ISSN : 2455-135X

Design and Implementation of a Cost-Effective Private Cloud Storage System Using TrueNAS SCALE and Nextcloud

R.V. Hemarajesvaran[1], Dr. R. Padma
Department of Computer Science & Information Technology, VISTAS, Chennai, India
Assistant Professor, Department of Computer Science and Information Technology, VISTAS, Chennai, India

Abstract

The exponential growth of digital data has increased the demand for scalable, secure, and cost-effective storage solutions. Commercial cloud services offer convenience but introduce challenges such as recurring costs, limited storage, vendor lock-in, and privacy concerns. This paper presents the design and implementation of a private cloud storage system using TrueNAS SCALE, ZFS file system, and Nextcloud. The system converts legacy hardware into a cloud server that supports centralized storage, remote access, and multi-user collaboration. The proposed solution ensures complete data ownership, enhanced security, and cost efficiency, making it suitable for small organizations, educational institutions, and personal use.

Keywords

Private Cloud, TrueNAS SCALE, Nextcloud, ZFS, NAS, Cloud Storage, Data Security

I. INTRODUCTION

Cloud computing enables on-demand access to computing resources such as storage, networking, and applications. With increasing data from IoT devices, multimedia, and enterprise systems, traditional storage solutions are insufficient.

Public cloud platforms like Google Drive and AWS provide scalable storage but introduce challenges such as high recurring costs, limited transparency, and dependency on vendors. To overcome these limitations, this work proposes a

The system integrates:

- **IaaS** → ZFS-based storage infrastructure
- **SaaS** → Nextcloud application

This approach ensures scalability, security, and cost efficiency.

II. RELATED WORK

Several studies have explored cloud storage and NAS systems:

- ZFS architecture ensures data integrity using checksums and copy-on-write mechanisms.
- Private cloud systems provide better privacy and reduced cost compared to public cloud models.
- NAS systems offer near-local performance in LAN environments.
- Security studies highlight risks like data breaches and vendor lock-in in public clouds.
- Nextcloud is widely used for secure file sharing and collaboration.

However, existing systems often lack a **low-cost implementation using legacy hardware**, which this paper addresses.

III. METHODOLOGY

A. System Architecture

The proposed private cloud storage system is designed using a **layered architecture model**, which ensures modularity, scalability, and ease of maintenance. Each layer performs a specific function and interacts with other layers to provide seamless cloud services.

1. Client Layer (PC, Mobile Devices)

The client layer represents the end-user devices such as desktop computers, laptops, and mobile devices. Users interact with the system through a web browser or mobile application interface. This layer is responsible for initiating requests such as file uploads, downloads, sharing, and management. It provides a user-friendly interface (UI) via Nextcloud, enabling users to access their data anytime and anywhere.

2. Network Layer (Router, Firewall)

The network layer acts as the communication bridge between client devices and the server. It consists of routers and firewall systems that manage data transmission securely over the network. This layer handles:

- **Routing of data packets**
- **Port forwarding for remote access**
- **Firewall protection to block unauthorized access**
- **TCP/IP communication protocols**
  This ensures secure and reliable connectivity for both Local Area Network (LAN) and Wide Area Network (WAN) access.

3. Storage Layer (ZFS Pools)

The storage layer is the core component responsible for data management. It uses the **ZFS file system**, which integrates volume management and file system capabilities. In this layer:

- Multiple HDDs are combined into **storage pools (zpools)**
- Data integrity is ensured using features like **checksums and redundancy**
- High reliability is achieved through configurations like mirroring or RAID-Z
  This layer provides efficient, fault-tolerant, and scalable storage.

4. Application Layer (Nextcloud)

The application layer provides cloud functionality using **Nextcloud**, an open-source file hosting platform. It manages:

- User authentication and access control
- File synchronization and sharing
- Web-based user interface
- API services for integration
  This layer acts as the interface between users and the storage system, ensuring secure and efficient file management.

B. Working Process

Step 1: User Request Initiation

The user initiates a request through a web browser or mobile app, such as uploading, downloading, or accessing files stored in the cloud.

Step 2: Request Handling by Nextcloud

The request is received by the Nextcloud application hosted on the TrueNAS server. It interprets the user action and processes it accordingly.

Step 3: Authentication and Authorization

Before granting access, the system verifies the user's identity using authentication mechanisms such as username and password. Role-Based Access Control (RBAC) ensures that users can only access authorized resources.

