IoT single board computer to replace a home server

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***Abstract*—Home servers are popular among computer enthusiasts for hosting various applications, including Linux OS with web servers, database solutions, and private cloud services, as well as for VPN, torrent, file-sharing, and streaming. Single Board Computers (SBCs), once used for small projects, have now evolved and can be used to control multiple devices in the IoT space. SBCs have become more powerful and can run many of the same applications as traditional home servers. In light of the energy crisis, this study will examine the feasibility of replacing a conventional home server with an SBC while maintaining service quality and evaluating performance and availability. The power consumption of both solutions will be compared.**

***Index Terms*—Home servers, Single Board Computers, Linux, Operating system performance, power consumption**

I. Introduction

Home servers are a cost-effective way to set up private servers using old or low-performance computers. Running on a free Linux operating system, these servers offer the advantage of hosting a private cloud and can support IoT devices such as sensors and cameras. Energy efficiency is key as the server must be on 24/7 to receive IoT data, and a display is not required as applications can be accessed remotely. To ensure data security, multiple hard drives in a RAID array can be used. Single Board Computers (SBCs) have become a more energy-efficient alternative to PCs or home servers. With the improvement of components in the last five years, SBCs now boast multi-core CPUs, up to 8GB DDR4 RAM, and improved storage options like USB and eMMC ports. This study will compare the performance and energy consumption of a PC upgraded with SSDs to two modern SBCs with different disk connection sockets (PCIe and MVMe). However, obtaining equivalent SBCs for testing is currently not feasible due to component shortages or high costs.

II. Single Board Computers

A. The history of Single Board Computers

A Single Board Computer (SBC) is a computer in the form of a single motherboard that houses a processor, memory, and I/O connections. In the past, individual components such as sound cards, network cards, and video cards were sold separately. However, now most consumer motherboards are considered SBCs as they come with most of the necessary functionalities integrated on the board, with the option to upgrade through the addition of expansion cards. [1].

The first SBC available for home and IT enthusiasts was the Arduino. Arduino was born in 2005 at the Interaction Design Institute Ivrea, Italy, as a fork of the open-source Wiring Platform. The founders of the project, Massimo Banzi, and David Cuartielles, named the project after Arduin of Ivrea, the main historic character of the town [2]. The first Arduino board was released in 2006 but lacked universal interfaces like USB, other boards were developed until 2010 when the Arduino Uno was released to the public, and it was a huge success, changing the background of IoT.

Today there are many Arduino (or equivalents) boards available. While those boards are elegant, reliable, and extremely energy efficient, they lack processing power or memory size. In 2006, a group based in the University of Cambridge's Computer Laboratory decided to address the need for a low-cost computing platform that would allow kids to learn how to program without needing a full-fledged home computer. The result was a $35 single board computer named Raspberry Pi [1]. While initially designed as a tool for students to learn programming, the Raspberry Pi was adopted by makers, designers, students, and even professional engineers and helped to launch the current boom in interest in SBCs [1]. Over the last decade, several upgrades or new models were developed and launched. The current version is RPi4, which is available in different models with different RAM sizes.

Over the years, many other manufacturers developed SBCs that were alternatives to the Raspberry Pi, with the same small form format. Many differ mainly on CPU type: clock rate and number of cores; RAM: speed and size; GPU: graphic card and interface format, HDMI, mini-HDMI, for example;

III. SBCs Data storage and interfaces

A. Data storage

Despite the popularity of Single Board Computers (SBCs), early models faced limitations when it came to data storage. In the early years prior to 2014, all SBCs relied solely on an SD card to boot and run the operating system. Later models continued to require an SD card for booting, but added the option to combine it with a USB device like a flash drive or hard drive. Today, many SBCs still require an SD card for booting purposes

While external hard drives are very popular, there are better ways than connecting the HDD via USB. The first device that changed and provided a solution was the Banana Pi BPI-M1 [3]. Released almost simultaneously, the Raspberry Pi 2 had a quad-core ARM Cortex-A7 processor with 1 GB RAM, while the Banana Pi BPI-M1 had Allwinner A20 Dual-core, also with 1 GB RAM. The big difference between them was the possibility of connecting a hard drive directly via a SATA 2 port, which changed everything.
Since the first SBCs were released, all devices came equipped with general-purpose input/output (GPIO) pins. This type of interface is used to connect sensors and other devices but, is outside of the scope of this work.

