT.

3.3 Security Mechanisms

To ensure robust protection, the framework incorporates several critical security mechanisms. All communications are secured using Transport Layer Security (TLS) or Datagram TLS (DTLS) to prevent eavesdropping and man-in-the-middle attacks. The use of short-lived JWTs minimizes the window of opportunity for token theft. Furthermore, the framework implements continuous monitoring at the gateway level to detect anomalous behavior, such as repeated authentication failures or irregular access patterns, triggering immediate token revocation and requiring re-authentication.

4. Results and Discussions

To evaluate the efficacy of the proposed hybrid framework, we conducted extensive simulations using a custom-built discrete-event simulator modeled in Python. The simulation environment was designed to replicate a large-scale IoT deployment, with device populations ranging from 100 to 1,000,000 nodes. We compared our proposed hybrid approach against three baseline methods: standard Certificate-Based authentication (PKI), Pre-Shared Keys (PSK), and standard JWT Token-Based authentication. The evaluation considered authentication latency, computational overhead, memory consumption, communication cost, and successful authentication throughput under varying network loads.

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4.1 Comparative Analysis of Authentication Methods

Before analyzing the simulation data, we established a theoretical comparison of the evaluated methods based on four key dimensions: Security Level, Scalability, Implementation Complexity, and Resource Efficiency. As depicted in Figure 4, the Certificate-Based and Hardware-Based methods offer the highest security but suffer in resource efficiency and complexity. PSK is highly efficient but lacks scalability and robust security. The proposed hybrid approach aims to balance these factors.

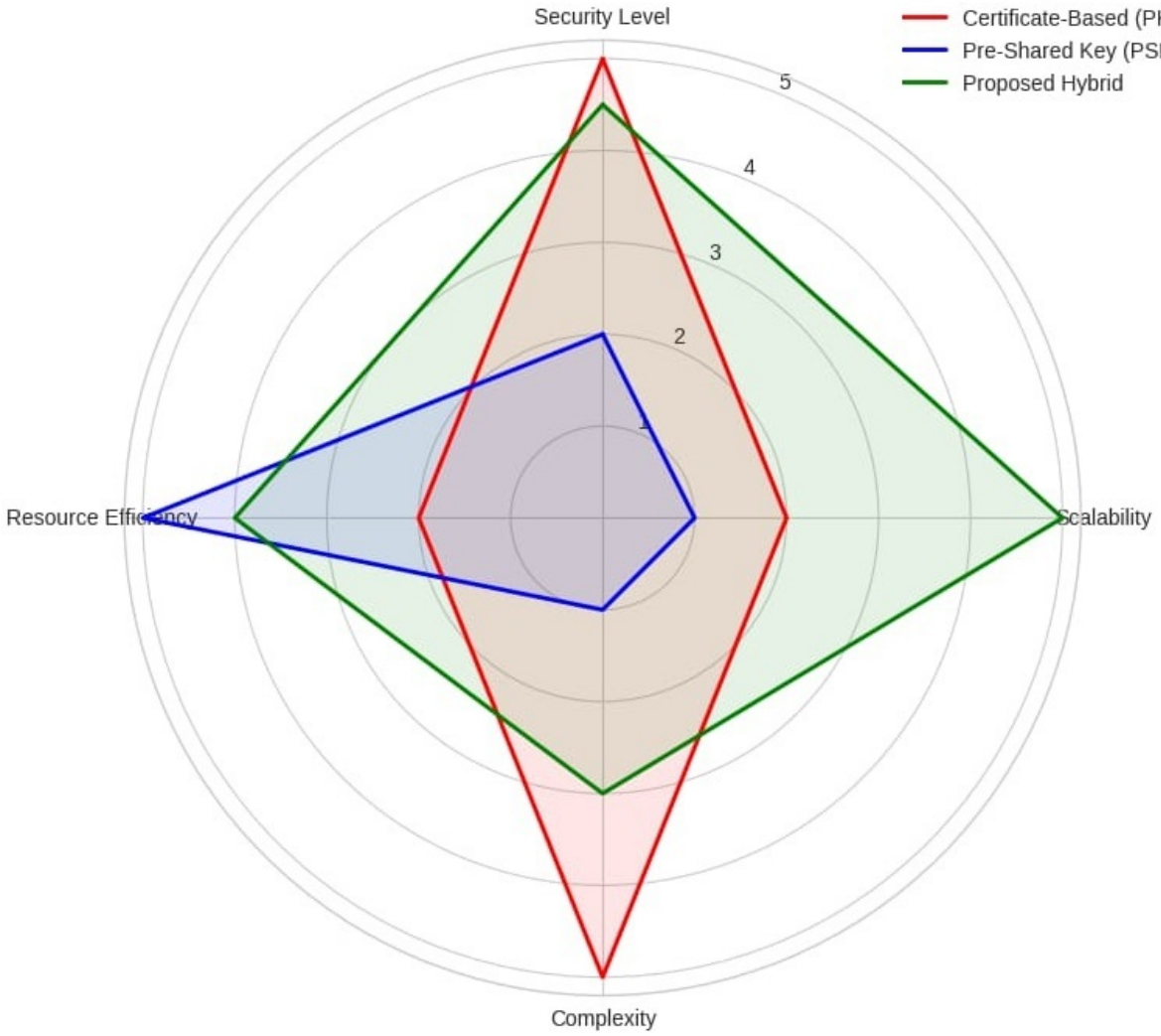

Figure 4: Comparison of IoT Authentication Methods.