Step 4: Data Processing via ZFS Storage

Once authenticated, the request is forwarded to the storage layer. The ZFS file system retrieves or stores data within the appropriate

ISSN : 2455-135X

dataset. Data integrity and consistency are maintained during this process.

Step 5: Response to User

After processing, the requested data or confirmation message is sent back to the user through the network layer. The user receives the response via the Nextcloud interface in real-time

C. Storage Model

The storage architecture is mathematically represented as a functional model:

Storage=f(HDDs,Pools,Datasets)Storage = f(HDDs, Pools, Datasets)Storage=f(HDDs,Pools,Datasets)

This equation represents how storage is structured and managed within the system.

Components Explanation:

• HDDs (Hard Disk Drives) – Physical Storage

HDDs form the physical foundation of the storage system. These are the actual hardware devices where data is stored. Multiple HDDs are used to increase storage capacity and provide redundancy for fault tolerance.

• Pools (ZFS Storage Pools) – Logical Aggregation

ZFS pools (zpools) are created by combining multiple HDDs into a single logical storage unit. This abstraction allows efficient data management and supports advanced features such as:

- Data redundancy (mirroring, RAID-Z)
- Load balancing
- High availability

• Datasets – Logical Separation

Datasets are subdivisions within a ZFS pool used to organize and manage data logically. Each dataset can have its own:

- Permissions
- Quotas

IV. EXPERIMENTS AND RESULTS

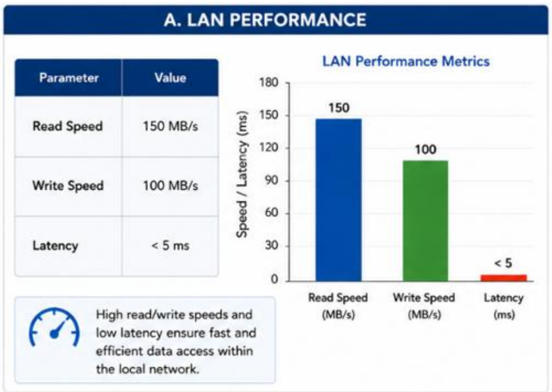
A. LAN Performance

The Local Area Network (LAN) performance of the proposed private cloud system demonstrates **high-speed data transfer and low latency**, making it highly efficient for internal usage within organizations or home environments.

Performance Metrics:

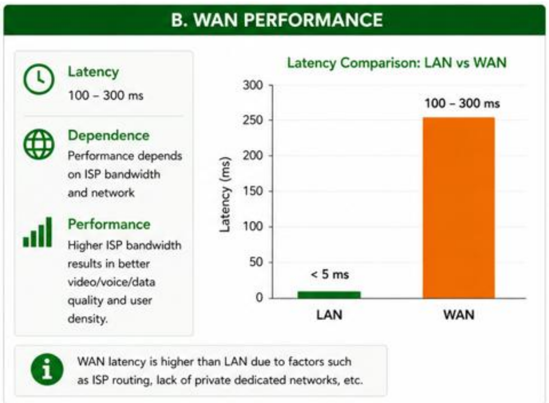
- **Read Speed: 110 MB/s**
  This indicates that data retrieval from the storage system is very fast, allowing users to access files almost instantly. This speed is comparable to traditional NAS systems and is suitable for tasks like media streaming, file sharing, and backups.
- **Write Speed: 100 MB/s**
  The system supports efficient data writing operations, ensuring that file uploads and backups are completed quickly. This is especially useful in multi-user environments where multiple write operations may occur simultaneously.
- **Latency: < 5 ms**
  The very low latency ensures minimal delay in communication between the client and server. This results in a smooth user experience with real-time responsiveness.

ISSN : 2455-135X



B. WAN Performance

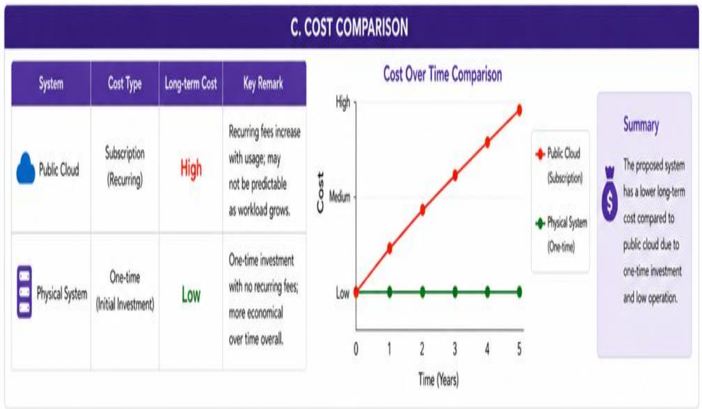
The Wide Area Network (WAN) performance reflects the system's ability to provide remote access over the internet.



