Personal cloud-based NAS development

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January 29, 2025

Resum–El Network-Attached Storage (NAS) s'ha convertit en una solució essencial per als usuaris que requereixen un emmagatzematge de dades fiable, configurable i eficient. Mentre que els serveis d'emmagatzematge basats en el núvol com Google Drive o Dropbox ofereixen facilitat d'accés, presenten limitacions pel que fa a la privacitat de les dades, el control sobre el hardware i les dades i els costos de subscripció continuats. Aquest article explora el desenvolupament d'una solució NAS personalitzada utilitzant OpenMediaVault que proporciona als usuaris un sistema d'emmagatzematge econòmic, privat i escalable. El projecte està centrat en la implementació d'una configuració RAID 5 per garantir la redundància de les dades i el rendiment, tot integrant funcionalitats similars al núvol mitjançant Nextcloud per a l'accés remot i la col·laboració. Per analitzar el rendiment de la configuració RAID 5, s'ha utilitzat CrystalDiskMark com a eina de referència. Aquesta utilitat àmpliament reconeguda s'especialitza a mesurar el rendiment dels discs avaluant tant les velocitats de lectura/escriptura seqüencials com les aleatòries. Finalment, s'ha fet un anàlisi econòmic fent servir mètriques del TCO, el període de recuperació i el ROI per avaluar la viabilitat econòmica de la solució proposada. Els resultats demostren que la nostra solució supera les alternatives pel que fa a l'eficiència econòmica i la sostenibilitat a llarg termini.

Paraules clau– Emmagatzematge Connectat a Xarxa; Emmagatzematge al núvol; Protocols de Compartició de Fitxers; Gestió de Dades; OpenMediaVault; Sistema de Fitxers; Redundància de Dades; RAID5; Desplegament; Accés Remot; VPN; WireGuard.

Abstract– Network-Attached Storage has become an essential solution for users who require reliable, configurable and efficient data storage. While cloud-based storage services like Google Drive or Dropbox offer ease of access, they come with limitations regarding data privacy, control and ongoing subscription costs. This paper explores the development of a custom-built NAS solution using OpenMediaVault that provides users with a cost-effective, private and scalable storage system. The project focuses on deploying a RAID 5 configuration to ensure data redundancy and performance while integrating cloud-like features using Nextcloud for remote access and collaboration. To analyze the performance of the RAID 5 configuration, CrystalDiskMark was used as the benchmarking tool of choice. This widely recognized utility specializes in measuring disk performance by evaluating both sequential and random read/write speeds. Finally, an economic analysis was conducted using metrics such as TCO, payback and ROI to evaluate the economic viability of the proposed solution. Results demonstrate that the proposed solution outperforms alternative approaches in terms of cost-efficiency and long-term sustainability.

Keywords– Network-Attached Storage; Cloud Storage; File Sharing Protocols; Data Management; OpenMediaVault; File System; Data Redundancy; RAID5; Deployment; Remote Access; VPN; WireGuard;

1 Introduction

Data storage and management are at the core of modern digital infrastructure, both for personal and professional applications. In today's homes devices such as smartphones, cameras, smart TVs and home automation systems continuously generate large volumes of data, especially multime-

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dia files like photos, videos, music, digital books and academic materials. With the exponential growth of these data types, particularly in terms of high-definition media, personal files and university resources, the need for efficient, reliable and secure storage solutions for home users has never been greater. Network-Attached Storage (NAS) [1, 2] systems provide a platform for managing and sharing data across devices, offering centralized access, redundancy and enhanced reliability compared to other storage solutions.

While commercial NAS devices from brands like Synology [3] and QNAP [4] dominate the market, they come with great cost implications and limited customization options. These devices often have proprietary hardware and software, restricting the ability to upgrade, modify or repair the system to meet specific needs. Also, they may not support custom configurations or software, limiting users who require more personalized setups. On the other hand, cloud-based services provide convenience, allowing users to easily use storage without worrying about physical hardware. However, they often lack the privacy and control desired by many users. Data is stored on third-party servers, meaning users have limited control over their data. This project aims to address these limitations by developing a custom-built NAS with cloud features, aimed at home users, using OpenMediaVault (OMV).

The main objective of this project is to deliver a cost-effective, secure and configurable storage solution for home users, taking into account that most users will be using Windows as their operating system. For the development of this project, OpenMediaVault (OMV) has been chosen for its robust performance and flexible configuration options. Firstly, OMV is tailored for small scale, home based NAS systems, providing an intuitive graphical user interface for easy setup and management. On top of that it offers the flexibility for more experienced users to control the system through the terminal. This approach mimics professional environments where most tasks are performed through a web interface. OMV's modular architecture, powered by plugins, allows for extensive customization and integration with additional features, such as software RAID configurations and advanced file-sharing protocols like Samba (SMB) or NFS. Furthermore, OMV supports a wide range of file systems, including EXT4. Given the importance of the data to be stored, EXT4 was selected due to its proven reliability, ensuring the integrity and security of the machine's stored information.

This project also explores the incorporation of cloud features to enhance file accessibility and collaboration. Aiming to replicate a 'Google Drive'-like experience. Although the integration of Nextcloud is not the primary purpose of the NAS in this project, it serves as an additional feature for enhanced file sharing and co-editing possibilities.

To enhance the accessibility of the NAS, a secure remote access solution was implemented using a VPN. WireGuard, an open-source VPN software known for its high-speed performance, was selected for its security and efficiency. This allows system administrators to manage the NAS and access files remotely, even outside the local network.

