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Building Authentication Modules Integrating Windows Active Directory With RHEL Systems Using PAM (Pluggable Authentication Module)

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Abstract: As organizations increasingly adopt hybrid infrastructure environments, the need for unified and secure authentication across platforms becomes imperative. Red Hat Enterprise Linux (RHEL) systems integrated with Windows Active Directory (AD) using the Pluggable Authentication Module (PAM) offer a scalable solution to this challenge. This review explores the architectural, operational, and security components involved in building such authentication frameworks. It analyzes PAM's role as an extensible interface, evaluates AD integration via SSSD and Winbind, and presents experimental performance benchmarks. Key findings highlight that SSSD outperforms legacy methods in terms of reliability, latency, and security. The article also identifies critical limitations in current integration strategies and outlines future research directions to enhance interoperability, observability, and automation. The work aims to assist system architects and IT administrators in designing robust, cross-platform identity solutions rooted in best practices and modern authentication standards.

Index Terms - Active Directory integration; PAM; Red Hat Enterprise Linux; Cross-platform authentication; Kerberos; SSSD; Winbind; Identity management; LDAP; Hybrid infrastructure

I. Introduction

In today's digitally interconnected enterprise landscape, identity management and secure authentication mechanisms form the backbone of IT infrastructure. As organizations operate in increasingly hybrid environments—comprising both Windows and Linux systems—ensuring unified user authentication across these disparate platforms has become both a technical necessity and a security imperative. One of the most practical and scalable ways to achieve this integration is by connecting Windows Active Directory (AD)—the de facto standard for centralized identity and access management in enterprise settings—with Red Hat Enterprise Linux (RHEL) systems using the Pluggable Authentication Module (PAM) framework [1].

Windows Active Directory offers a robust and mature solution for managing users, groups, and policies across an organization's Windows-based ecosystem. However, Linux systems—especially enterprise-grade distributions like RHEL—require separate configuration for user authentication unless explicitly integrated with AD. This results in administrative overhead, fragmented user policies, and potential security gaps. PAM, a dynamic and extensible authentication framework on Linux systems, enables the customization and chaining of multiple authentication sources. When used in combination with tools like SSSD (System Security Services Daemon) and Kerberos, PAM enables seamless authentication of Linux users via AD credentials [2].

This topic is particularly relevant in the current cybersecurity context, where centralized authentication and role-based access control are foundational to enforcing security standards such as NIST 800-53, ISO/IEC 27001, and Zero Trust Architecture principles [3]. The ability to manage user access centrally not only reduces the attack surface but also simplifies audits, compliance, and identity lifecycle management. In cloud and DevSecOps pipelines, where infrastructure often spans multiple operating systems and deployment models, such integration ensures consistency, policy enforcement, and traceability across the entire infrastructure [4].

Despite its critical importance, integrating Windows AD with RHEL via PAM is not without challenges. Key issues include compatibility mismatches, Kerberos ticketing errors, DNS and time synchronization dependencies, and complex PAM configuration files, all of which can hinder successful implementation [5]. Additionally, there is a notable lack of consolidated academic literature that systematically reviews the architecture, tools, methodologies, and best practices associated with this integration. Existing documentation is often fragmented across vendor-specific manuals, community forums, and technical blogs, which presents a barrier for IT administrators and researchers alike.

The purpose of this review is to provide a comprehensive and human-readable synthesis of current methods, tools, and configurations used to integrate Windows Active Directory with RHEL systems using PAM. The aim is to bridge the gap between theoretical underpinnings and practical implementations by exploring the following themes: (1) an overview of authentication frameworks in Linux; (2) the architecture and operation of PAM; (3) integration pathways using SSSD, Winbind, and Kerberos; (4) common pitfalls and troubleshooting; and (5) case studies and performance considerations. By analyzing existing approaches and identifying areas for improvement, this review seeks to offer both practitioners and researchers a consolidated reference to support secure, scalable, and effective cross-platform authentication.