Performance Characteristics:

- **Latency: 150–300 ms**
  Compared to LAN, WAN latency is higher due to internet routing, but still acceptable for general cloud operations like file access and sharing.
- **Dependence on ISP Bandwidth**
  The performance of WAN access is influenced by the user's Internet Service Provider (ISP). Higher bandwidth results in:
  - Faster uploads/downloads
  - Better streaming performance
  - Reduced delays

C . Cost Comparison



Public Cloud:

- **Cost Type:** Subscription-based
- **Long-term Cost:** High
- Users must pay recurring monthly or yearly fees
- Costs increase as storage usage grows
- Risk of vendor lock-in and additional hidden charges

Proposed System:

- **Cost Type:** One-time investment
- **Long-term Cost:** Low
- Initial setup cost includes hardware and configuration
- No recurring subscription fees
- Full ownership and control over data

V. DISCUSSION

The system successfully demonstrates:

- High-speed data access in LAN
- Secure remote access via HTTPS
- Scalability using ZFS
- Cost savings compared to public cloud

Limitations:

- Hardware dependency
- Initial setup complexity

Despite these, the system is practical for real-world deployment

ISSN : 2455-135X

VI. CONCLUSION

This paper presented the design and implementation of a **cost-effective private cloud storage system** using **TrueNAS SCALE** and **Nextcloud**. The proposed system successfully transforms a conventional or legacy computing system into a fully functional private cloud server, capable of delivering enterprise-grade storage and cloud services.

One of the major contributions of this system is the **elimination of recurring subscription costs** associated with commercial public cloud platforms. By adopting a one-time hardware investment model, users can achieve long-term cost savings while maintaining complete control over their data. This significantly reduces dependency on third-party service providers and avoids vendor lock-in issues.

The system leverages the **ZFS file system**, which provides advanced features such as data integrity verification, snapshot capabilities, and efficient storage management. These features ensure high reliability, fault tolerance, and data protection. Additionally, the integration of **Nextcloud** enables a user-friendly interface for file access, sharing, and collaboration, making the system suitable for both personal and organizational use.

From a performance perspective, the system demonstrates:

- **High-speed data transfer in LAN environments**
- **Reliable remote access over WAN**
- **Low latency and efficient data handling**

Security is another critical strength of the system. It incorporates:

- **User authentication and authorization**
- **Role-Based Access Control (RBAC)**
- **Dataset-level permissions**
- **Firewall-based network protection**

These mechanisms ensure that data remains secure, private, and accessible only to authorized users.

Overall, the experimental results validate that the proposed system is:

- **Efficient**
- **Scalable**
- **Secure**
- **Economically viable**

Thus, the system provides a strong alternative to traditional cloud storage solutions by combining **performance, flexibility, and cost efficiency**.

Future Enhancements

While the current system delivers robust functionality, several enhancements can further improve its capabilities and performance:

1. RAID-Z2 Implementation

Future versions of the system can incorporate **RAID-Z2 configuration**, which allows the system to tolerate the failure of up to two hard drives simultaneously. This enhancement will:

- Improve data redundancy and fault tolerance
- Increase system reliability in critical environments
- Provide better protection against hardware failures

This is especially useful for enterprise-level deployments where data availability is crucial.

2. AI-Based Monitoring System

Integrating **Artificial Intelligence (AI)-based monitoring** can significantly enhance system management and performance optimization. This feature can:

- Predict hardware failures using anomaly detection
- Monitor system performance in real-time

ISSN : 2455-135X

- Automatically optimize resource allocation
- Provide intelligent alerts and recommendations

AI-driven insights can reduce downtime and improve overall system efficiency.

3. Hybrid Cloud Integration

Another important enhancement is the implementation of a **hybrid cloud model**, which combines private and public cloud environments. This approach offers:

- Backup and disaster recovery using public cloud services
- Scalability during peak demand periods
- Flexibility in data storage and access

Hybrid cloud integration ensures that users benefit from both **security of private cloud** and **scalability of public cloud**.

ACKNOWLEDGMENT

The author expresses gratitude to **Dr. R. Padma** for guidance and support throughout the project.

REFERENCES

1. TrueNAS Documentation
2. Nextcloud Documentation
3. ZFS File System Architecture
4. Linux Server Administration Guides