B. eMMC

The eMMC storage modules are an evolution from the SD cards. The MultiMediaCard (MMC) storage is used on the embedded version (eMMC) to provide cost, and energy-efficient hardware since, like other types of flash memory (USB sticks, SSDs, etc.) doesn't require power to retain data. Inherently, using an SD card for IoT devices is a risk as it is not tolerant to power outages; some efforts have been made to improve reliability [4], yet, the speed of an eMMC module will depend on the BUS size used. For example, the Pi engineers increased the eMMC bus from 4 bits to 8 bits, so it can get more bandwidth out of the eMMC storage, as shown in Fig. 1 [5].

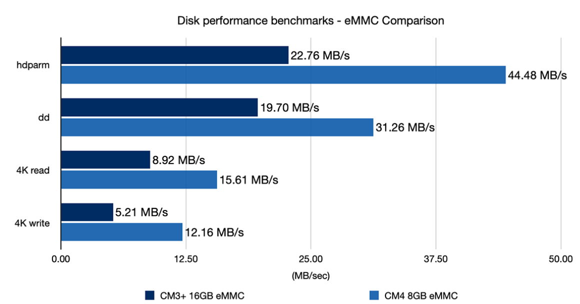

Fig. 1: Compute Module 4 eMMC vs Compute Module 3+

C. PCI Express

PCI Express (Peripheral Component Interconnect Express), officially abbreviated as PCIe or PCI-e, sata is a high-speed serial computer expansion bus standard designed to replace the older PCI, PCI-X, and AGP bus standards [6].
A PCIe lane consists of a T (transmit) and an R (receive) LVDS signal pair. Data packets are sent at a signaling rate of 2.5 GHz in simplex form. The T and R pairs, each transfer data at 250MB/sec with a combined rate of 500MB/sec. A link can be formed with multiple lanes, the configurations defined are x1, x4, x8 and x16 [7].
While PCI is a single parallel connection connected to the PCI bus, the PCIe card is a high-speed serial connection connected to a switch that controls several point-to-point serial connections. Each one of these connections is called a lane, and physical PCI Express links may contain 1, 4, 8, or 16 lanes, usually prefixed with an X.
Over the years, new versions of the PCIe standard were announced, allowing greater bandwidth for each version. Currently, most motherboards and SBC devices support at least PCIe 3.0 or 4.0 (Fig. 2).

	Bandwidth
x1	**Single Direction:** 2.5 Gbps/200MBps **Dual Direction:** 5 Gbps/400MBps
x4	**Single Direction:** 10 Gbps/800MBps **Dual Direction:** 20 Gbps/1.6 GBps
x8	**Single Direction:** 20 Gbps/1.6 GBps **Dual Direction:** 40 Gbps/3.2 GBps
x16	**Single Direction:** 40 Gbps/3.2 GBps **Dual Direction:** 80 Gbps/6.4 GBps

Fig. 2: PCIe cards sizes and bandwidth

Some SBCs are equipped with PCIe slots, but it is essential to check in the specification documentation which PCIe version and the type of connections are available since, for example, a PCIe-X4 slot allows the use of PCIe-X1 boards.

D. M.2 NVMe

Solid state drives (SSD) can be connected to PCs using the SATA interface, which was also used for mechanical hard drives with a bandwidth limit of around 6 Gbps. Alternatively, SSDs can also be connected through a newer form factor called M.2, which utilizes the PCI Express (PCIe) interface. M.2 NVMe SSDs typically consist of NAND flash memory packages, a DRAM package, and a controller. Even on a PCIe 3.0 interface, NVMe technology can utilize 4 lanes with a theoretical maximum speed of 31.5 Gbps, which is significantly higher than the SATA interface [8].