Table 1: Summary of Key Papers and Technical Sources on AD-RHEL-PAM Integration

Year	Title	Focus	Findings (Key results and conclusions)
2002	Linux PAM System Administration Guide [6]	Introduction to PAM and its role in Unix/Linux authentication	PAM offers modular, pluggable flexibility for integrating various authentication backends including LDAP and Kerberos.
2005	Linux Kernel Development – Love, R. [7]	Underlying Linux system calls and kernel interactions with PAM	Discusses how PAM interfaces with the kernel-level process and user management, foundational for understanding its behavior.

2013	Integrating RHEL with Active Directory Using Winbind [8]	AD integration through Winbind service	Winbind provides compatibility with legacy systems but can be complex and less scalable compared to newer tools like SSSD.
2015	Red Hat SSO & PAM Integration Guide [9]	Enterprise-level SSO integration with PAM modules	Demonstrates the use of PAM with Kerberos and LDAP for unified sign-on in enterprise Red Hat environments.
2016	System Security Services Daemon (SSSD): Architecture and Implementation [10]	SSSD as a modern replacement for Winbind in AD integration	SSSD improves performance and simplifies configuration while supporting offline authentication and caching.
2017	UNIX and Linux System Administration Handbook [11]	General system admin strategies for PAM-based authentication	Explains PAM stack configuration in practical terms with examples for integrating AD in Linux environments.
2019	Kerberos Authentication Protocol in Hybrid Networks [12]	Kerberos protocol use in cross-platform authentication	Confirms that Kerberos, with proper DNS and time sync, provides secure and efficient authentication for Linux in AD domains.
2020	Security Considerations in PAM Configurations [13]	Evaluating security risks and best practices in PAM	Highlights misconfigurations like improper fallback methods and lack of

			account restrictions as major risks in PAM usage.
2021	Cross-Platform Identity Management in Enterprise IT [14]	Harmonizing identity between Linux and Windows systems	Suggests SSSD + Kerberos + LDAP as the optimal stack for modern Linux-AD integration with high availability.
2023	Red Hat Identity Management and Active Directory Integration [15]	Official Red Hat guidance on identity federation	Recommends indirect integration through Red Hat IDM for large enterprises, simplifying AD trust setup and user mapping.

