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Bachelor Thesis

A Comparative Analysis of Private (on-premises) and Public Cloud Storage Deployments: Performance, Security, and Cost Factors for small businesses or households.

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Executive summary

As the demand for efficient data storage solutions continues to grow, small businesses and households face the challenge of choosing between private (on-premises) and public cloud storage deployments. Despite the extensive coverage of cloud computing in academic literature, there is a lack of comprehensive comparative analyses that consider performance, security, and cost factors.

This bachelor thesis aims to bridge the research gap by conducting a comparative analysis of private (on-premises) and public cloud storage deployments, focusing on performance, security, and cost factors relevant for small businesses and households. The study seeks to guide small businesses and individual users in making informed choices about storage options.

The research employs a mixed-method approach, integrating academic and non-academic sources to provide a complete view. The author conducts hands-on performance tests comparing a Synology DS923+ Network Attached Storage (NAS) device with three public cloud storage providers: Google Drive, Microsoft OneDrive, and Dropbox. The tests measure download and upload speeds for various file types and sizes across two different networks. A cost comparison is also performed between the NAS and cloud storage solutions.

The performance tests reveal that the Synology DS923+ NAS outperforms all cloud storage providers on a local network, with Dropbox being the closest competitor. When accessed remotely, the NAS remains competitive, surpassing Google Drive and Microsoft OneDrive and only slightly trailing behind Dropbox. The cost analysis indicates that a NAS solution becomes more cost-effective than cloud storage when storing at least 2TB of data

without redundancy or 3TB with redundancy, with break-even periods of approximately 20 and 24 months, respectively.

The results provide valuable insights for small businesses and households considering public and private cloud storage solutions. The study highlights the optimal storage choices based on factors such as performance requirements, data redundancy needs, and cost-effectiveness. It also identifies the strengths and weaknesses of different RAID configurations and cloud storage providers in various scenarios.

The research faced limitations, including a limited geographical scope for performance testing, the absence of multi-user scenarios, and the exclusion of potential internet connectivity cost changes based on the chosen storage solution. These limitations provide opportunities for future research to refine the accuracy and comprehensiveness of the findings.

Future studies could expand the performance testing scope to include international locations, investigate the impact of multiple simultaneous users on NAS and cloud solutions, and consider the potential cost implications of internet connectivity changes based on the chosen storage solution. Additionally, researchers could explore the ease and flexibility of scaling storage up or down, which favors cloud providers, and its impact on the overall cost analysis.

Keywords: cloud storage, Network Attached Storage (NAS), performance, cost, security

Abstrakts

Mūsdienu digitālajā laikmetā efektīva datu glabāšana ir būtiska gan maziem uzņēmumiem, gan privātpersonām. Izvēle starp privāto (iekšējo) un publisko mākoņkrātuvi var būt sarežģīta – katram risinājumam ir savi plusi un mīnusi. Šis bakalaura darbs sniedz padziļinātu salīdzinošo analīzi, lai palīdzētu maziem uzņēmumiem un mājsaimniecībām Latvijā pieņemt informētus lēmumus par piemērotāko datu glabāšanas stratēģiju.

Darbā tiek izmantota jaukta pieeja, kas apvieno gan teorētisko izpēti, gan praktiskus testus. Salīdzināsim privāto NAS ierīci (Synology DS923+) ar populāriem publiskās mākoņkrātuves pakalpojumu sniedzējiem – Google Drive, Microsoft OneDrive un Dropbox. Šajā darbā tiks veikti detalizēti veiktspējas testi, izvērtējot dažāda veida un izmēra failu augšupielādes un lejupielādes ātrumus gan lokālajā tīklā, gan izmantojot attālināto piekļuvi. Tāpat rūpīgi tiks analizēta NAS un mākoņkrātuves risinājumu izmaksu atšķirības ilgtermiņā.

Šis pētījums koncentrēsies uz trim būtiskiem aspektiem. Pirmkārt, cik ātri un ērti var piekļūt datiem – veiktspējas salīdzinājums ir īpaši svarīgs, ja uzņēmuma darbībai svarīgu lomu spēlē laiks, kas nepieciešams, lai piekļūtu glabājamajiem datiem, it īpaši ja strādā ar lielāka izmēra failiem. Otrkārt, drošības jautājums – privātie NAS risinājumi piedāvā lielāku kontroli pār datiem, taču prasa arī lietotāja atbildību, savukārt mākoņkrātuvē drošību nodrošina pakalpojuma sniedzējs. Visbeidzot, šis darbs salīdzinās NAS izmaksas ar publisko mākoņkrātuves pakalpojumu sniedzējiem un noskaidros no kāda datu apjoma glabāšanas ar un bez datu dublēšanas NAS paliek financiāli izdevīgāks kā publisko mākoņkrātuves pakalpojums.

Pētījuma rezultāti var sniegt vērtīgus ieteikumus Latvijas iedzīvotājiem un uzņēmumiem, palīdzot izvēlēties savām vajadzībām atbilstošāko un izdevīgāko datu glabāšanas risinājumu.

Atslēgas vārdi: mākoņkrātuve, tīkla disks (NAS), veiktspēja, izmaksas, drošība, datu dublēšana, Latvija

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Introduction

In an era where the volume of global data is exponentially increasing, the demand for efficient data storage solutions is becoming increasingly critical. According to recent projections, the worldwide demand for data storage is expected to surge from 120 zettabytes in 2023 to an estimated 181 zettabytes by 2025 (P. Taylor, 2023). This staggering growth underscores the necessity of evaluating different storage options across various parameters.

Cloud computing remains a popular keyword in today's tech landscape, offering scalable and flexible solutions for storing and processing data (Goyal, 2023). Understanding the differences between private and public cloud deployments is crucial for organizations and individual users in a market dominated by big names like Microsoft, Google, and Amazon (Richter, 2023). These major companies hold a significant portion of the market, raising important questions about data concentration and potential risks (M. Taylor, 2022).

Private clouds offer a dedicated space with various types, including virtual private clouds, managed private clouds, hosted private clouds, and on-premises private clouds (Patil & BasuMallick, 2022). This research focuses on on-premises Private Clouds, where the infrastructure is owned and managed internally to avoid too centralized data storage risks. This setup allows for the possible use of existing hardware, potentially reducing the need for new investments. A vital part of this research will be deploying private Cloud using Network-Attached Storage (NAS), a device or file server that centralizes Storage and allows multiple users and devices to access and share data.

By directly setting up and managing a private cloud using NAS, this study aims to give an accurate picture of the financial and operational sides of Private Cloud Storage compared with Public Cloud for individuals and small businesses in terms of cost, security, and performance. This hands-on approach is vital for understanding the details of managing hardware compared to using a cloud provider. Through this thesis, the goal is to offer a complete look at the benefits and disadvantages of each cloud deployment model, helping those making the decisions to choose what is best for them.

The research will involve a thorough literature review, practical performance tests comparing NAS with public cloud storage providers, and a detailed cost comparison between NAS and cloud storage solutions. By examining these crucial aspects, this thesis aims to provide valuable insights and guidance for small businesses and individuals navigating the complex landscape of data storage options in an increasingly data-driven world.

Theory

Cloud Computing concepts

Cloud computing is not a new concept by any means. It has been around since the 1960s and was invented by Dr. Joseph Carl Robnett Licklider (Pedamkar, 2023). Over the last three decades, cloud computing has seen a vast growth in adaptation and the total amount of data handled in the Cloud (Hassan et al., 2022). The total amount of data stored in the Cloud is expected to be around 100 Zettabytes in 2025, or more than half of the total data stored (Morgan, 2020). Cloud computing is a broad term for everything that involves delivering hosted services over the Internet. This broad term can be split into three main categories: Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS).

Platform as a Service (PaaS) is a cloud computing model that provides customers with a platform to develop, run, and manage applications without the complexity of building and maintaining the underlying infrastructure (Rani & Ranjan, 2014). Software as a Service (SaaS) delivers applications over the Internet as a service, freeing users from installing and maintaining Software by accessing it through the web or an API (Rani & Ranjan, 2014). Infrastructure as a Service (IaaS) provides virtualized computing resources over the Internet, allowing users to outsource and scale their hardware resources on demand, typically billed on a pay-as-you-go basis (Rani & Ranjan, 2014).

A cloud resource can be Private, Public, or Hybrid. The public Cloud offers on-demand computing resources over the Internet to multiple users. Providers like Amazon Web Services, Microsoft Azure, and Google Cloud Platform deliver services such as virtual machines, Storage, and applications, charging customers based on usage (Ang Li et al., 2011). Users access resources remotely, which reduces the need for personal IT infrastructure. In the public Cloud, resources are shared across customers with safeguards like virtualization and access controls to maintain security and privacy (Paxton, 2016).

In contrast, a private cloud is dedicated to a single organization or an individual. This model provides similar benefits to public clouds but with more control. Hosted on-site or by third-party providers, private clouds serve enterprises and agencies with the most vital security and compliance needs (Samarati & De Capitani Di Vimercati, 2016). The private Cloud's dedicated resources allow organizations to set specific security policies and compliance measures (Samarati & De Capitani Di Vimercati, 2016)

Hybrid cloud storage combines public and private cloud elements, allowing data and applications to be shared between them. This approach facilitates flexibility and more data deployment options, with the ability to keep sensitive assets privately stored while leveraging the scalability of public cloud resources when necessary (Weinman, 2016). Organizations can optimize their IT infrastructure for security, compliance, and performance by selectively using both cloud models (Weinman, 2016).

What is Networked Attached Storage?

Network-attached Storage (NAS) is a specialized file storage technology that enables multiple users and various client devices to retrieve data from a centralized disk capacity (Bigelow, 2022). Central to NAS is its ability to provide file-level Storage instead of block-level Storage typically seen in Storage Area Network (SAN) systems (Bigelow, 2022). NAS systems are composed of one or more storage drives, either hard disk drives (HDDs) or solid-state drives (SSDs), which can be configured in various RAID (Redundant Array of Independent Disks) levels for improved performance and redundancy (Subramanian, 2023). These systems operate on an embedded operating system, optimized for data storage and retrieval, and are designed for seamless integration into existing networks via Ethernet connections (Bigelow, 2022). A defining feature of NAS is its simplicity in setup and maintenance, often managed through user-friendly, web-based interfaces (Bigelow, 2022).

NAS is similar to a computer in that it shares some basic computing components like CPUs, RAM, hard drives, their design, and operating systems (Deng, 2009). Although their use cases differ, NAS devices specialize in efficient, network-based Storage and data sharing. In contrast, personal computers are versatile, general-purpose devices designed for various tasks.