To evaluate the effectiveness of the proposed solution, an economic and a performance analysis were conducted. The total cost of ownership for 6TB of storage across different options is presented, along with the return on investment and payback period for the physical alternatives (Synology and the proposed system). Google One was used as the baseline price for these calculations. The RAID 5 configuration was tested with a simulated disk failure. A read and write test was also performed using CrystalDiskMark.

The rest of the paper is organized as follows. In Section 2, related works are reviewed, including an overview of Network-Attached Storage (NAS), RAID configurations, file systems, network file-sharing protocols and presents the available alternatives. Section 3 describes the proposed methodology, detailing the software and hardware selection, the setup of the local NAS environment and the integration of cloud-based solutions. Section 4 presents the results of the economic and performance analyses, comparing the proposed solution with commercial alternatives. Finally, Section 5 concludes the paper with conclusions and future works, highlighting the potential enhancements and long term benefits of the custom NAS solution.

2 STATE OF THE ART

2.1 What is a NAS?

A NAS is a specialized device designed to store and manage data files. It allows multiple users and devices to access the stored data simultaneously over a Transmission Control Protocol/Internet Protocol (TCP/IP) network through WiFi or Ethernet. Most of the time, NAS devices use multiple hard drives or solid-state drives (SSDs) or hard disk drives (HDDs) configured using a technology called Redundant Array of Independent Disks (RAID) [5] arrays to ensure data redundancy and reliability.

2.2 Redundant Array of Independent Disks

RAID refers to various taxonomy definitions for organizing disk arrays. Each RAID level offer unique trade-offs between speed, fault tolerance and storage efficiency [5].

There are six basic levels of RAID [6]:

- **RAID 0:** Divides data across multiple disks to improve performance. It does not offer redundancy, if one disk fails, all information is lost (Figure 1).

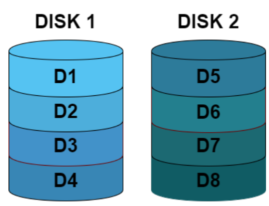

Fig. 1: RAID 0 with two disks. D*X* accounting for data chunks.

- **RAID 1:** Duplicates data on two disks. It offers high reliability, as if one disk fails, the data is still available on the other (Figure 2).

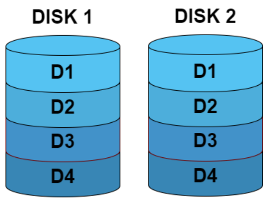

Fig. 2: RAID 1 with two disk. DX accounting for data chunks.

- **RAID 2:** Uses error correction (ECC) to detect and correct bit-level failures. However, because the error correction disks are used for Hamming code, the usable space is limited and inefficient in practice.
- **RAID 3:** Data is split at the bit level with a dedicated disk for parity. Four 1 TB disks in RAID 3 provide 3 TB of usable space (4 TB total minus 1 TB of parity).
- **RAID 4:** Similar to RAID 3, but distributes data in blocks.
- **RAID 5:** Parity is distributed among all disks, improving both performance and fault tolerance. This setup is ideal for achieving a balance between performance and data redundancy. RAID 5 can tolerate failure of a single disk without data loss (Figure 3).

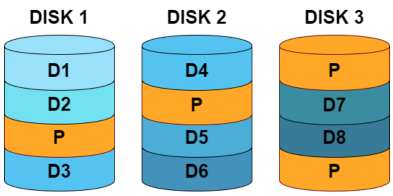

Fig. 3: RAID 5 configuration with three disks. Data chunks are denoted by DX and parity chunks by PX.

- **RAID 6:** Similar to RAID 5, but with double parity, allowing the failure of two disks. Offers higher security, though with a slight performance decrease (Figure **??**).

Additionally, a combination of some of the RAID levels listed before is often employed to improve both performance and fault tolerance. The most widely used hybrid RAID alternative is [7]:

- **RAID 10 (1+0):** Using four or more disks, data is mirrored within each pair of disks (RAID 1) and then striped across multiple pairs of disks (RAID 0). This provides the benefits of both. If a single disk in any mirrored pair fails, the system can continue running with the surviving disk in that pair.

2.3 File systems

A file system [8] is used by an operating system (OS) to manage and organize files on storage devices such as disks or tapes. It maps logical files (which are sequences of logical records) onto physical storage, managing the conversion between logical and physical records when necessary. A file system uses directories to organize files, with the ability to create hierarchical structures such as single-level, two-level or tree-structured directories to address naming and organizational challenges. It also handles the storage of file metadata, including file location, type, size and access details and facilitates file sharing, access control and protection. The file system may support file sharing across users or systems and can manage file access using techniques like access lists or passwords to ensure security. Additionally, file systems may be mounted into the system's structure to make files available and unmounted when needed.

The most widely used file systems are Zettabyte File System (ZFS), Fourth Extended File System (EXT4), B-tree File System (BTRFS), Extended File System (XFS). Each has its own advantages and disadvantages. An overview of these file systems is as follows [9]:

- **ZFS [10]**: ZFS uses a transactional copy-on-write model, integrated volume management and checksums for every block of data. ZFS offers pooled storage, enabling multiple filesystems to share a common storage pool and supports dynamic filesystem resizing. Its focus on consistency ensures that data on disk remains self-consistent, even in the event of a system crash..
- **EXT4 [11]**: EXT4 is a robust journaling file system developed for use in Linux environments. It supports large file sizes and volumes, with a maximum file size of 16 TiB and a maximum volume size of 1 EiB. Key features include improved performance through delayed allocation, which reduces fragmentation and the ability to efficiently manage metadata and data structures. EXT4 also offers increased reliability with features like journaling of metadata, checksumming for metadata integrity and support for fast file system checks, making it suitable for systems with high performance and data integrity requirements. Additionally, it supports flexible allocation strategies, ensuring optimal storage efficiency. EXT4 is the default filesystem for many popular Unix-like distributions, including Ubuntu, Debian, Fedora and CentOS.
- **BTRFS [12]**: BTRFS is a modern Linux filesystem that emphasizes scalability, data integrity and adaptability to various workloads. It uses a copy-on-write (COW) model, which enables efficient snapshots and clones. BTRFS incorporates B-trees [13] to manage data and metadata and provides built-in RAID support, checksums for both metadata and data and online defragmentation. Its design aims to work across a wide range of devices, from smartphones to enterprise servers.
- **XFS [14]**: XFS is a high-performance, scalable filesystem developed by Silicon Graphics for IRIX OS and optimized for handling large files and filesystems. It supports features like dynamic inode allocation, asynchronous write-ahead logging and B+ trees for managing free space and directories.

2.4 Network file sharing protocols

Network file sharing protocols are standardized communication rules that allow computers and devices to access, manage and share files over a network. These protocols define how files are stored, transmitted and retrieved from remote systems, enabling file sharing across different devices, regardless of their operating system or hardware. In enterprise or home network environments, the two primary network file sharing protocols are the Network File System (NFS) and Server Message Block (SMB) now Common Internet File System (CIFS). While other protocols like File Transfer Protocol (FTP) and Apple Filing Protocol (AFP) are also widely used, the focus will be set on NFS and SMB. The following subsections detail their features, use cases and comparative advantages.

- **Network File System**: NFS [15] is described as a protocol that enables the sharing of file systems over a network. It allows remote systems to mount and access directories as if they were on their local disk. NFS operates on a client-server model, where the server exports file systems and clients mount these directories remotely. The protocol is stateless, meaning the server does not keep track of client activity, which simplifies server recovery. It is commonly used in UNIX and Linux environments, but it also supports cross-platform compatibility with other systems through additional software.

- **Server Message Block / Common Internet File System**: SMB [15] is a network file-sharing protocol that allows computers to share files, printers and other resources over a network. It was developed in the early 1980s by IBM as part of the NetBIOS API [16], it was designed to allow computers on the same network subnet to communicate using names instead of IP addresses.

  Microsoft and Intel later adapted NetBIOS for file sharing over networks and created SMB, which became the core protocol for file and printer sharing in Windows environments. SMB enables various operations like file access. As it evolved, a version of SMB known as CIFS was created, which was optimized for operation over wide area networks (WANs) and is commonly used nowadays.

  To enable systems running UNIX or Linux to use SMB/CIFS, Samba [17] was introduced, it an open-source software suite that implements the server-side of the SMB/CIFS protocol on Linux and UNIX systems. Samba allows these systems to share files and printers with Windows machines.

2.5 Commercial Storage Alternatives

Currently, there are two main alternatives to building your own NAS. On one hand, there are cloud-based solutions such as Google Drive/One [18] or Dropbox [19]. On the other hand, there are hardware-based solutions such as Synology or QNAP.

Cloud-based solutions offer the ability to store data remotely on off-site servers managed by the provider. These providers usually offer a free plan with a limited amount of storage, but additional space comes with increased costs. Additionally, the client has no control over the hardware or the privacy/security of their data. These characteristics make cloud-based solutions ideal for people with minimal data storage needs, those with limited knowledge on the topic or anyone who prefers not to be bothered with managing hardware and security.

In contrast, hardware-based solutions offer a range of pre-built NAS devices that can be installed on-premises. These solutions provide a high degree of control and customization over hardware and data security. However, they come with higher upfront costs and more complex setup and management. They are suited for users who have a big budget, need more extensive storage capacity, have specific security requirements or prefer to handle the management of their own hardware.

3 Proposed Methodology

This section presents the methodology used to develop the local NAS solution and extend it with cloud-based capabilities. The approach is divided into five stages, beginning with the selection of appropriate software and hardware components and then the setting up of the local NAS environment. In addition, the integration of cloud-based solutions into the NAS is detailed, including considerations for safety and remote access. The process incorporates practical steps, from hardware assembly and software installation to the configuration of shared folders and the integration of cloud solutions for file sharing and collaboration.

3.1 Software selection

An analysis of various software options for NAS solutions was conducted, including:

- **OpenMediaVault (OMV)** [20]
- **SnapRAID** [21] (combined with MergerFS [22])
- **Unraid** [23]
- **StableBit** [24]
- **FlexRAID** [25]
- **TrueNAS** [26]

Most of these options are Linux-based, except for StableBit, which is designed for Windows. The free options are OMV, SnapRAID, TrueNAS and FlexRAID. All of these solutions support software RAID configurations.

OMV, StableBit DrivePool, TrueNAS and Unraid are specifically targeted towards home-based users.

The comparison of these options leads to a decision between OMV and TrueNAS. A key deciding factor is the availability of the EXT4 file system in OMV, which aligns well with the project's requirements and goals. Additionally, OMV offers the possibility to integrate with many GUI-based plugins, making configurations more intuitive and visible. Therefore, OMV is the chosen software.

3.2 Hardware selection

The selection criteria for the hardware components focused on meeting the requirements outlined by OMV. However, when a higher performing alternative was available and found at a reasonable price point, it was also chosen. The hardware components listed below were selected.