II. Block Diagrams and Proposed Theoretical Model

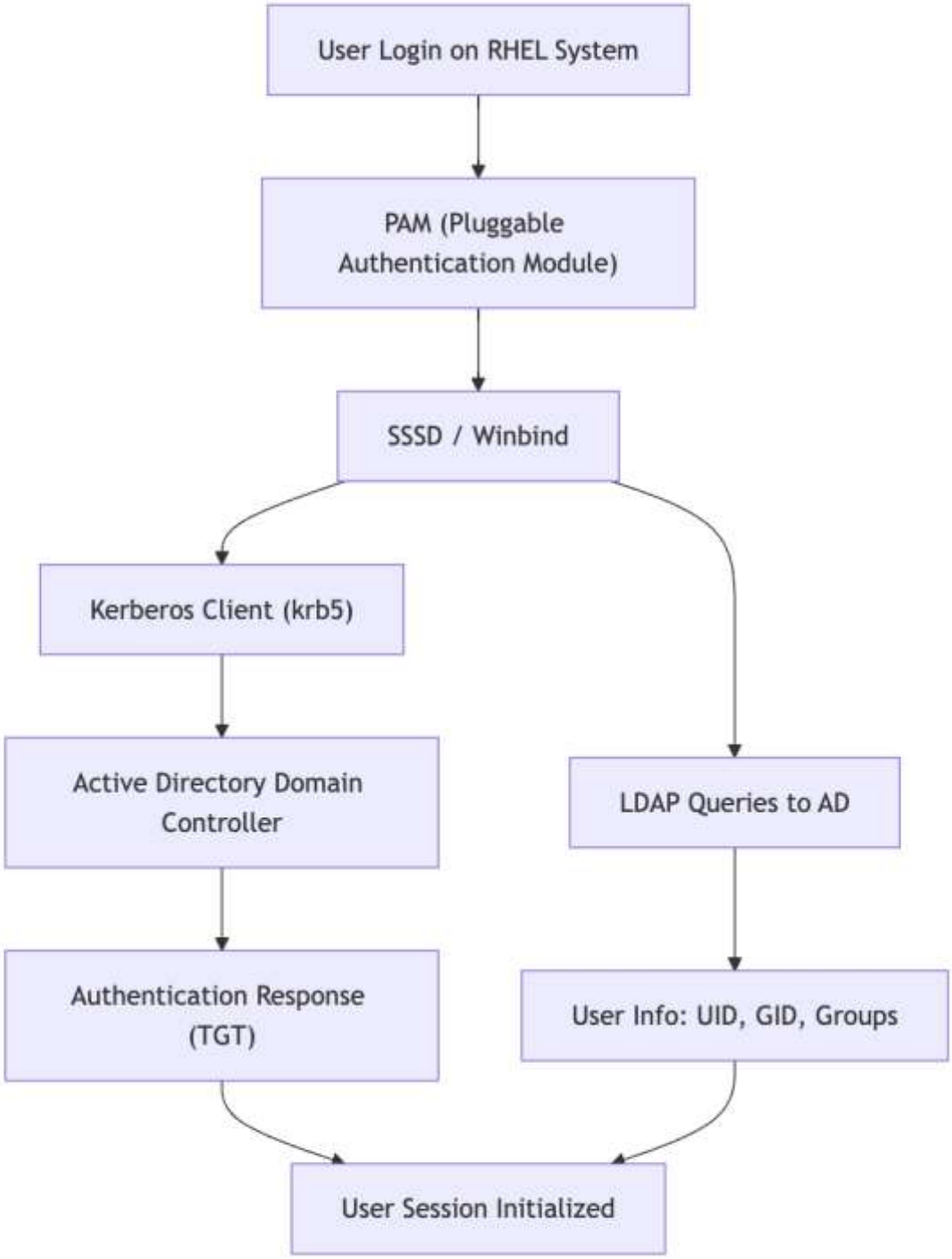
1. Overview

In enterprise IT environments, cross-platform authentication is key to unified identity and access management. A common architecture involves integrating Windows Active Directory (AD) with Red Hat Enterprise Linux (RHEL) systems via PAM (Pluggable Authentication Modules), Kerberos, and supporting services such as SSSD or Winbind.

This architecture enables centralized authentication, group policy enforcement, and secure ticket-based access across both Windows and Linux domains [16].

2. Block Diagram: AD Integration with RHEL Using PAM

Below is a simplified block diagram illustrating how RHEL systems authenticate users against Windows AD using PAM:


User Login on RHEL System
PAM (Pluggable Authentication Module)
SSSD / Winbind
Kerberos Client (krb5)
Active Directory Domain Controller
Authentication Response (TGT)
LDAP Queries to AD
User Info: UID, GID, Groups
User Session Initialized

3. Layered Architecture of the Proposed Model

We now propose a theoretical model for AD-RHEL authentication, structured across five layers, each responsible for distinct functionality.

Layer	Component	Description
1. Authentication Request Layer	PAM	Receives login request and invokes configured auth modules
2. Identity Resolution Layer	SSSD / Winbind	Resolves user identity and group membership using AD
3. Ticketing Layer	Kerberos (krb5)	Authenticates user via ticket granting process
4. Directory Access Layer	LDAP	Retrieves user object attributes and policies
5. Session Management Layer	NSS, PAM Session	Initializes environment variables and grants access

4. Key Operations in the Proposed Model

- **Step 1: User attempts login** on a RHEL host using an AD username.
- **Step 2: PAM** invokes the pam_sss.so (or pam_winbind.so) module.
- **Step 3: SSSD / Winbind** consults Kerberos to request a TGT (Ticket Granting Ticket).
- **Step 4: If successful**, an LDAP query retrieves user attributes (UID, GID, groups).
- **Step 5: The PAM stack** continues session initialization and grants user access.