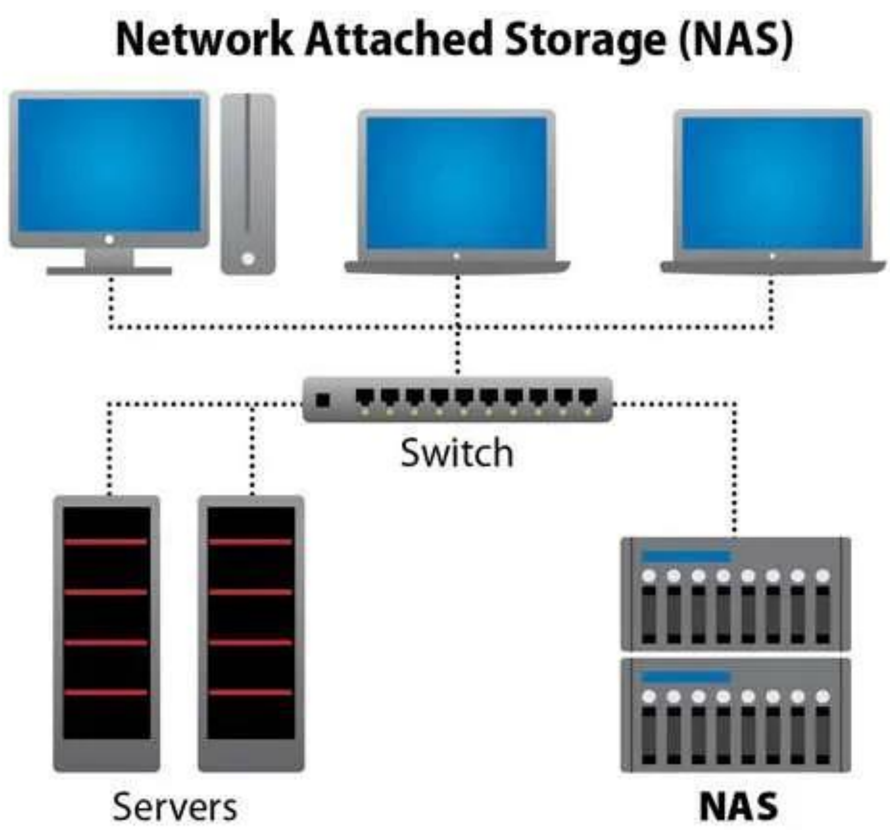
Why use a NAS, not a Storage Area Network (SAN), for this comparison?

Network Attached Storage (NAS) and Storage Area Network (SAN) are two main storage technologies (see Figure 1 and Figure 2) for Storage connected to a network. While both NAS and SAN were developed to solve the data storage problem, each achieves this goal differently (Subramanian, 2023b). NAS, characterized by its simplicity in setup and deployment, is a cost-effective solution particularly suited for environments like small to medium-sized businesses and households (Kumar et al., 2021). It operates at the file level, offering easier management and flexible access to data across a network, often using protocols like NFS and SMB/CIFS (Singh & Anand, 2014). This makes NAS ideal for collaborative projects and scenarios where ease of access and data sharing are crucial.

On the other hand, SAN, functioning at the block level, is designed for high-performance and large-scale environments, like large enterprises, where speed and low latency are most important (Kumar et al., 2021). SAN's high cost and complexity in setup and management make it less suitable for smaller organizations (Subramanian, 2023b). The selection between NAS and SAN in an enterprise largely depends on the specific needs for data accessibility, performance requirements, scale of the operations, and the cost factor. Due to these reasons, NAS is the choice of this thesis research as the focus lies on small businesses and households.

Figure 1

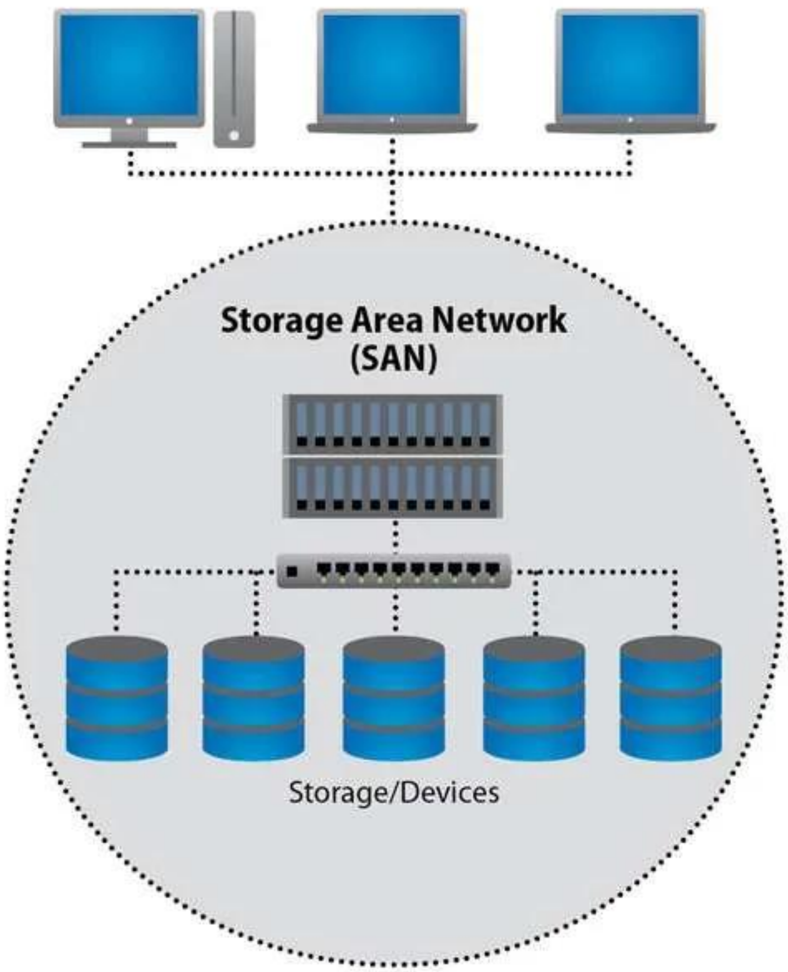
Basic NAS architecture



Note. Adapted from "NAS vs. SAN," by Hypertec Group, n.a (https://hypertecsp.com/knowledge-base/nas-vs-san/). Copyright 2023 by Hypertec Group Inc.

Figure 2

Basic SAN architecture



Note. Adapted from "NAS vs. SAN" by Hypertec Group, n.a (https://hypertecsp.com/knowledge-base/nas-vs-san/). Copyright 2023 by Hypertec Group Inc.

Networked Attached Storage and Cloud storage performance comparison.

In the comparison of Network Attached Storage (NAS) and Public Cloud Storage, three critical factors emerge as most influential: I/O Operations Per Second (IOPS), Latency, and Throughput (Staimer, 2022). IOPS, which measures the number of individual read/write operations a storage system can handle per second, is crucial for evaluating performance, especially in environments with frequent small data transactions or where multiple operations occur simultaneously (BuffaloTech, 2023). Latency, encompassing both network latency and access time, significantly impacts cloud storage performance, affecting the responsiveness of applications and the efficiency of data retrieval (Staimer, 2022). Throughput, the rate at which data is transferred over a period, is imperative for understanding the actual performance of storage systems under typical workloads, especially in environments with high data traffic (BuffaloTech, 2023). These factors collectively dictate the overall efficiency and suitability of NAS and Public Cloud Storage solutions in varying operational contexts (Staimer, 2022).

In a study conducted by Ou et al. (2018) about Performance comparison of representative IP-based storage systems, the authors compare NAS, SAN, and Cloud storage performance under different internet conditions. The three research questions for this study were: Is cloud storage a viable replacement in scenarios that NAS and SAN traditionally dominate? Is cloud storage universally better than NAS and SAN? How much do network conditions and application behaviors impact the performance of each technology? This literature review scope will focus only on the author's findings about NAS and Cloud Storage comparison.

According to Ou et al. (2018), when comparing the performance characteristics of Network Attached Storage (NAS) and Cloud Storage, key distinctions emerge in their operational efficiencies and adaptability to varying network conditions. NAS, particularly exemplified by the Network File System (NFS) protocol, offers a file-based interface for accessing remote storage servers. Cloud Storage, represented in the study by OpenStack Swift, operates on an object-based storage model. This system organizes data into objects within containers, offering a flat namespace and avoiding the complexities of nested structures typical in file systems. A significant aspect of Cloud Storage, particularly Swift, is its ability to utilize multiple Transmission Control Protocol (TCP) connections, which is an implementation detail that significantly impacts performance, especially under network conditions involving delays and packet loss. This feature demonstrates the inherent adaptability of Cloud Storage in varied network environments.

Ou et al. (2018) discussed how the comparative performance of NAS and Cloud Storage is clearly highlighted under different network conditions. While NAS, through NFS, provides efficient and reliable file access in controlled network environments, its performance is challenged under Internet-like conditions, where latency and packet loss are prevalent. Conversely, Cloud Storage exhibits robust resilience in such fluctuating network scenarios, maintaining performance levels where NAS struggles. This contrast is pivotal in understanding the suitability of NAS and Cloud Storage for different application contexts. Although NAS offers a mature and feature-rich environment for file storage, its performance under less-than-ideal network conditions is a limiting factor. In contrast, Cloud Storage, with its flexible architecture and ability to handle variable network scenarios effectively, emerges as a viable alternative to NAS, particularly in environments that mimic the diverse and unpredictable nature of the Internet.

In summary of the in-depth comparison by Ou et al. (2018), when considering NAS versus Cloud Storage, the key factors to evaluate are the network conditions under which the storage system will operate and the specific performance requirements of the application. With its advanced features and file-based access, NAS is suitable for controlled network environments. In contrast, Cloud Storage, particularly object-based systems like OpenStack Swift, presents a more adaptable and resilient option in diverse and challenging network scenarios, making it a potential alternative to NAS in many use cases.

Other articles on this topic have different views on performance and suggest that NAS performs better than the cloud offering in all conditions (Sears, 2022; Zhou, 2023). However, both articles lacked proof of these statements.

The scholarly literature appears to be limited in providing comprehensive comparative analyses of Network-Attached Storage (NAS) and Public Cloud storage. This gap is particularly evident beyond the scope of the study of Ou et al. (2018). Such an observation suggests a significant opportunity for further practical research focused on hands-on performance comparisons between these two storage solutions.

Networked attached Storage versus Cloud storage cost.

In the decision-making process for storage options among small businesses, cost emerges as the most important consideration (Jayeola et al., 2022). Despite its critical importance, there is a noticeable scarcity of scholarly research explicitly addressing the cost comparison between Network-Attached Storage (NAS) and Public Cloud Storage. This contrasts with many comparisons found in various web pages and blogs, highlighting a discrepancy between academic research and online discourse on this comparison.

The author went over 11 different publications that compare the cost of NAS and Public Cloud Storage. See the overall positions by source of this comparison in Table 1.