- **Processor**: Intel Celeron G5905, x86-64 compatible with a shared 4MB L2 cache.
- **RAM**: 8GB DDR4, exceeding the OMV minimum requirement of 1 GiB.
- **System Drive**: 256GB NVMe SSD, far exceeding the minimum required 4 GiB.
- **Data Drives**: 4 Seagate 2TB HDDs, each with a 64MB buffer and SATA 6Gb/s interface.

Additionally, the following components were chosen to complement the setup:

- **Power Supply Unit**: Corsair CV450.
- **Motherboard**: MSI Pro H510M-B, offering 4 SATA connections and a 1Gb/s LAN connection. It can host all of the components chosen and still has space for future improvements (Figure 4).
- **Case**: Antec 900, 4 fans and a disk bay for 3.5" drives.

Using the NVMe SSD for the OS results in all four SATA ports being available and improves the overall system speed. The selection of 4 data drives allows flexibility to experiment with different RAID configurations.

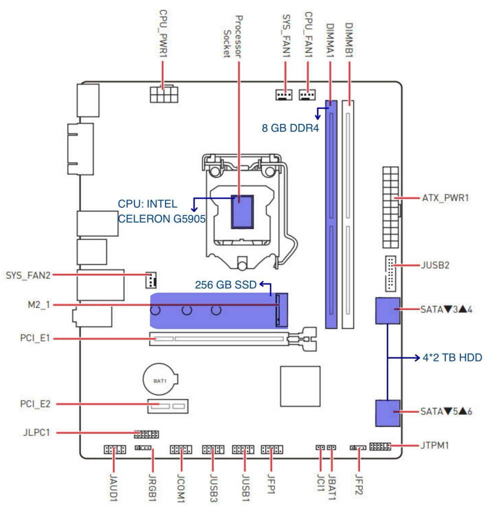

Fig. 4: MSI Pro H510M-B motherboard schematic with hardware components labeled.

3.3 Set-up of the local NAS environment

The initial phase of the NAS development involves the assembly of the machine. After the physical setup, specific adjustments are made to the BIOS to ensure optimal performance and compatibility. These adjustments include disabling Fast Boot, MSI Fast Boot and Secure Boot, as well as configuring the system to boot from a USB device, which is crucial for installing the OS.

After completing the BIOS adjustments, the next step is to create a bootable USB using Rufus [27], containing the OMV's ISO. The installation process proceds smoothly, requieres standard system configurations such as setting the hostname and selecting the time zone.

Although the installation is requires careful attention over several hours, it remains a straightforward process. Once completed, the system is accessible through the OMV dashboard at the machine IP, which is reached through a web browser. Initially, default login credentials are used to access the system, allowing for further configuration of the NAS environment.

The following command retrieves a script that installs essential plugins for extending OMV's capabilities by accessing the OpenMediaVault Plugin Developers repository [28].

By installing OMV-Extras, the "Linux MD (Multiple Device)" plugin becomes available. This plugin simplifies the process of creating and managing RAID arrays.

For this project, a RAID 5 configuration is selected (Figure 5), offering the best balance between usable storage space and data redundancy through parity (Figure 3).

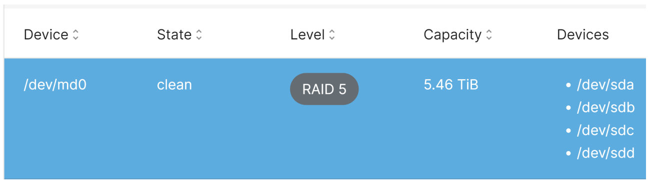

Fig. 5: RAID 5 mounted.

Once the RAID 5 configuration is complete, the next step is to set up the filesystem. As previosuly mentioned, EXT4 has been selected as the preferred filesystem for this set-up.

After the filesystem is established, a shared folder is created and mounted on the RAID device (Figure 6). In addition, a user account is created to access the shared folder.

To configure access to the shared folder, it is mounted using Samba, chosen due to its compatibility with Windows PCs, that will be the primary user base.

Fig. 6: Shared folder from Windows PC.

To ensure that the NAS maintained a consistent IP address on the network, the IP is bound to the NAS's MAC address in the router settings. This step is necessary to prevent the IP from changing every time the NAS is powered on, ensuring reliable access for network users.

3.4 Incorporation of cloud-based solutions into the NAS

To achieve a 'Google Drive'-like experience, where users can access files from the internet and co-edit documents with others, several alternatives were considered. Options such as Seafile [29], OwnCloud [30] and Nextcloud [31] were explored. Ultimately, due to its appealing interface Nextcloud was selected as the preferred solution. It is also important to note that this method is not the primary function of the NAS portrayed in the project, but rather an additional feature. To get Nextcloud running, it is essential to have SSL encryption, both as a security measure and because many of Nextcloud's functionalities, such as the ability to share files via a link, are not available without it. Therefore, two Docker containers are needed: one for Nginx Proxy Manager (NPM) [32] and another for Nextcloud AIO (All-in-One) [33]. NPM is a user-friendly interface for managing Nginx reverse proxy setups, allowing for easy configuration of domain names, SSL certificates and access control. Nextcloud AIO, on the other hand, is an all-in-one solution that bundles Nextcloud with necessary components like the database and web server, simplifying the deployment process and providing a comprehensive file sharing and collaboration platform.

3.5 Remote access

In order to access the NAS from outside the local network, a VPN was chosen to provide a secure way to manage the system and access files remotely. Using OMV extras, WireGuard was selected as the VPN software of choice due to its cutting-edge open-source nature and high-speed performance. This method is particularly well-suited for administrative use, as it offers strong security, though it requires setup on both the server and the administrator's client devices.