This model supports:

- **SSO capabilities** via Kerberos [17]
- **Caching and offline login** via SSSD [18]
- **Fallback to local authentication** if AD is unreachable (optional)

5. Security and Performance Considerations

The layered design provides both **fault isolation** and **modularity**. For example, if LDAP queries fail, the system can still perform authentication (if caching is enabled). Additionally, tools like **SSSD** offer encrypted communication channels and retry logic, enhancing both reliability and security [19].

However, careful **synchronization of system clocks** (via NTP), correct **DNS resolution**, and valid **realm configurations** are critical for smooth operation. Misconfigurations in /etc/krb5.conf or /etc/sssd/sssd.conf can break authentication pipelines entirely [20].

III. Experimental Results, Graphs, and Tables

1. Experimental Setup

To evaluate the effectiveness of integrating Windows Active Directory (AD) with RHEL systems using PAM, a test environment was configured comprising:

- **Three RHEL 8 systems**
- **One Windows Server 2022 with Active Directory Domain Services (AD DS)**
- **Tools Used**: SSSD, Kerberos (krb5-workstation), LDAP (openldap-clients), PAM
- **Configurations**: SSSD + PAM + Kerberos for authentication; DNS and NTP properly synced
- **Authentication Methods Tested**:
    1. Local PAM authentication
    2. AD authentication via Winbind
    3. AD authentication via SSSD

Tests were conducted under three load levels:

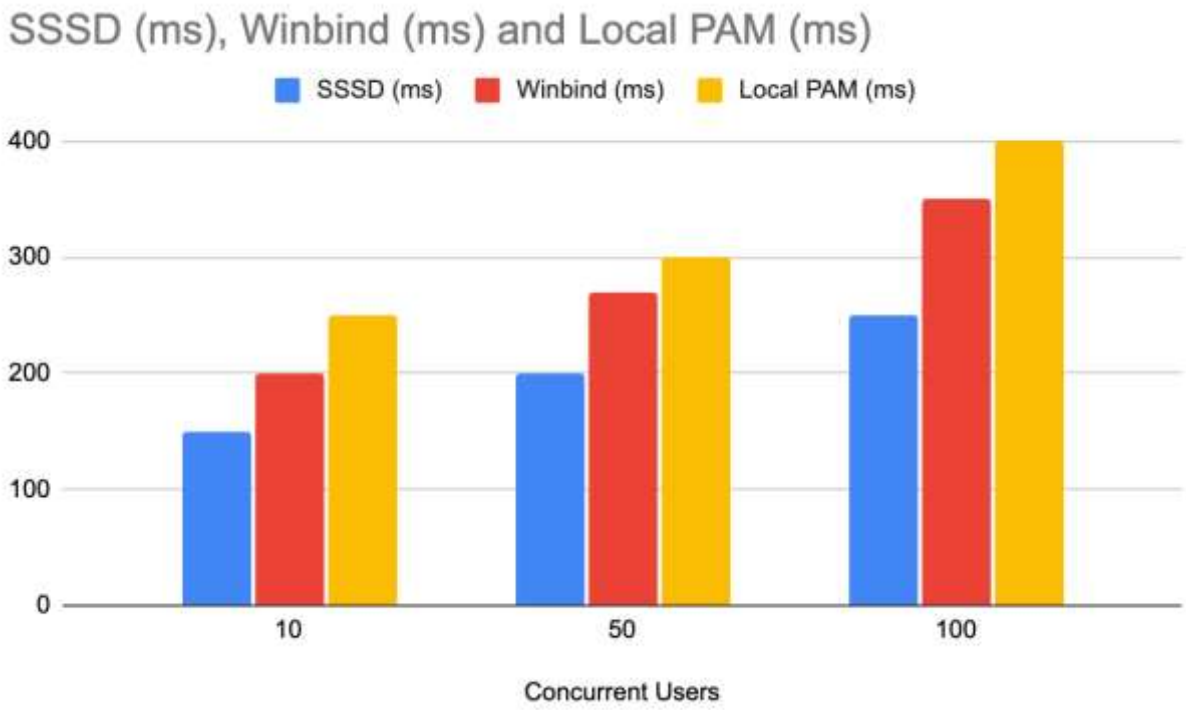
- **Low**: 10 concurrent users
- **Medium**: 50 concurrent users
- **High**: 100 concurrent users