Table 1

Summary of 11 websites about the cost comparison for NAS versus Public Cloud Storage

Website, Authors, Date	Year	Which is overall cheaper, NAS or Public Cloud storage?	Notes
EaseUs.com, Jane Zhou	2023	Cloud	The author suggests that Public Cloud storage has lower cost and maintenance than NAS.
Pics.io, Pics.io Team	2022	NAS	Provides actual data for cost comparison, showing that NAS is cheaper starting from at least 2TB of data.
TechTarget.com, Rich Castagna	2022	NAS	The author states that comparing NAS and Public Cloud storage costs is challenging but admits that, theoretically, NAS is cheaper.
NordLocker.com, John Sears	2022	NAS	The author states that NAS offers significant cost savings over time
Stonefly.com, StoneFly	n.a	NAS	The article states that NAS is less expensive than cloud services in the long run, especially if dealing with larger amounts of data.
Makeuseof.com, Andy Betts	2022	NAS	The author states that for any data amount exceeding the free limits of Cloud storage providers, NAS is a

			far more cost-effective storage solution.
LogMeOnce.com, Nicole Vasquez	n.a	NAS	The article states that the cost of setting up a NAS system is minimal compared to public cloud storage options.
Solink.com, Timothy Ware	2023	NAS	The author suggests that NAS is the cheaper option for large volumes of data.
Iternity.com, Iternity	n.a	NAS	NAS and Cloud Storage are compared over 5 years. Then, NAS is the more affordable alternative.
BackUpevErything.co.uk, BackupEverything	2023	Cloud	This article states that the Cloud offers lower overall costs.
nirvanix.com, Nirvanix	2023	Cloud	This article states that storing data in the Cloud is usually cheaper

Note. This table is created from 11 different data sources (BackUpEverything, 2023; Betts, 2022; Castagna, 2022; Iternity, n.d.; Nirvanix, 2023; Pics, 2022; Sears, 2022; StoneFly, n.d.; Vasquez, 2023; Ware, 2023; Zhou, 2023)

Based on the analysis of various sources seen in Table 1, the overall conclusion regarding the cost-effectiveness of Network-Attached Storage (NAS) versus Public Cloud Storage for small businesses presents a nuanced picture. While some sources advocate for the cost efficiency of Public Cloud Storage, particularly highlighting its low maintenance and almost no initial costs (BackUpEverything, 2023; Nirvanix, 2023; Zhou, 2023). A majority of the sources reviewed lean towards NAS as the more economical option in the long run. These sources generally point out that NAS offers significant cost savings, especially when dealing with larger volumes of data or over extended periods, such as five years (Betts, 2022; Castagna, 2022; Iternity, n.d.; Pics, 2022; Sears, 2022; StoneFly, n.d.; Vasquez, 2023; Ware, 2023). Consequently, while Public Cloud Storage may be initially more attractive for its lower upfront costs, NAS emerges as a more cost-effective solution for sustained usage and more extensive data volumes. The fact that almost 30 % of sources suggested that Public Cloud Storage is cheaper than NAS overall suggests that there is still room for more data to be gathered for this comparison, allowing small businesses and households to make more educated choices regarding storing data.

Networked attached Storage versus Cloud storage security.

NAS gives users direct control over their data, as it is stored on physical servers on-premises. This direct control allows for more direct access management policies, as administrators can directly oversee who accesses the data and how it is used (Lai & Ma, 2018). In contrast, Cloud Storage, provided by third-party vendors, requires trust in the provider's ability to manage and protect access to data (Kumar & Shafi, 2020). While cloud providers offer high-quality access management tools, the control is not as direct as with NAS (Yang et al., 2020).

Both NAS and Cloud Storage offer encryption methods to protect data (Yang et al., 2020). NAS systems can be configured with encryption solutions to secure data both at rest and in transit (Liu, 2017). However, the effectiveness of this encryption can depend on the administrator's expertise and diligence (Liu, 2017). Cloud Storage typically includes built-in encryption features, ensuring data is automatically encrypted when stored or transmitted (Yang et al., 2020). The encryption maintenance and updates are the responsibility of the cloud provider, not the user (Yang et al., 2020).

The physical nature of NAS makes it susceptible to on-site risks such as theft, physical damage, or natural disasters (Liu, 2017). Although a NAS (Network Attached Storage) provides a localized solution and is generally less vulnerable to online threats than cloud storage, it can still be exposed to the Internet and consequently face similar risks (Yan et al., 2016). Configuring the NAS device properly is crucial to mitigate these risks. Implementing robust security measures, such as using a VPN and other protective protocols, is essential to minimize potential threats (Yan et al., 2016). Cloud Storage, while not prone to physical damage in the same way, is more susceptible to online threats such as cyber-attacks (Zhe et al., 2017). Cloud providers invest heavily in security measures to mitigate these risks, but the exposure to online threats is inherently higher due to the nature of cloud computing (Zhe et al., 2017).

In conclusion, both NAS and Cloud Storage have distinct security advantages and vulnerabilities. NAS offers more direct control and potentially higher security for localized threats, whereas Cloud Storage provides robust encryption and protection against physical damage while facing higher exposure to online threats. The choice between NAS and Cloud Storage for security should be based on the user's or organization's specific needs and capabilities. Another critical aspect is that many security issues stem from individuals not handling their data cautiously (Li et al., 2019). This highlights the importance of prioritizing the education and training of employees who work with data rather than focusing solely on the storage systems' security (Li et al., 2019).

Private (on-premises) Cloud versus Public Cloud Storage general comparison.

In a study by Fisher (2018), a cost comparison between cloud-based and on-premises computing for a medium-sized business was examined over ten years. The study revealed that the total cost of owning an on-premises computing solution was approximately 56% of the cost of operating a comparable cloud-based solution. Notably, the operating costs of cloud computing exceeded those of on-premises solutions by the third year. The research also highlighted that on-premises solutions were less susceptible to price fluctuations, data leakage, and security breaches, offering a more stable environment. However, the cloud solution provided advantages in terms of rapid scalability, which could be a significant benefit for businesses needing quick expansion.

Despite these findings, the research presented by Fisher (2018) has notable limitations. The cost analyses were theoretical, lacking practical implementation of the compared computing solutions. Additionally, the study did not specify the types of computing resources being compared, such as whether the focus was on GPU resources or Storage, which could significantly impact the results. Furthermore, the research only superficially addressed security considerations and did not explore potential performance differences between the two solutions, leaving critical aspects of the comparison unexamined.

In a case study by Bondarsen (2023), the research question "Is it cost-efficient for Swedish grocery retail companies to utilize public clouds compared to utilizing private clouds in terms of storage and computational costs?" was explored. The findings indicated that the primary disadvantages of public cloud usage included the lock-in effect (being locked in with the same provider, as it is costly to change), necessitating increased cost awareness among analysts, increased abstraction, and limited influence on Cloud Service Providers regarding bug resolution. However, the significant advantage of the public Cloud was its scalability features. Contrary to Cameron Fisher's findings, Bondeson's research concluded that using a public cloud provider for this specific scenario was 20% more cost-effective than a privately hosted on-premises solution, contrary to the findings by Fisher (2018). However, it was also mentioned that using the on-premise option would be cheaper if the service was required to run 24 hours, seven days a week, with a stable workload. However, Bondeson cautioned against generalizing these results as definitive proof of public clouds' superior cost efficiency in all Storage and compute scenarios.

The study by Bondarsen (2023) faced limitations, primarily the methodological approach of estimating Storage and computing costs through calculations derived from experiments rather than measuring real-life outcomes. Bondeson suggested that more accurate results could be obtained by running identical tasks on each Platform within similar environments. Furthermore, while this literature review primarily targets small businesses, Bondeson's study focused on a large retail company, indicating that the findings might not directly apply to smaller entities. Nevertheless, these insights contribute to a broader understanding of cloud computing's cost implications in different business scales.

Modisane and Jokonya (2021) conducted a survey to evaluate the benefits of cloud computing in Small, Medium, and Micro-sized Enterprises (SMMEs). Their research revealed that cost savings, security concerns, and compatibility issues are pivotal factors influencing companies' decisions regarding cloud computing implementation. The methodology employed in this study was a survey, which provided insights into these critical determinants. However, it is essential to note that the survey was conducted within South Africa, suggesting that the results might not be universally applicable. Despite this geographical limitation, the findings from this study can still serve as valuable indicators for understanding the factors affecting cloud computing adoption in similar business environments.

A study by Laatikainen et al. (2014) explored the cost-efficiency of private and public cloud storage, examining how various factors, including pricing differences, charging periods for public Storage, acquisition intervals for Private Storage, and the predictability of storage demand growth, influence it. Their research indicated that for organizations experiencing rapid storage growth, such as exponential growth, public cloud storage is generally more cost-efficient, particularly for those with longer acquisition cycles, like annual updates. Conversely, private cloud storage might be more cost-effective for organizations that reexamine and update their Storage frequently, for example, every two months. The study also found that private cloud storage offers more significant advantages in situations where storage demand increases slower, such as logarithmically.

Research questions

According to the information gathered in this paper, performance-wise, NAS is preferred in controlled network environments due to its efficiency, while Cloud Storage excels in adaptability under varying network conditions. Cost analysis is mixed, with NAS often being more economical in the long run, especially for larger data volumes, despite Cloud Storage's lower initial costs. Security-wise, NAS provides more direct control and is less vulnerable to online threats. In contrast, Cloud Storage offers more resilience against physical risks and requires less or no maintenance from the IT staff. These distinctions highlight that the choice between NAS and Cloud Storage depends significantly on the specific needs and contexts of their use.

This literature review reveals a substantial body of research focused on Network-Attached Storage (NAS) and Cloud Storage individually. However, it highlights a notable deficiency in academic exploration concerning the comparative analysis of these two storage alternatives, with a particular emphasis on cost considerations. This identified gap underscores the need for an additional research paper to compare the cost, performance, and security aspects of NAS and Cloud Storage. The most significant emphasis is on cost, which is the factor most important to small businesses.

Considering all of this, the research questions for this thesis will be: How do the cost, performance, and security aspects of small size Network-Attached Storage (NAS) compare with Public Cloud Storage for small businesses and individual users? From what amount of data stored, if at all, does Network-Attached Storage (NAS) become more cost-effective than Public Cloud Storage?

Performance comparison Method

The performance comparison will be made between Synology DS923+ with two 4 TB Seagate Iron Wolf NAS Hard Drive 256MB and Google Drive, Microsoft OneDrive, and Dropbox cloud storage. The Synology DS923+ will be tested in 4 different Raid types. The 4 different raid types for the comparison used will be RAID SHR, RAID 1, RAID 0, and RAID JBOD.