The main challenge encountered was the dynamic IP address of the router. To overcome this, the NO-IP service was utilized, allowing a domain to be linked to the dynamic IP. Configurations were also needed on the router to keep NO-IP informed of the current IP address. Additionally, port forwarding was set up to ensure access from the internet. With WireGuard in place, the NAS can be accessed using its fixed IP address, ensuring consistent connectivity. Since this method requires detailed configuration on both the server and the client sides, it is suitable only for the system administrator.

3.6 Final System Architecture

Figure 7 illustrates the fully configured NAS system, which integrates technologies such as WireGuard, SAMBA and Nginx to balance efficiency, accessibility, and security. Remote access is achieved through a WireGuard VPN, while local file sharing is managed via the SAMBA protocol, distributing files stored in the RAID 5 /shared folder.

For external collaboration, Nextcloud AIO, hosted internally on port 1100, provides cloud-like file sharing, with Nginx securely routing external requests through SSL encryption. Additionally, OpenMediaVault's administrative interface is secured with SSL and accessible on port 4430. The NAS connects to the router via a 1 Gbps Ethernet link.

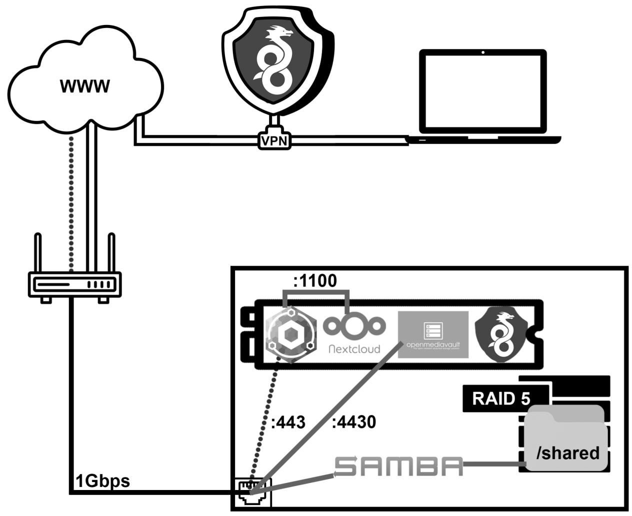

Fig. 7: Architecture of the proposed system.

4 RESULTS

This section presents an economic analysis for various options that provide reliable 6TB storage, it includes both cloud-based services and hardware-based solutions, as well as the proposed model.

The performance analysis begins with a test of the RAID 5 configuration, assessing data redundancy and fault tolerance. Following this, read/write speeds over both WiFi and Ethernet connections are examined to evaluate performance under different network conditions.

4.1 Economic analysis

When comparing the options, it is important to consider both the initial investment and the long-term costs.

There are four cloud-based plans available, with pricing varying depending on whether payment is monthly or annual. For simplicity, this analysis will focus on the yearly cost for those opting for annual payment. The business plans available have been excluded, as they don't provide a fair comparison to consumer level options.

For Dropbox [19], there are four main plans:

I. **Free plan**: 2 GB of storage.

II. **Plus plan**: 2 TB of storage, priced at *€143.33*/year.

III. **Essentials plan**: 3 TB of storage, priced at *€239.88*/year.

For Google Drive/One [18], there are four main plans:

I. **Free plan**: 15 GB of storage.

II. **Basic plan**: 100 GB of storage, priced at *€19.99*/year.

III. **Premium plan**: 2 TB of storage, priced at *€99.99*/year.

To reach 6 TB of storage, neither the Dropbox nor Google Drive/One plans will be enough individually. For Dropbox, the largest available plan is the Essentials plan, offering 3 TB. Therefore, two subscriptions to the Essentials plan are required, totalling *€479.76* per year. Similarly, for Google Drive/One, the Premium Plan offers 2 TB meaning three subscriptions to this plan would be needed to achieve 6 TB, adding up to *€299.97* per year. In both cases, additional subscriptions are necessary to meet the 6 TB storage requirement.

In hardware-based solutions, only Synology is analysed due to the limited availability of competing products. Access to other products from prominent competitors, such as QNAP, has been impossible.

For Synology's product range, one notable option is the 2-bay DiskStation DS224+ [34], priced at approximately *€369*. In terms of storage, for 6TB the available drives are either a 6 TB unit [35], priced at *€180.29* or a combination of a 2TB unit for *€102.85* and a 4TB for *€119.79*. The total hardware cost would amount to *€549.29* for one drive or *€591.64* for two drives both of them with no RAID configuration, excluding ongoing electricity costs. A 4-bay option is the DiskStation DS423+ [36], priced at *€570*.This bay is similar to the build wich allows to use four of the same 2TB drives [35] *€102.85*. This would allow for a RAID5 configuration. The total cost of this setup (NAS device and drives) would be *€981.4*, excluding ongoing electricity costs.

Both systems have a built-in memory of 2GB DDR4, which is upgradeable to 6GB.

The total investment for this build was *€403.76*. The component prices are as follows: processor at *€45.99*, motherboard at *€61.01*, RAM at *€15.99*, NVMe SSD at *€21.99* and four HDDs for data storage totaling *€165.96*. The power supply cost *€46*, the second-hand case was priced at *€35* and SATA cables were priced at *€11.82*.