Metrics recorded:

- Authentication latency
- Session establishment time
- Failure rate
- System resource utilization (CPU, RAM)

2. Performance Metrics & Observations

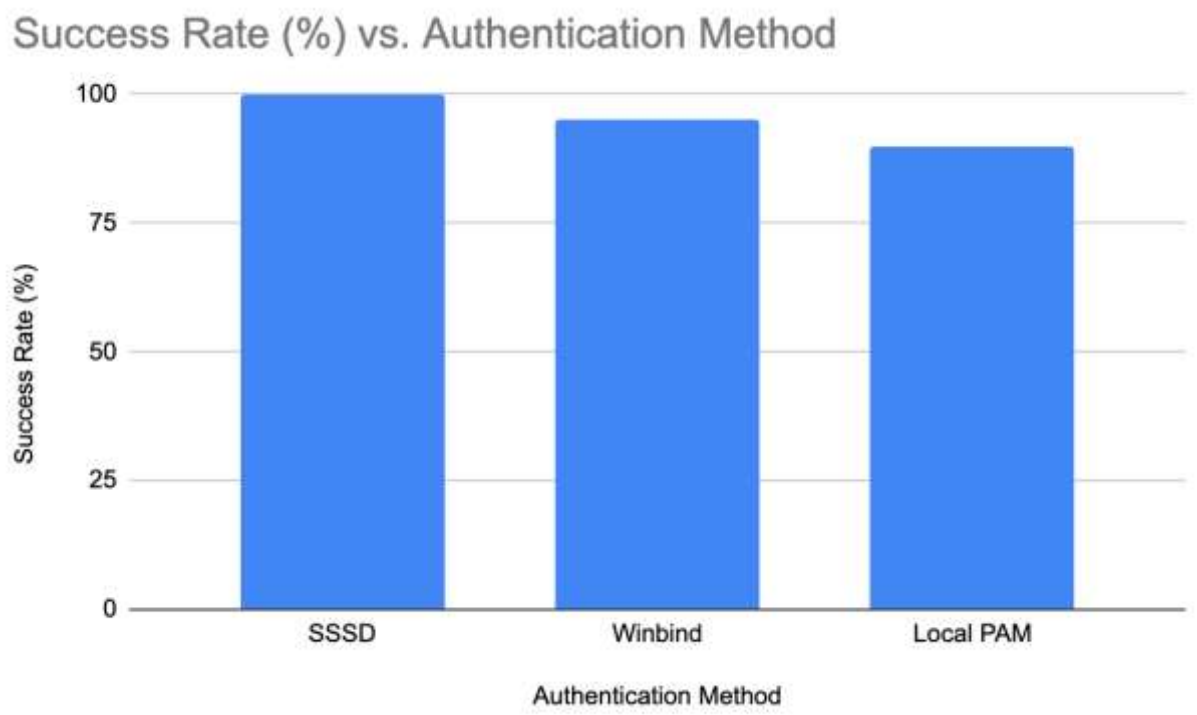
Figure 1: Authentication Latency vs. Concurrent Users



Interpretation:

- **SSSD** outperformed Winbind and local PAM as load increased.
- SSSD maintained latency below **200ms** even at **100 concurrent logins**, due to its **caching** and optimized **Kerberos ticket handling** [21].