To determine the performance of the various storage solutions, a rigorous performance test will be conducted. This test will involve timing the downloads and uploads of several strategically chosen files. A 10MB text file will represent a typical small file, a 500MB text file will simulate a medium-sized file, and a 5GB test file will address large file scenarios. For additional diversity and to better reflect real-life usage patterns, a 2.09 GB file consisting of 511 pictures and videos will also be employed. This mixed file test will provide insights into file allocation performance alongside standard file transfer speeds. By analyzing the results of these tests, the strengths and weaknesses of each storage solution will be revealed, providing a comprehensive benchmark for evaluation.

These tests will be conducted from 2 networks. The first testing part will take place on the local network of the Synology DS923+, this means that the NAS device is locally connected to this network. The first network (network 1) is based in Riga, its an optical connection with average speeds of around 800 Mbps upload and 900 Mbps download, the network provider is Balticom. The second network (network 2) is located around 40 km outside of Riga it also has an optical internet connection with an average speed of around 95 Mbps upload and 95 Mbps download, the network provider is Tet.

The testing computer to make all these comparisons will be the same for all tests to make the comparison as fair as possible. The specs of the computer: MSI Laptop with Intel i7-7700HQ CPU, GTX 1070 GPU, 16GB RAM, Samsung MZVLW 256 GB SSD, 2TB HDD and Killer E2500 Gigabit Ethernet Controller.

These performance tests will be conducted using Python scripts to download and upload files and time these actions. For timing these downloads I will use a Python library called “Time” and these tests will be made with an accuracy of 0.01 seconds. Each measurement will be taken at least 3 times in each location.

To interface with Google Drive, Microsoft OneDrive, and Dropbox, their respective Python APIs (Google Drive API, OneDrive SDK, and Dropbox API) were utilized.

This thesis utilizes several Python scripts (Appendices A) for comprehensive interactions with various cloud storage providers and a local Network Attached Storage (NAS) device. Scripts dedicated to Google Drive (Appendix A), Microsoft OneDrive (Appendix A), and Dropbox (Appendix A) employ specific libraries or APIs provided by each service. These tools enable seamless file upload and download operations between the respective cloud storage platforms and a local solid-state drive (SSD).

A distinct approach is taken for the NAS device (Appendix A). By mapping the NAS as a network drive on the local network (network 1), the Python script can bypass the need for an external API and interact with files directly using a local path. This simplifies the process and allows for a direct assessment of the NAS device's performance within the local network. When connecting to Synology DS923+ from network 2 there is a necessity to use APIs to facilitate file transfers to and from the local SSD (Appendix A).

A fundamental aspect of these scripts is their ability to precisely measure file transfer times. Both download and upload operations are timed with 0.01-second accuracy. This level of precision yields detailed data, crucial for the performance analysis conducted within this thesis.

Results for Public Cloud providers

Figure 3

Google Drive timed upload and download tests on Network 1

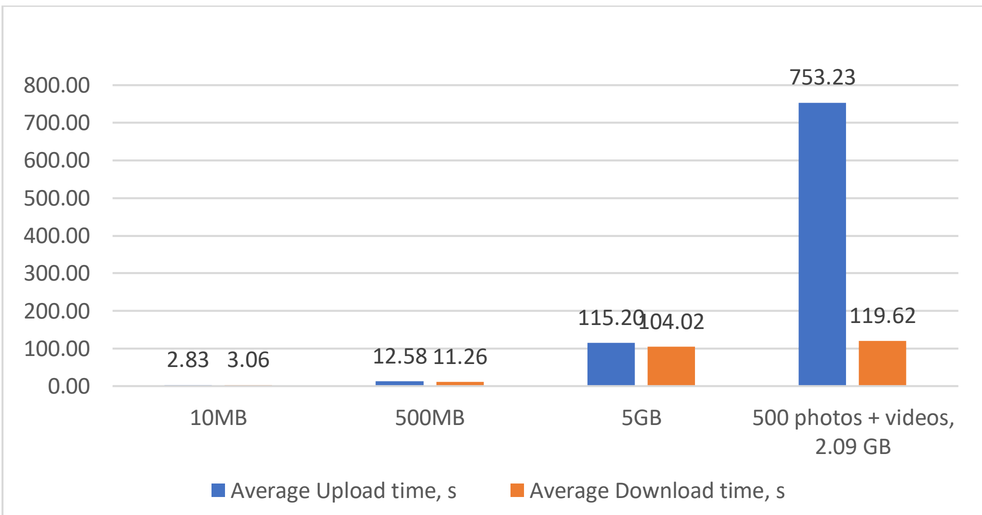
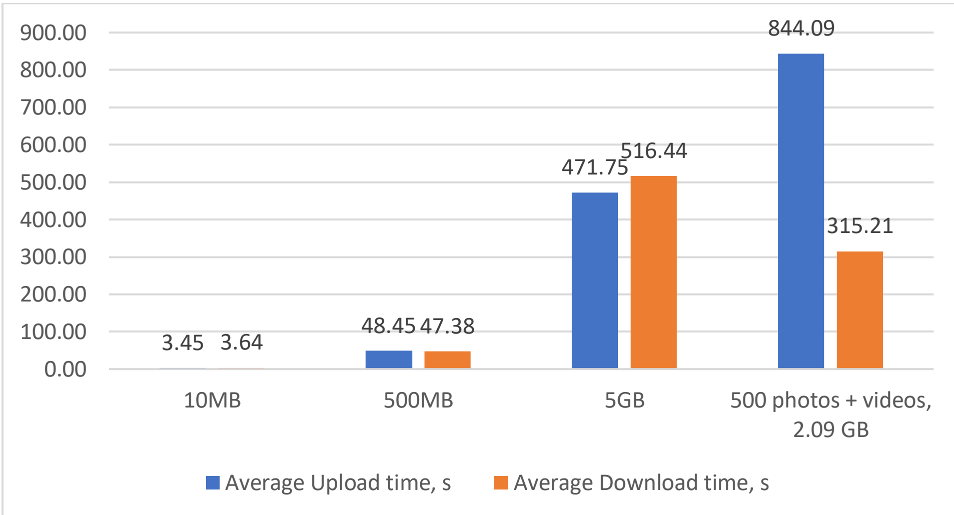


Figure 4

Google Drive timed upload and download tests on Network 2



Google Drive performance tests revealed a significant impact from network conditions and file size variations. On Network 1, peak download, and upload speeds of 393 Mbps and 356 Mbps were achieved, representing approximately 43% and 44% of the measured internet speed capacity. In contrast, Network 2 demonstrated better bandwidth utilization with peak download and upload speeds of 84 Mbps (88%) and 87 Mbps (92%) of internet capacity. Performance noticeably decreased when handling numerous small files, particularly for uploads, averaging around 23 Mbps on Network 1 and 20 Mbps on Network 2 which can be seen in Figure 3 and 4. This decline can be attributed to the overhead of creating file entries, allocating storage, and establishing network connections for each small file. Interestingly, although Network 1 is around 8.5 times faster than Network 2 (according to "speedtest.net"), Google Drive performance gains on Network 1 were only around twice as fast, suggesting that internet speed was not the primary bottleneck in that scenario.

Figure 5

Microsoft OneDrive timed upload and download tests on Network 1

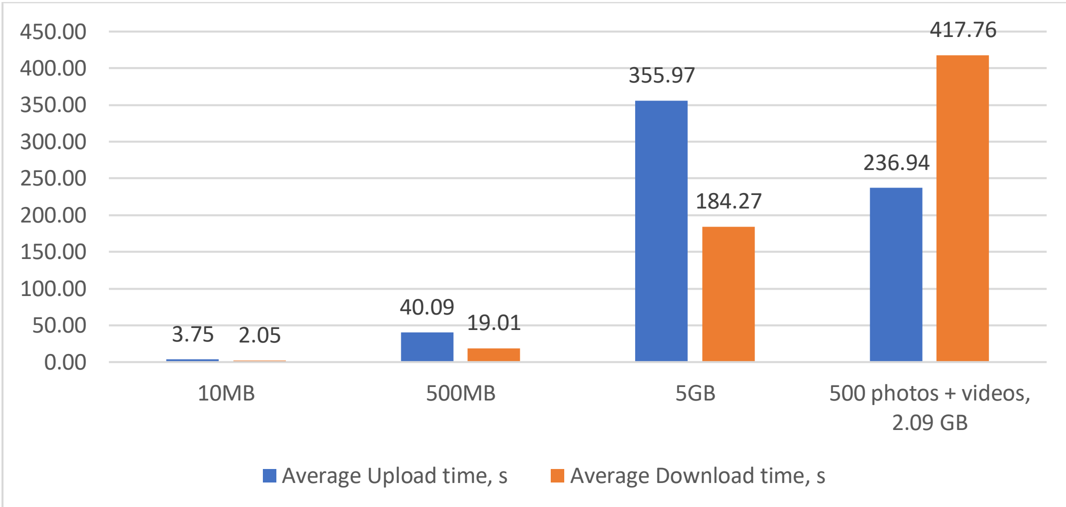
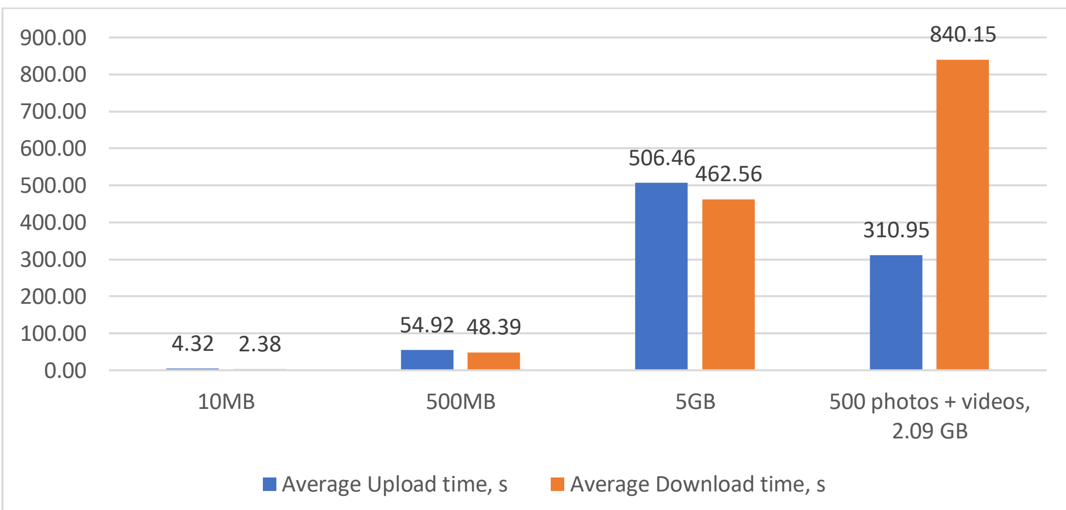


Figure 6

Microsoft OneDrive timed upload and download tests on Network 2



Microsoft OneDrive performance tests exhibited substantial fluctuations across both network conditions and file types. On Network 1, peak average download and upload speeds reached 223 Mbps (approximately 25% of "speedtest.net" measured capacity) and 115 Mbps (around 14% of capacity), respectively. Network 2 demonstrated significantly better bandwidth utilization, with peak download and upload speeds of 88 Mbps (93% of capacity) and 81 Mbps (85% of capacity).