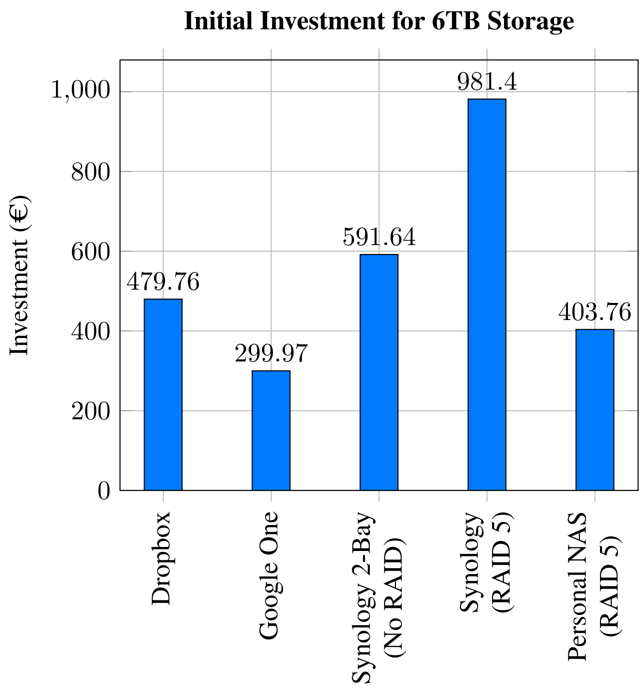

Fig. 8: Initial investment comparison for storage options

To estimate the annual cost of energy for a 6TB storage solution, the power consumption of the custom-built system was measured, yielding an average consumption of *76W*. The Synology 2-bay DiskStation DS224+ reports a power consumption of *14.69W* during active use and *4.41W* in idle mode. Similarly, the 4-bay DiskStation DS423+ has a reported active power consumption of *28.3W* and *8.45W* when idle. These figures provide a benchmark for evaluating the efficiency of different storage configurations.

For this calculation, the average electricity price in Spain for 2024 [37] has been determined to be *0.1227€/kWh*. This value is used to estimate the cost of electricity.

The custom built system operates from 9:00 am to 10:00 pm and remains off the rest of the day. For Synology products, power consumption is considered active when the system is on and idle when the custom built is powered off.

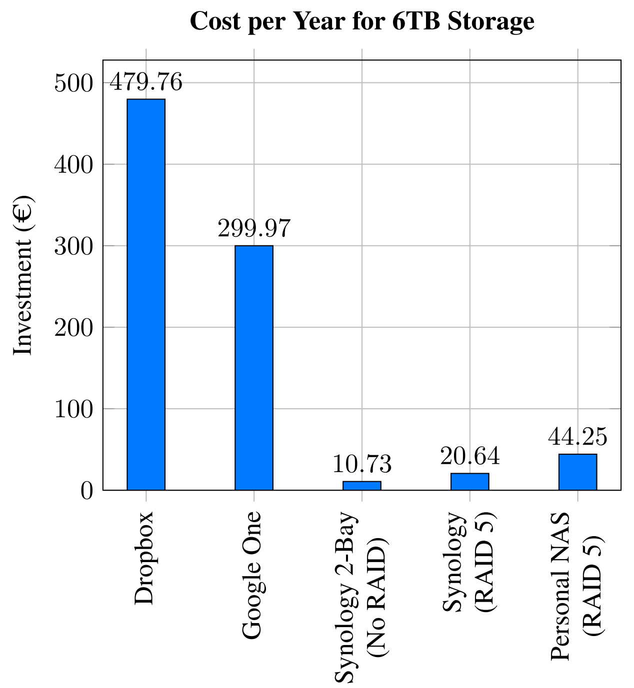

Fig. 9: Cost per year comparison for storage options

The Total Cost of Ownership (TCO) is calculated using (1).

$$\text{TCO} = \text{Initial Investment} + (\text{Annual Cost} \times \text{Number of Years}) \tag{1}$$

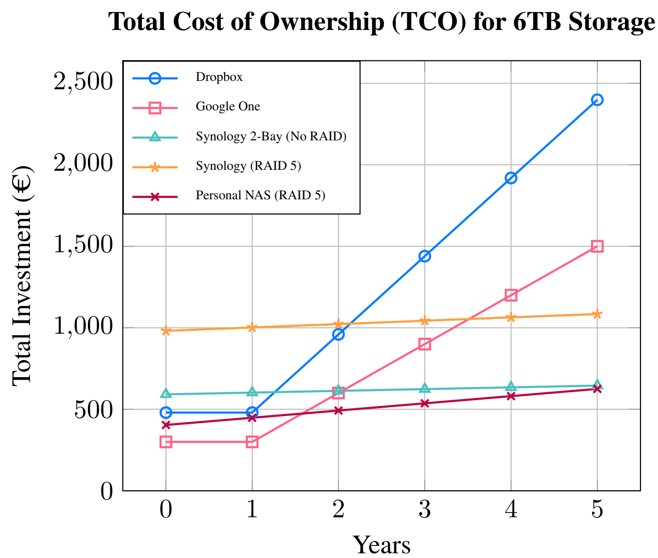

Fig. 10: TCO (0 to 5 years) for different storage options

While the Personal NAS has a higher initial investment (Figure 8) than cloud solutions like Google One or Dropbox, its TCO increases more slowly (Figure 10) due to lower initial costs and moderate annual fees (Figure 9). Over 5 years, it offers a balanced solution between upfront costs and yearly expenses, making it a cost-effective long-term alternative to cloud storage providers.

To provide a detailed analysis, the Return on Investment (ROI) [38] and payback period [38] were calculated. The cheaper option, Google One, is used for comparison.