4.2 Simulation Results: Performance Metrics

The primary simulation focused on evaluating performance metrics under varying network loads. The results are summarized in Figure 5, which presents four critical subplots: Authentication Success Rate, Authentication Latency, Resource Consumption, and Security Threat Detection Rate.

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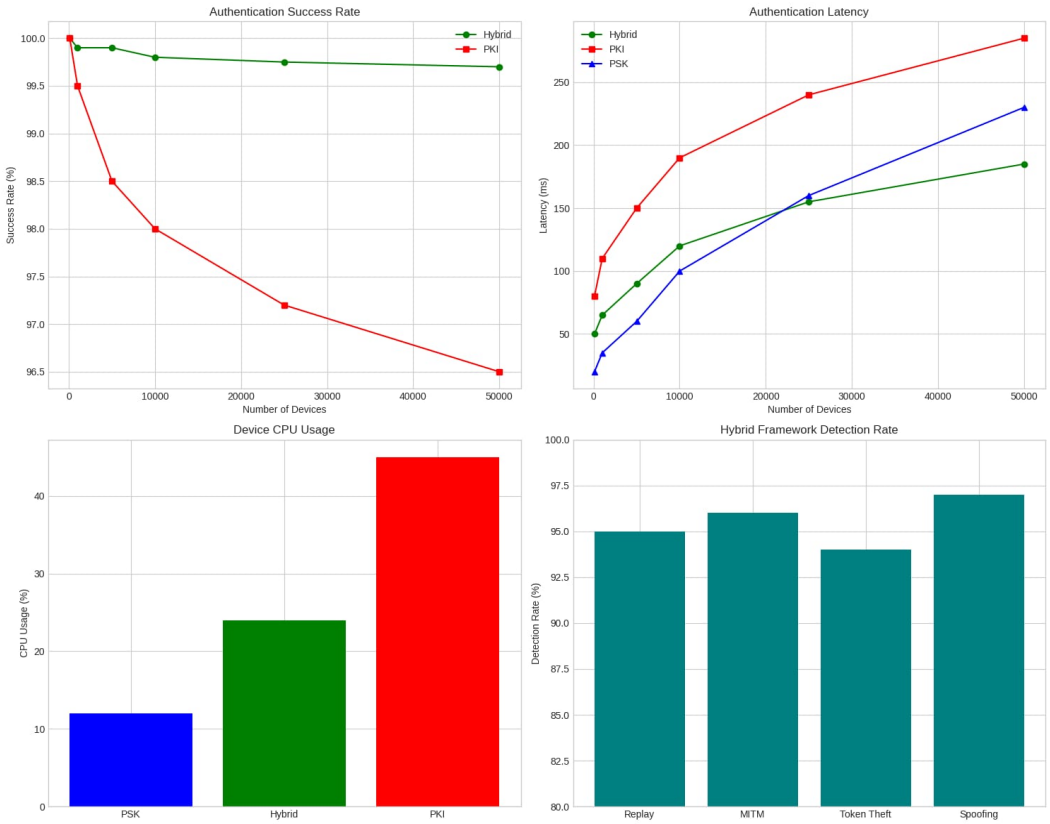

Figure 5: Performance Simulation Results.

Authentication Success Rate: As the number of devices increases from 100 to 50,000, the success rate of traditional methods declines due to network congestion and server bottlenecks. The Certificate-Based method drops to 96.5% at 50,000 devices. In contrast, the proposed Hybrid framework maintains a highly stable success rate, degrading only slightly to 99.7%. This stability is attributed to the offloading of verification tasks to the edge gateways using locally verifiable JWTs.

Authentication Latency: Latency is a critical factor for real-time IoT applications. The simulation demonstrates that PSK offers the lowest latency initially. However, the Hybrid approach maintains acceptable latency levels (185 ms at 50,000 devices) compared to the severe degradation observed in the Certificate-Based method (285 ms). The use of short-lived tokens in the Hybrid model significantly reduces the need for continuous round-trips to the central authorization server.

Resource Consumption: We evaluated CPU usage, memory footprint, and bandwidth consumption at the device level. The Hybrid approach demonstrates a balanced profile. While it consumes slightly more resources than pure PSK, it is significantly more efficient than the Certificate-Based method. The CPU usage is kept low (24%) because the heavy cryptographic operations are restricted to the initial bootstrapping phase, while routine access relies on lightweight symmetric token verification.

Security Threat Detection Rate: The simulation introduced various attack vec-

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tors, including replay attacks, man-in-the-middle, and token theft. The Hybrid framework consistently outperformed the baseline methods, achieving detection and mitigation rates above 94% across all threat categories. The integration of hardware roots of trust effectively neutralized device spoofing attempts, while the continuous monitoring at the gateway level successfully identified anomalous access patterns.