Figures 5 and 6 highlight a performance decline in OneDrive when handling multiple small files. This behavior contrasts with Google Drive, where OneDrive exhibited noticeably slower download speeds but outperformed Google Drive in upload scenarios. Network 1 demonstrated OneDrive speeds approximately 1.77 times faster than those observed on Network 2, further reinforcing the impact of network conditions on OneDrive's performance.

Figure 7

Dropbox storage timed upload and download tests on Network 1

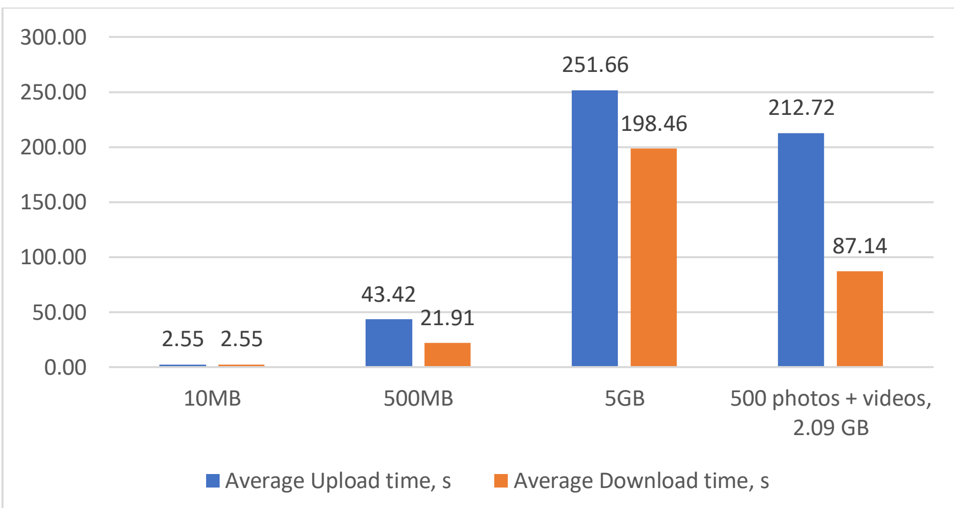
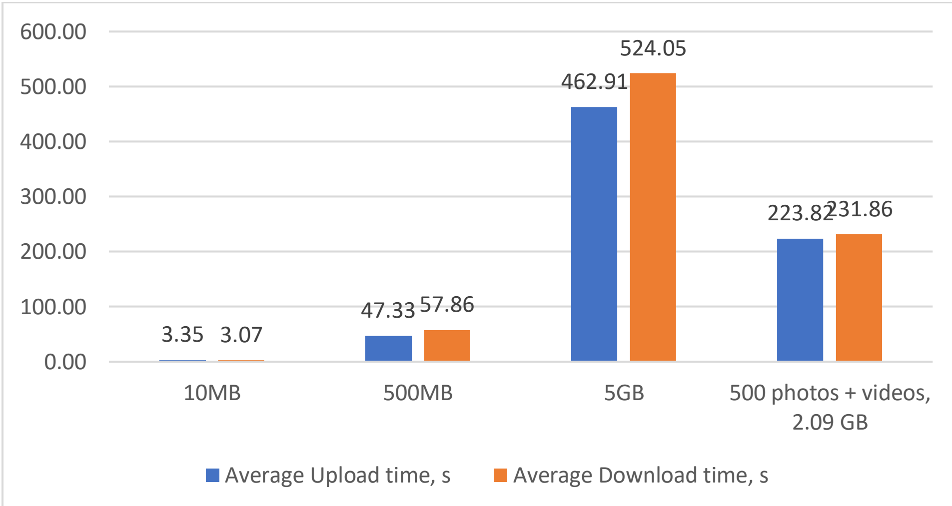


Figure 8

Dropbox storage timed upload and download tests on Network 2



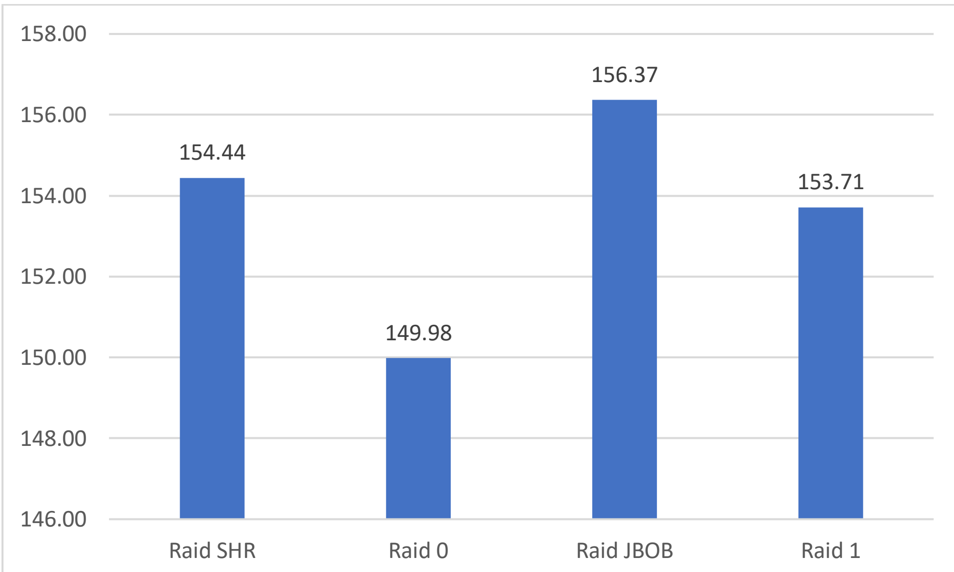
Dropbox exhibited remarkable performance consistency across both network conditions and file types during testing. On Network 1, peak average download and upload speeds reached 206 Mbps (23% of "speedtest.net" measured capacity) and 163 Mbps (20% of capacity), respectively. Network 2 demonstrated slightly improved utilization, with peak download and upload speeds of 78 Mbps (82% of capacity) and 88 Mbps (93% of capacity). Figures 7 and 8 emphasize Dropbox's stability in comparison to the performance fluctuations observed with Google Drive and OneDrive. Network 1's Dropbox speeds were approximately 1.89 times faster than those observed on Network 2.

Results for Synology DS923+ NAS using RAID types: RAID 0, RAID 1, RAID SHR and RAID JBOD

Figures 9, 10, 11, and 12 present the aggregated average time required to complete all performance tests. Each test was executed three times per storage solution, file size, and on each network. The charts, therefore, display the sum of the average upload and download times across all measurements, providing a comprehensive performance overview.

Figure 9

Synology DS923+ Raid type average total time in seconds for all tests on local network (network 1)



As can be seen in Figure 9 the best-performing raid type on a local network for the Synology DS923+ was Raid 0, although all the results were close with the difference between the slowest raid type (RAID JBOB) and the fastest being only 4% and difference between the second fastest (Raid 1) and fastest being only 2.4% slower. These results can be explained by the fact RAID 0 splits data across all the drives in the array, essentially creating a single large volume. When reading or writing data, the NAS can access multiple drives simultaneously, dividing the workload and speeding things up. This contrasts with RAID 1, JBOD, and SHR which rely on single disk access for reads and writes in most scenarios.

The results for all raid types across all tests on a local network (Network 1) stayed similar with no specific outliers in any testing category (Appendix B).

As the results were almost the same for all Raid types for further comparisons with the Cloud provider alternatives the average score of all 4 raid types will be used.

Figure 10

Synology DS923+ Raid type average total time in seconds for all tests on Network 2

As can be seen in Figure 10 the best-performing raid type on network 2 for the Synology DS923+ was Raid 1 and the slowest one was Raid 0, which is in contrast to the results obtained when testing these raid types on their local network. However, when taking a closer look at the results the difference between slowest (RAID 0) and fastest (RAID 1) raid types in these tests was only 1.1%. This shows that the bottleneck for the obtained results was the internet speed and the differences in results can be explained by small fluctuations in the internet connectivity.

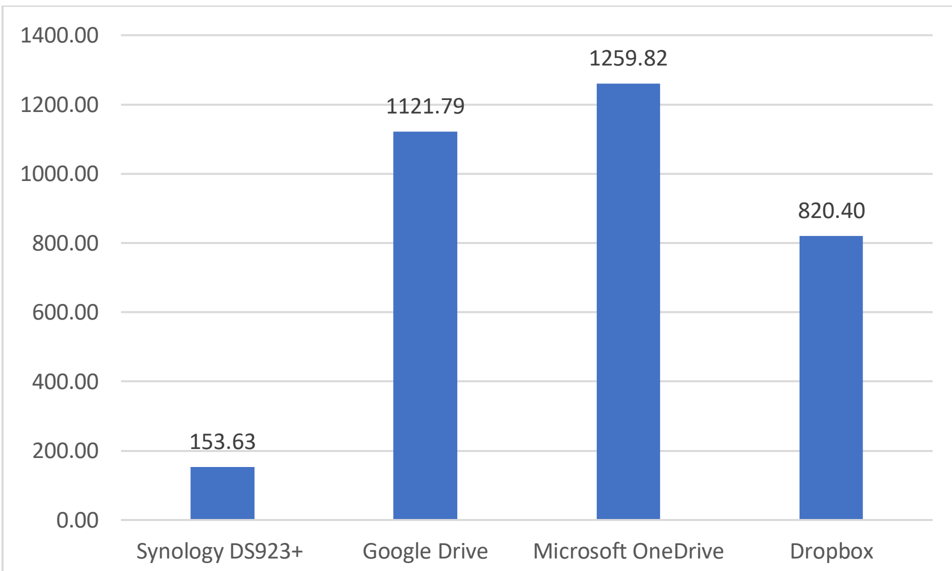
The results for all raid types across all tests on local networks stayed similar with no specific outliers in any testing category (see Appendix C).

As the results were almost the same for all Raid types for further comparisons with the Cloud provider alternatives the average score of all 4 raid types will be used.

Comparison of all tested storage solutions results.