ROI is calculated using the formula in (2).

$$\text{ROI} = \frac{\text{Net Profit}}{\text{Initial Investment}} \times 100 \tag{2}$$

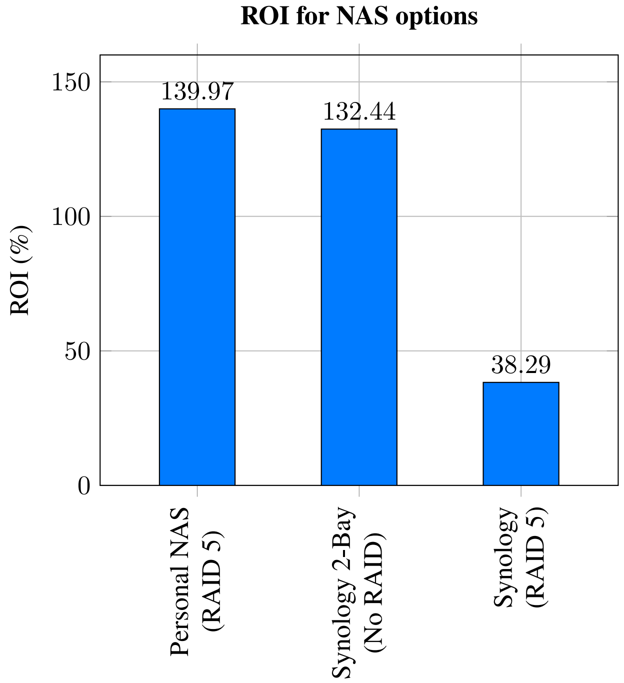

Fig. 11: Return on Investment (ROI) comparison for NAS options

The Personal NAS provides the highest ROI over 5 years at 139.97% (Figure 11), which indicates the best return relative to its initial investment. With a significant ROI, it proves that it is an excellent option for users who want to maximize the value of their investment in storage.

The Payback Period formula is defined in (3).

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Annual Savings}} \tag{3}$$

The Personal NAS also offers the shortest payback period of just 1.58 years (Figure 12). This means that users will recover their initial investment in less than two years, notably faster than the other NAS options.

The comparison of cloud-based storage solutions and hardware-based NAS options reveals several key considerations. While cloud storage services like Dropbox and Google One provide flexible, scalable options, they come with recurring costs that can accumulate significantly over time. Specifically, for a 6 TB storage requirement, both services require multiple subscriptions, resulting in higher annual costs. In contrast, hardware-based solutions such as the Synology NAS or a custom-built Personal NAS offer a one-time initial investment with lower annual costs. The Personal NAS stands out with the highest ROI (139.97%), reflecting a strong return relative to its initial cost, as well as a short payback period of 1.58 years, demonstrating its cost-efficiency compared to other NAS options. At last, the

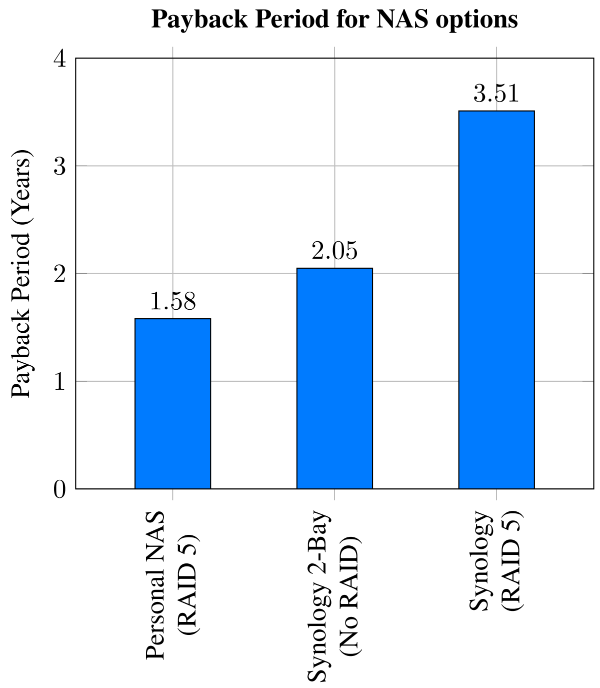

Fig. 12: Payback Period comparison for NAS options

Personal NAS represents a great choice for users seeking a balance between upfront costs and long-term savings, with the benefit of being able to replace components as needed.

4.2 Performance

This section evaluates the performance of the proposed NAS solution, focusing on data redundancy, fault tolerance and read/write speeds. Experiments were conducted using a RAID 5 configuration to evaluate the system's resilience to disk failures and its performance under different network conditions. The results offer an overview of the system's ability to deliver reliable and high-speed data access.

4.2.1 RAID 5

To test the functionality of RAID5, an experiment was conducted where data, including documents and videos, was added to the /shared folder. One disk was then disconnected to simulate a failure. The test confirmed that files remained accessible, though the first access after the failure showed some loading time, likely due to the RAID system rebuilding the data In the admin view, removing a disk from the RAID configuration changes the RAID device state from 'clean' to 'clean, degraded,' and the disk is marked as 'removed.' To re-add the disk, all data must be erased. During the process, the RAID device state shows 'clean, degraded, recovering,' and the disk appears as 'spare rebuilding.' Once the disk is added, the state returns to 'clean,' and the disk appears as 'active sync,' like the others.

4.2.2 Speed

When considering speed, Although SATA3 supports 6 Gbps, the motherboard's 1 Gbps Ethernet port creates a bottleneck, limiting data transfer speeds to around 1 Gbps, assuming no other factors affect performance.