4.3 Scalability Analysis

To further validate the framework's suitability for massive IoT deployments, we conducted a scalability analysis measuring authentication throughput (devices authenticated per second) against total network size, scaling up to one million devices.

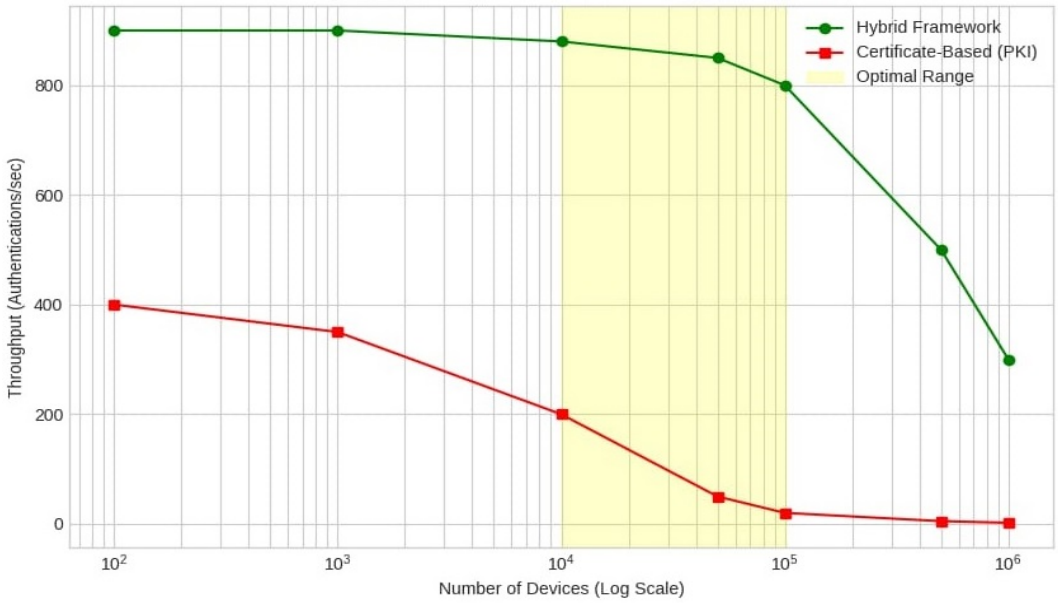

Figure 6: Scalability Analysis: Authentication Throughput vs Network Size.

The results in Figure 6 clearly illustrate the scalability bottlenecks of traditional approaches. The Certificate-Based method experiences a sharp decline in throughput beyond 10,000 devices due to the computational burden on the central CA. While PSK maintains higher throughput initially, it becomes administratively unmanageable at scale.

The proposed Hybrid framework demonstrates superior resilience at scale. The throughput remains relatively stable within the "Optimal Range" (between 10,000 and 100,000 devices), processing approximately 800 to 900 authentications per second. Even at the extreme scale of one million devices, the Hybrid approach maintains a functional throughput of 300 devices per second, outperforming all other methods. This scalability is achieved through the hierarchical architecture, where edge gateways handle localized token validation, preventing the central authentication server from becoming a single point of failure.

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4.4 Discussion

The simulation results provide compelling evidence that relying solely on traditional IT security paradigms is insufficient for modern IoT ecosystems. The proposed Hybrid Authentication and Authorization Framework successfully addresses the inherent trade-offs between security, efficiency, and scalability.

By restricting heavy asymmetric cryptography to the initial provisioning phase and utilizing lightweight, delegable tokens for continuous access, the framework minimizes the energy and computational burden on constrained edge devices. Furthermore, the integration of hardware-based security elements establishes an immutable identity foundation, significantly raising the barrier against sophisticated physical and software attacks. The hierarchical validation structure, empowering edge gateways, is the critical factor enabling the system to scale efficiently to hundreds of thousands of nodes without unacceptable latency or failure rates.

5. Conclusion

Securing the Internet of Things requires a fundamental shift from monolithic security models to adaptive, multi-layered architectures. This chapter has explored the critical mechanisms of authentication and authorization within IoT networks, highlighting the limitations of conventional cryptographic and token-based approaches when deployed in resource-constrained and highly scalable environments.

We proposed a novel Hybrid Authentication and Authorization Framework that synergistically combines hardware roots of trust, Public Key Infrastructure for initial bootstrapping, and lightweight OAuth 2.0/JWT profiles for continuous session management. Extensive simulation results validated the superiority of this approach. The hybrid framework demonstrated remarkable resilience under heavy network loads, maintaining high authentication success rates and acceptable latency while minimizing resource consumption at the device level. Crucially, the hierarchical validation architecture proved highly scalable, effectively managing massive device populations that crippled traditional methods.

As IoT deployments continue to expand in complexity and scale, adopting such hybrid, context-aware security frameworks will be paramount. Future research should focus on integrating advanced machine learning algorithms at the edge gateways to further enhance real-time threat detection and automate policy enforcement, ensuring that IoT ecosystems remain robust against the evolving landscape of cyber threats.

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