Figure 11

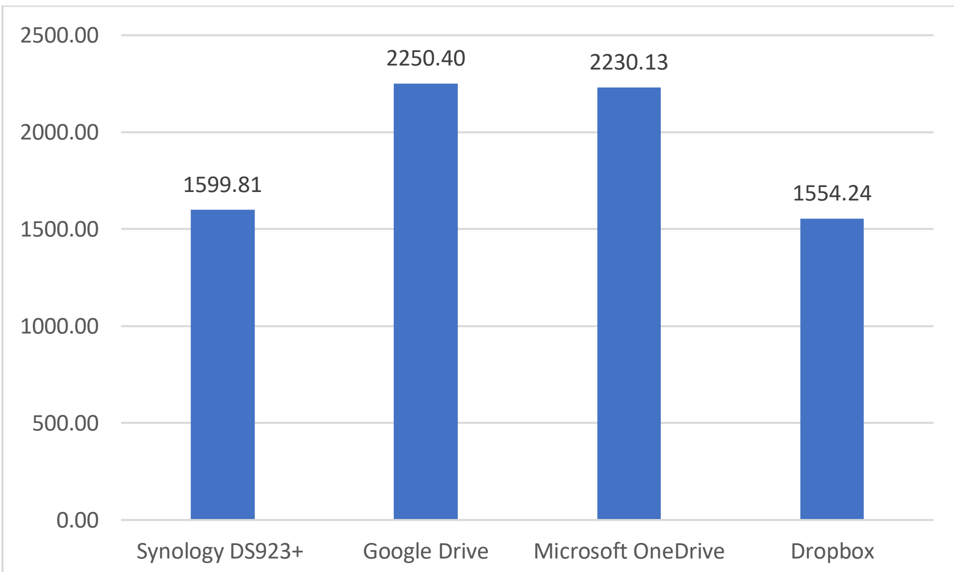
Storage solution average total time in seconds for all tests on Network 1



As can be seen in Figure 11 on the local network (Network 1) the Synology DS923+ NAS outperformed all the Cloud storage providers by a large margin with the closest competition being Dropbox, although still, the NAS was 5.34 times faster. The performance advantage for the NAS on the local network can be explained by the Physical distance of the storage device from the test PC and possible network bottlenecks for the cloud providers. Interestingly out of all the Public Cloud providers tested, Dropbox won with a large margin of being 26% faster than the closest competitor out of the 3 public cloud providers tested. The advantage of Dropbox cloud storage can be explained by its significantly better capabilities at handling large amounts of small files which can be seen when comparing Figures 3,5,7. This is likely because Dropbox does not sync files in the same way as Google Drive and Microsoft OneDrive (Zhang, 2024). It uploads files on a block basis. This way makes uploading a batch of small files much faster than Google Drive or Microsoft OneDrive.

Figure 12

Storage solution average total time in seconds for all tests on Network 2



Synology DS923+ NAS loses its advantage when it is not located on the local network which can be seen in Figure 12. Dropbox stays as the performance leader on Network 2, although the NAS is a close second with the overall difference being around 2.8%. Dropbox gained this lead by being faster at handling large amounts of small files which can be seen looking at Figures 4,6,8 and Appendix C.

Cost Comparison Method

The cost comparison will be made between the 3 tested Cloud storage providers (Google Drive, Microsoft OneDrive, Dropbox) and Networked-attached-storage (NAS) devices. For a more comprehensive cost comparison, multiple NAS devices will be included in the analysis in Raid types: Raid 0, Raid 1, Raid SHR, and Raid JBOB. For cost calculations, Raid 0 and Raid JBOB are the same as they both do not offer data redundancy. With only 2 hard drives the cost comparison for Raid 1 and Raid SHR are the same for cost calculations.

The cost for the cloud providers will be calculated based on the monthly subscription fees that are charged for the Cloud storage services. The NAS device cost calculation will encompass the hardware (NAS unit and hard drives) and estimated electricity usage per month. The electricity consumption for the Synology DS923+ NAS will be measured using an ETECH PM300 energy meter with an accuracy of 0.01 KW/h. For the other NAS devices mentioned the electricity consumption will be estimated using online sources. The electricity price used for calculating the cost will be 0.09989 euros per KW/h which was the average electricity price in Latvia in 2023 (AST, 2023).

The NAS Devices used for the comparison are a 4-bay Synology DS923+ (Price: 539 euro), 2-bay Synology DS223 (Price: 243 euro), and 1-bay Synology DS124 (Price: 159 euro) (NASSTORE, 2024).

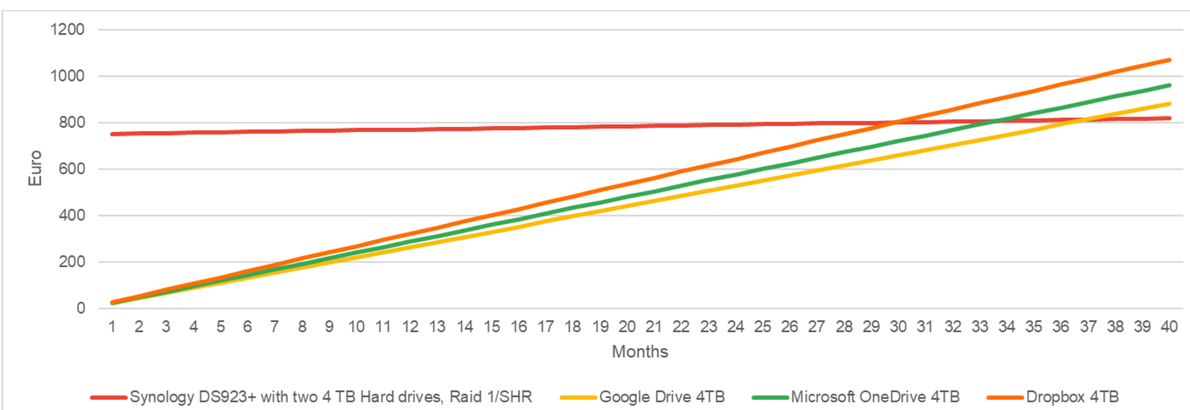
The electricity cost per month for Synology DS923+ is 1.71 euro (according to measurements by PM300 energy meter), 1.21 euro for DS223, and 0.719 euro for DS124 according to the manufacturer (Synology, 2024).

Hard drives possess an expected lifespan of 3-5 years, beyond which the probability of failure increases significantly (Genuine Modules, 2024). Most hard drives designed for NAS environments carry warranties of approximately 3 years (Sharma & Trivedi, 2024). This suggests that a NAS solution can demonstrate superior cost-effectiveness if the initial investment is recouped within the warranty period when compared to the ongoing costs of a cloud storage alternative.

Cost Comparison Results

Figure 13

Cost comparison of Synology DS923+ with two 4 TB Hard drives, Raid 1/SHR (this setup was used in performance testing) vs Google Drive 4TB vs Microsoft OneDrive 4TB vs Dropbox *4TB*



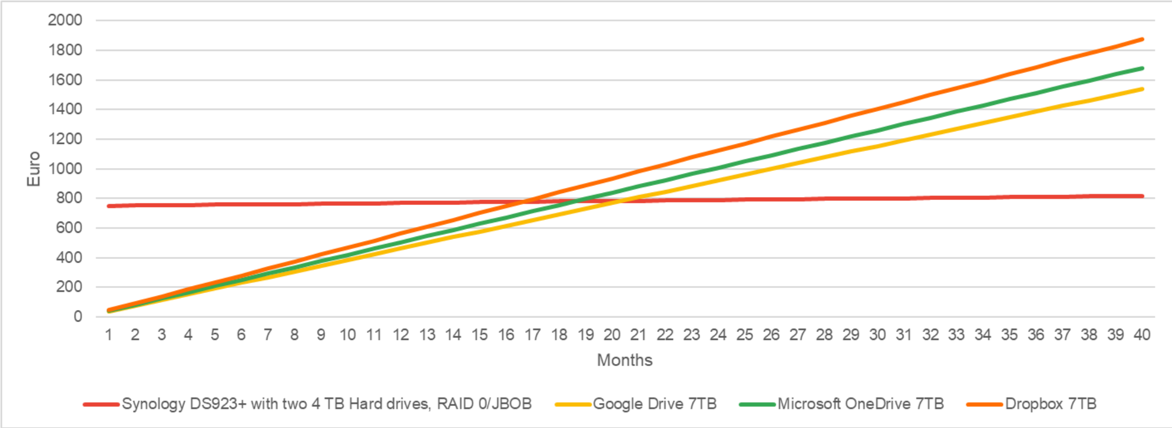
Note. Synology DS923+ with two 4 TB Hard drives with raid types of Raid 1 or Raid SHR has a total storage capacity of 3.6TB. The other half of the storage is for redundancy.

Cost analysis indicates that a Synology DS923+ configured with two 4TB hard drives in either RAID 1 or RAID SHR configuration becomes more cost-effective than Dropbox at month

30 (See Figure 13). Compared to Microsoft OneDrive, the NAS solution reaches cost parity at month 34, demonstrating a marginal advantage. However, Google Drive surpasses the NAS in cost by month 37, rendering the NAS less cost-effective in this specific scenario.

Figure 14

Cost comparison of Synology DS923+ with two 4 TB Hard drives, Raid 1/SHR vs Google Drive 7TB vs Microsoft OneDrive 7TB vs Dropbox 7TB

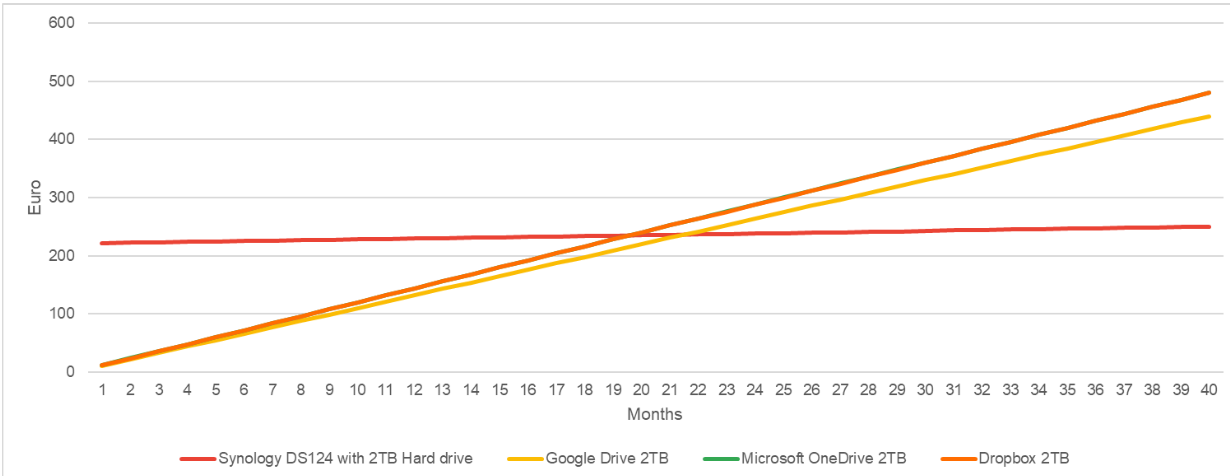


Note. Synology DS923+ with two 4 TB Hard drives with raid types of Raid 0 or Raid JBOB has a total storage capacity of 7.3 TB

Cost analysis indicates that a Synology DS923+ configured with two 4TB hard drives in either RAID 0 or JBOD configuration becomes more cost-effective than Dropbox at month 17, Microsoft OneDrive at month 19 and Google Drive surpasses the NAS in total cost by month 21 (See Figure 14). This demonstrates a clear financial advantage over all three cloud solutions. Importantly, it must be noted that neither RAID 0 nor JBOD offers data redundancy, meaning a single drive failure would result in permanent data loss. This reduced reliability makes cloud storage options inherently safer despite their higher long-term cost.