To test the transfer speed, CrystalDiskMark [39] was used to evaluate read and write speeds from the /shared folder on the NAS from a Windows client over WiFi and Ethernet. Tests included sequential and random operations: 1GiB transfers using 1MiB and 4KiB block sizes across varying queue depths (32, 8, and 1). The results of are presented in Figures 13 and 14.

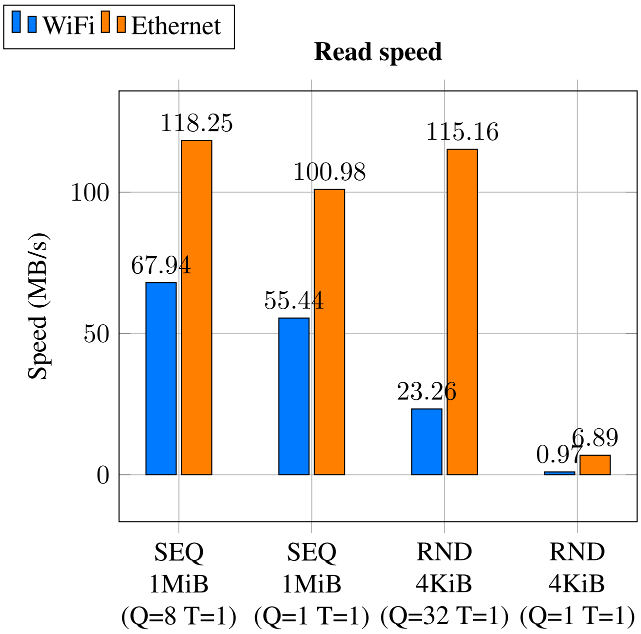

Fig. 13: 1 GiB Read: WiFi vs Ethernet Speed Tests

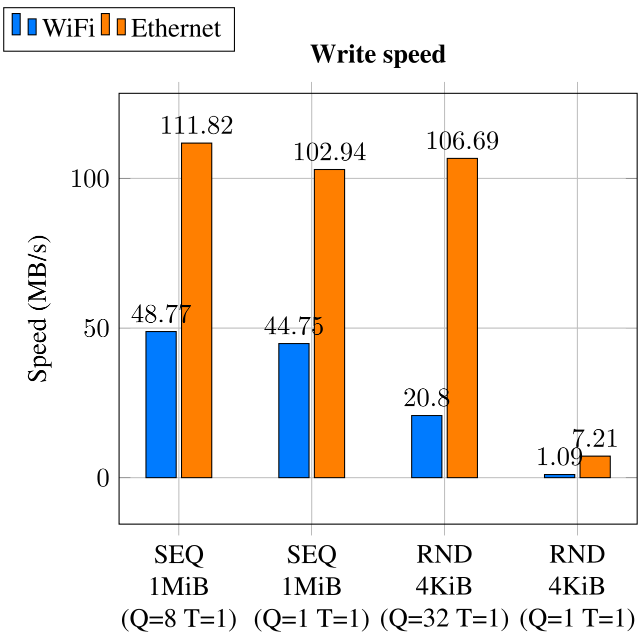

Fig. 14: 1 GiB Write: WiFi vs Ethernet Speed Tests

For Ethernet connections, the observed read and write speeds are generally near 1 Gbps (125 MB/s), with slight reductions possibly due to protocol overhead, network congestion, or other performance factors

Ethernet offers relatively consistent performance for sequential operations, while WiFi shows greater degradation under similar conditions. This difference arises from the direct, interference-free nature of Ethernet compared to WiFi's shared medium access, susceptibility to interference and need for retransmissions.

A ping analysis using 50 packets was conducted over both Ethernet and WiFi connections. No packet loss was observed, but latency averaged 1ms for Ethernet and 3-4ms for WiFi, highlighting the speed differences.

WiFi's higher latency affects operations with small, random data blocks (e.g., 4KiB reads/writes), where packet access time is crucial. In contrast, Ethernet's low latency enables more efficient handling of these operations.

Testing random 4KiB blocks with a queue depth (Q) of 1 and thread count (T) of 1 shows a notable performance drop. This slowdown in random read/write operations is due to how hard drives handle queued requests. The ST2000VM003, like other drives with Native Command Queuing (NCQ) [40], can reorder tasks to minimize mechanical movements when multiple requests are queued. However, with only one operation (Q=1), the drive cannot optimize request ordering, processing tasks individually and significantly slowing performance.

5 Conclusions and Future Work

This project involved designing and implementing a custom NAS solution using OpenMediaVault, configured with a RAID 5 setup for data redundancy and performance. Nextcloud was integrated for collaboration and WireGuard was used for secure VPN connectivity. The hardware was selected to balance cost and performance, while the open-source software enables customization and cost savings.

The custom NAS achieves reliable and competitive performance, with consistent read/write speeds over Ethernet and WiFi. The RAID 5 configuration provides fault tolerance, allowing uninterrupted access to data even after a disk failure. The proposed NAS solution provides full control over hardware and data, offering better privacy and security than commercial alternatives. With a lower TCO and high ROI, it is an economically attractive option. Its modularity and open-source platforms allow for future expansion, adapting to changing user needs. Additionally, cloud features provide remote access and collaboration, enhancing usability.

Several enhancements can be explored to improve the NAS system, including implementing Wake on WAN (WoW) for remote power management, adding advanced security features like two-factor authentication (2FA) or intrusion detection systems (IDS) and integrating Docker-contained applications to extend the system's functionality in a modular way. Additionally, energy optimization strategies, such as automated sleep modes or more energy-efficient components, can be investigated to reduce power consumption during idle periods.

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