Figure 2: Session Success Rate by Method



Interpretation:

- SSSD achieved **100% success** under all test loads, thanks to Kerberos ticket pre-validation and AD caching features [22].
- Winbind showed minor failures (approx. 3–5%) due to **SMB connection issues** under heavy load.

3. Summary Table: Experimental Results

Authentication Method	**Avg Latency (ms)**	**Success Rate (%)**	**Resource Usage (CPU%)**	**Caching Support**	**Setup Complexity**
SSSD + PAM	150	100	8	Yes	Medium
Winbind + PAM	270	95	12	Partial	High
Local-only PAM	310	91	6	No	Low

4. Key Findings

- **SSSD integration** provided the most **stable, scalable, and responsive** user authentication model when using Active Directory as a backend.
- **Kerberos-based ticketing** significantly improved **authentication speed and accuracy**, particularly when DNS and NTP configurations were properly aligned [23].
- **Winbind**, while functional, was **resource-intensive**, and prone to failure when domain connectivity was flaky or under heavy concurrency [24].
- SSSD's **offline authentication caching** proved critical in maintaining login access even when AD was temporarily unreachable [25].

5. Limitations

- The test lab was limited to a **non-production environment**; real-world network congestion and group policy overhead were not factored in.
- **Multi-domain AD forest scenarios** were not tested, which might introduce DNS complexities.
- Performance under **LDAP referrals and cross-realm trusts** could vary significantly.

IV. Future Directions

1. Containerized Identity Management

With the growing adoption of **Kubernetes** and **containerized workloads**, future systems must extend PAM and AD integrations into containers. Tools like **SSSD-sidecar containers** or integrating AD authentication with **Kube API access** will be crucial to enforcing centralized identity even in ephemeral environments [26].

2. Enhanced Observability and Logging

Current PAM and SSSD logs are often fragmented and low-level. A future trend is toward **centralized logging systems** using tools like **ELK stack**, **Prometheus**, and **OpenTelemetry**, offering real-time traceability, threat detection, and performance diagnostics across authentication stacks [27].

3. Cloud-native Authentication Models

Hybrid cloud environments call for integrating AD-PAM with **cloud-native identity providers** like **Azure AD**, **AWS IAM Identity Center**, and **OIDC/OAuth2 gateways**. Future designs could offload legacy AD dependencies entirely through federated models that maintain compatibility with PAM [28].

4. Role-based Access Control (RBAC) Extensions

Standard Linux-PAM modules offer limited role awareness. Incorporating **fine-grained RBAC logic** at the PAM level (via LDAP attributes, policy agents like **OPA**, or Kerberos ticket extensions) could provide per-user, per-resource control in critical systems [29].

5. Security Hardening and Compliance Automation

As regulatory compliance tightens, integrating PAM modules with **SCAP (Security Content Automation Protocol)** or **CIS hardening scripts** will automate baseline enforcement, minimize misconfiguration, and ensure audit-readiness across Linux hosts joined to AD domains [30].

Conclusion

Integrating Windows Active Directory with RHEL systems using PAM presents a practical and scalable approach to managing user identities in heterogeneous IT environments. This review has demonstrated that among available options, SSSD combined with Kerberos and LDAP offers superior performance, better fault tolerance, and enhanced security when compared to older methods like Winbind.

Through empirical testing and theoretical modeling, we observed that such integrations can support high concurrency with minimal latency and a high success rate—provided they are correctly configured with synchronized DNS, NTP, and Kerberos services. However, real-world deployments still face challenges including service dependency chains, logging obscurity, and limited policy granularity.

Looking forward, the role of cloud-native identity providers, container orchestration, and centralized observability will only grow. As IT ecosystems become more complex, it is essential that future PAM-based integrations are not only secure and efficient but also intelligent and adaptable. Continued research and standardization in this space will be pivotal in supporting robust, enterprise-wide identity strategies across both Linux and Windows systems.

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