Figure 15

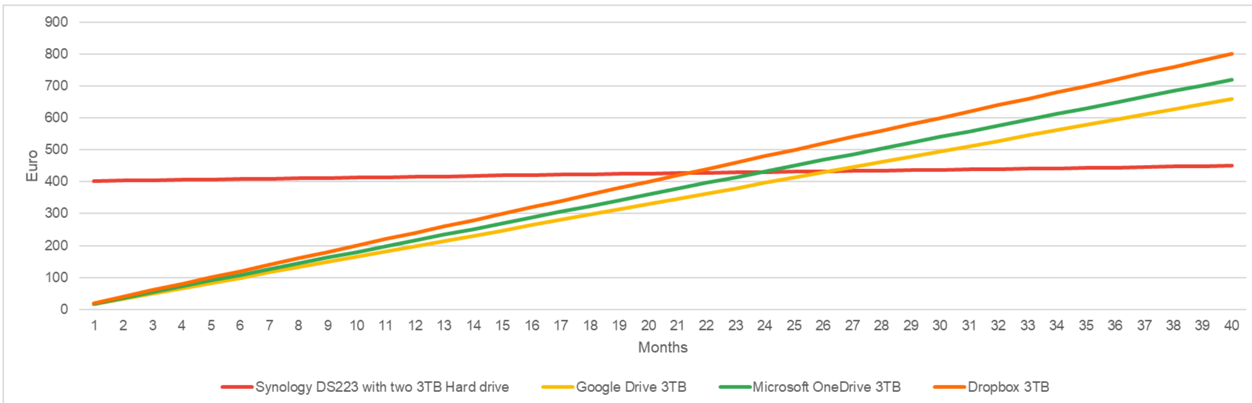
Cost comparison of Synology DS124 with 2 TB Hard drive vs Google Drive 2TB vs Microsoft OneDrive 2TB vs Dropbox 2TB



To determine the minimum data storage threshold for a cost-effective NAS solution, I found that capacities exceeding 1TB are necessary to compete with cloud alternatives. A 2TB configuration, such as the Synology DS124, becomes more cost-effective than Dropbox and Microsoft OneDrive after 20 months and surpasses Google Drive's affordability at 22 months (see Figure 15). However, it is important to note that this single-drive NAS setup lacks data redundancy, making cloud alternatives a safer storage option.

Figure 16

Cost comparison of Synology DS223 with two 3 TB Hard drives, Raid 1 vs Google Drive 3TB vs Microsoft OneDrive 3TB vs Dropbox 3TB



To determine the data threshold for a cost-effective NAS solution that also offers data redundancy, I found that configurations of 2TB or less were insufficient. However, a 3TB setup using the Synology DS223 with two 3TB hard drives becomes more cost-effective than Dropbox at month 22, and Microsoft OneDrive at month 24, and surpasses Google Drive's affordability by month 27 (see Figure 16). Therefore, a minimum of 3TB is necessary to create a NAS solution that is both cost-effective and provides data redundancy.

Discussions

Practical & Theoretical Implications

This research successfully answered both thesis questions, providing valuable insights for small businesses and large households considering public and private cloud solutions.

Performance tests revealed the NAS solution (Synology DS923+) as the clear winner within local networks. This suggests that for performance-sensitive businesses or households operating primarily from a single location (e.g., an office), the NAS is the optimal choice.

For optimal NAS performance within a local network, RAID 0 proved the fastest configuration. However, it's crucial to note that RAID 0 lacks data redundancy. Other RAID types (RAID 1, RAID SHR) offer data protection while exhibiting only slightly reduced performance. When accessed remotely, all RAID types performed similarly, suggesting that internet speed becomes the primary bottleneck.

Dropbox outperformed Microsoft OneDrive and Google Drive across both test networks when handling large quantities of small files. Google Drive excelled in single-file uploads and downloads, demonstrating that each provider possesses unique strengths.

Even outside the local network, the NAS remained competitive, surpassing Google Drive and Microsoft OneDrive and trailing only slightly behind Dropbox.

This study indicates that a NAS solution becomes cost-effective compared to cloud options when storing 2TB of data without redundancy. This break-even point occurs in approximately 20 months. If data redundancy is crucial, the minimum storage requirement for NAS cost-effectiveness rises to 3TB, with a break-even period of roughly 24 months.

Importantly, cloud storage costs were fairly consistent across Google Drive, Microsoft OneDrive, and Dropbox. On average, 1TB of storage costs slightly below 6 euros, with Google Drive offering a slight price advantage.

Research Limitations and Possible Improvements.

The present study faced several constraints, leaving opportunities for future research to further refine the accuracy and comprehensiveness of the findings.

Firstly, performance assessments were conducted solely from two locations within Latvia. While this offers insights for Latvian-based companies, a broader testing scope encompassing international locations would provide a more robust evaluation of NAS performance for businesses with a distributed workforce.

Secondly, performance testing was conducted with a single user accessing the systems at a time. Future studies could investigate the impact of multiple simultaneous users, both within a local network and with remote access, on both NAS and cloud solutions, providing a more realistic understanding of performance under varying workloads.

Furthermore, the cost comparison between cloud storage and NAS solutions could have included possible price changes for internet connectivity depending on the solution chosen. For example, organizations primarily utilizing storage over a local network could potentially reduce costs based on their internet usage. On the contrary, businesses relying heavily on external access for either Cloud storage or NAS would need to factor in the potential need for internet upgrades. Additionally, the ease and flexibility of scaling storage up or down favors cloud providers, making this an important consideration within the cost analysis.

These limitations offer valuable avenues for future research to develop even more comprehensive comparisons, aiding businesses in their storage solution decision-making.

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Appendices

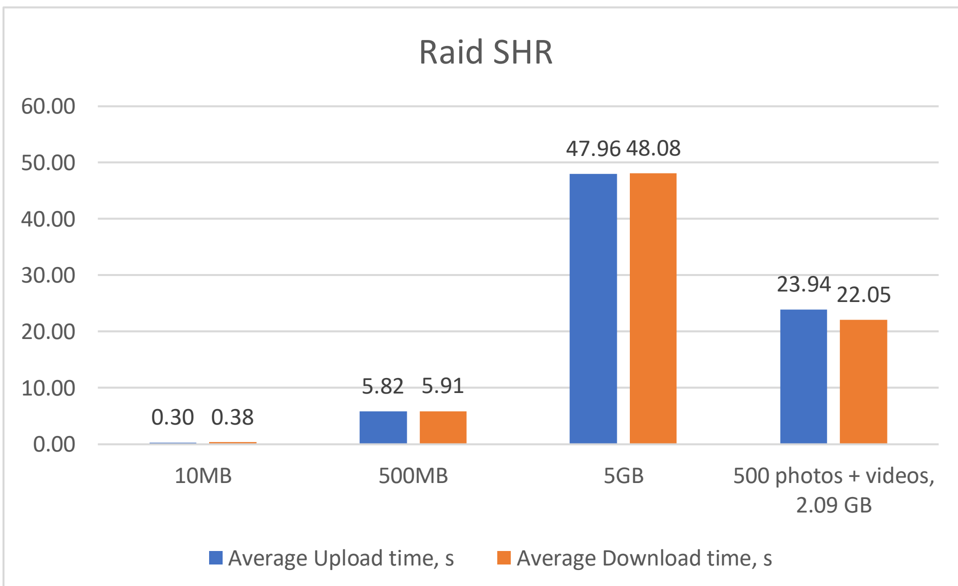
Appendix A

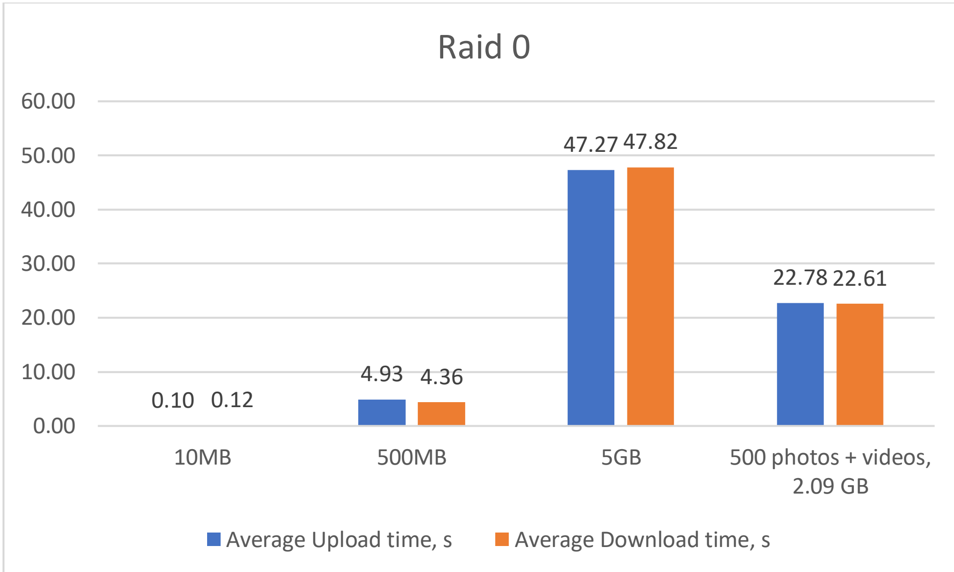
Replit link where all the python scripts are stored

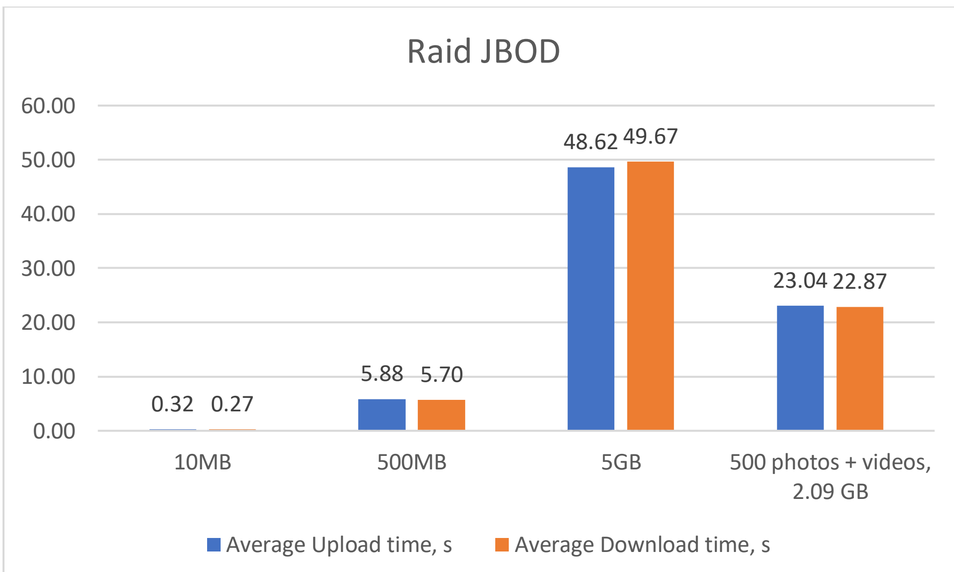
https://replit.com/@hacker564/BachelorThesisAlbertsJansons

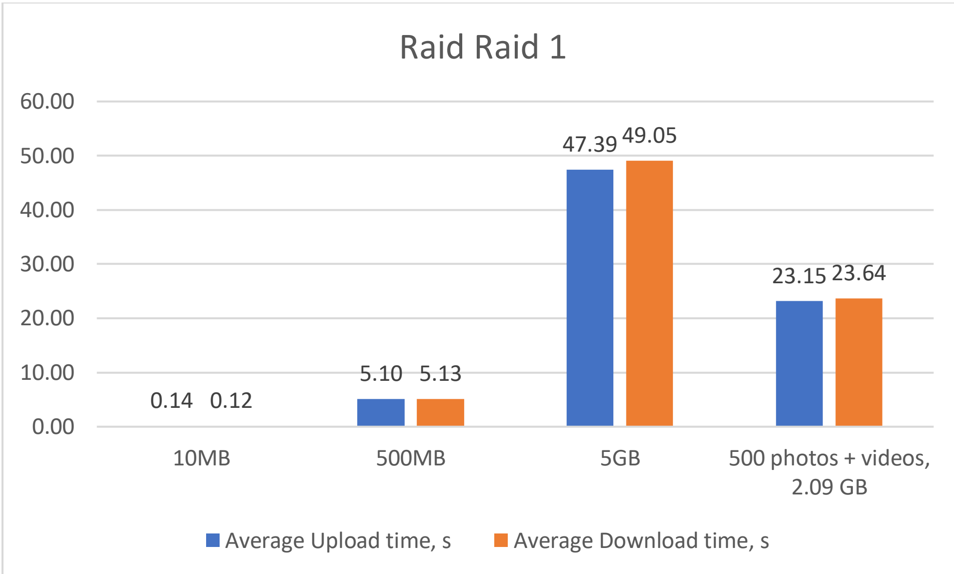
Appendix B

Synology DS923+ performance tests on a local network (network 1) for Raid types: Raid SHR, Raid 0, Raid JBOD, Raid 1



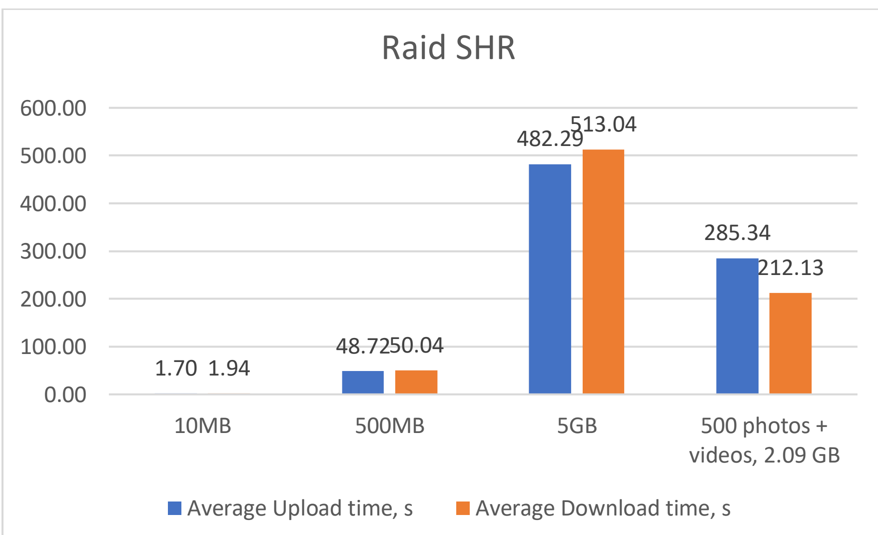

Raid 0
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.10
0.12
4.93
4.36
47.27
47.82
22.78
22.61
10MB
500MB
5GB
500 photos + videos, 2.09 GB
Average Upload time, s
Average Download time, s

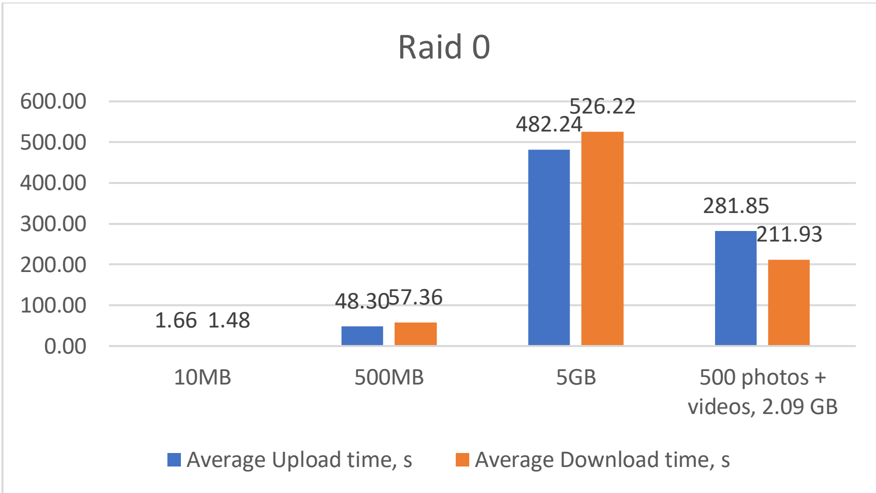

Raid JBOD
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.32
0.27
5.88
5.70
48.62
49.67
23.04
22.87
10MB
500MB
5GB
500 photos + videos, 2.09 GB
Average Upload time, s
Average Download time, s

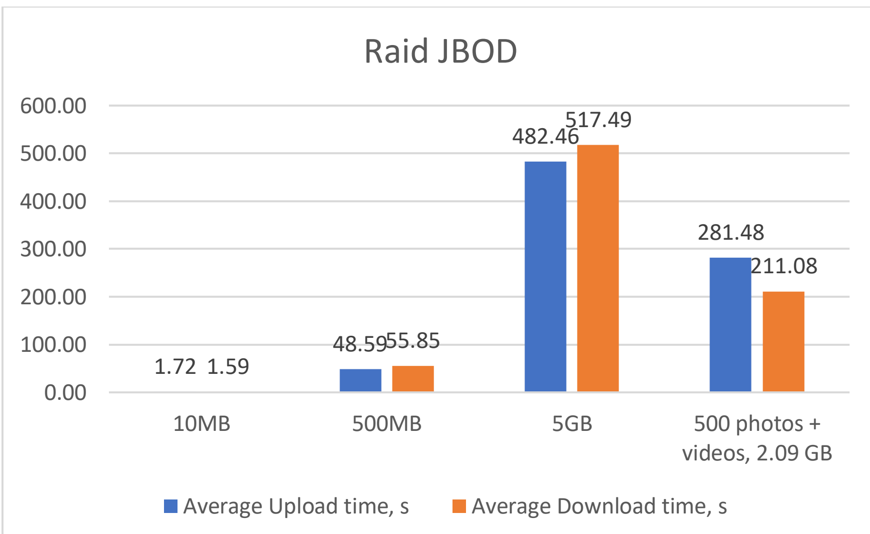


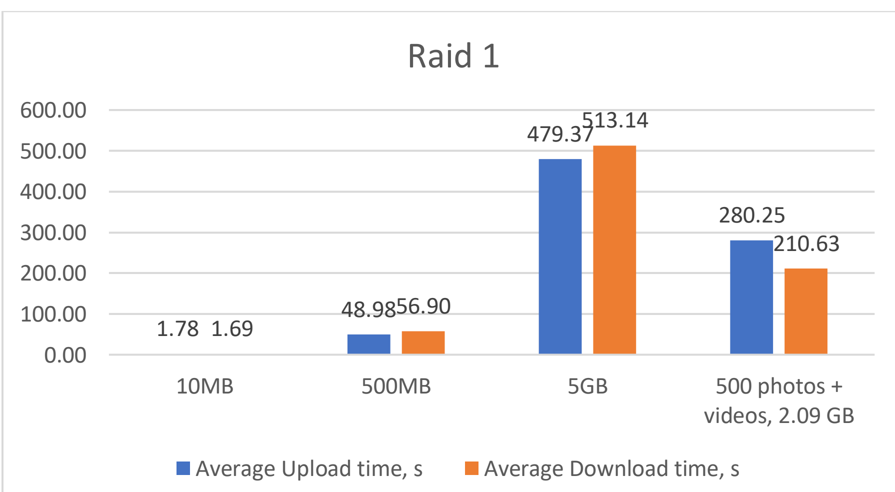
Appendix C

Synology DS923+ performance tests on local network 2 for Raid types: Raid SHR, Raid 0, Raid JBOD, Raid 1




Raid 0
600.00
500.00
400.00
300.00
200.00
100.00
0.00
1.66
1.48
48.30
57.36
482.24
526.22
281.85
211.93
10MB
500MB
5GB
500 photos + videos, 2.09 GB
Average Upload time, s
Average Download time, s


Raid JBOD
600.00
500.00
400.00
300.00
200.00
100.00
0.00
1.72
1.59
48.59
55.85
482.46
517.49
281.48
211.08
10MB
500MB
5GB
500 photos + videos, 2.09 GB
Average Upload time, s
Average Download time, s


Raid 1
600.00
500.00
400.00
300.00
200.00
100.00
0.00
1.78
1.69
48.98
56.90
479.37
513.14
280.25
210.63
10MB
500MB
5GB
500 photos + videos, 2.09 GB
Average Upload time, s
Average Download time, s

GUARANTEE

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April 14, 2024

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Date: 2024.04.14 16:38:38 EEST
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Reason: Bachelor Thesis