IV. PCIe and NVMe to Sata interfaces

Connecting multiple SSDs/hard drives to an SBC can be challenging. Most SBCs only have one interface of type: PCIe, NVMe, or SATA. Multiple adapters allow multiple SATA ports to be connected to one of these interfaces. One of the objectives of this work is to create a RAID 5 array attached to an SBC, so any of those adapters should have at least 4 SATA ports. SATA version 3.0 provides a downstream bandwidth of 6 Gbps (600 MB/s) through its SATA ports. Connecting four SATA SSDs to a SATA port can result in a read/write speed ranging from 200 MB/s to 550 MB/s for each individual SSD. The potential bottleneck lies in the upstream connection, which depends on the PCIe version and the number of lanes used. It's important to carefully choose components to avoid compatibility issues, as some motherboards may have unsupported chips for Linux operating systems. Additionally, advertised speeds for a PCIe-connected SSD may not be accurate, and can sometimes be misleading. It's important to verify the specifications carefully and consider the actual capabilities of the PCIe version and the number of lanes available.

A. PCI-e 1X Adapter with 4-Port SATA III

The first adapter acquired connects the SSDs to the SBCs via a PCIe x1 slot, but as refereed in section III-C, this device can be connected to PCIe x2, x4, x8, or x16, Fig. 3.

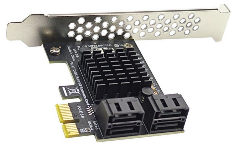

Fig. 3: 4 Port SATA III Card 6Gbps SATA 3.0 to PCIe X1

An adapter that connects SATA drives to a PCIe slot can support up to four SATA drives. The adapter in question uses the Asmedia ASM1064 controller and supports PCIe 2.0 and 3.0, but not PCIe 4.0. The bandwidth of the PCIe x1 interface is 4 Gbps (500 MB/s) for PCIe 2.0 and 8 Gbps (1 GB/s) for PCIe 3.0. According to the controller manufacturer's specifications, the read and write speeds for the adapter on PCIe 2.0 are 417 MB/s and 407 MB/s, respectively, and 565 MB/s and 507 MB/s on PCIe 3.0.

B. PCI-E 4X Adapter with 4-Port SATA III

The second adapter is an improved version of the one referred on section IV-A. This board uses a PCIe x4 connection instead of a PCIe x1, Fig. 4.

Fig. 4: 4 Port SATA III Card 6Gbps SATA 3.0 to PCIe X4

While this adapter uses the newer Asmedia ASM1166 chip, it still only supports PCIe 2.0 and 3.0. The PCIe x4 upstream on version 2 has a bandwidth of 16Gbps (2 GB/s), while on version 3 is around 32Gbps (4 GB/s). In theory, comparing the specifications from this adapter, using 4 PCIe lanes versus the first adapter, there should be a significant performance improvement. Still, the performance will depend on the SBC to which the adapter is connected, so further is required in a real-life scenario.

C. M.2 B-Key to 5 port SATA

The third adapter chosen was an M.2 to SATA using the JM575 controller, Fig. 5. This is a PCIe version 3.0 board, using two lanes (x2), provided upstream on version 2 has a bandwidth of 8Gbps (1 GB/s), while on version 3 is around 16Gbps (2 GB/s).

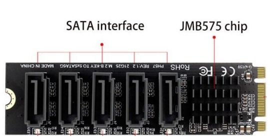

Fig. 5: M.2 B-Key To SATA

D. NVME M.2 B-Key to 6 port SATA

The final adapter is an NVME to 6 SATA ports, Fig 6. This adapter uses the same Asmedia ASM1166 chip as the PCIe adapter from section IV-B.

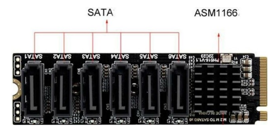

Fig. 6: NVME M.2 B-Key To SATA

Using the same chip on a different socket type can provide performance comparisons from PCIe and NVME M.2 if both sockets are available on the same SBC.

V. Testing hardware and operating system

The point of this work is to build an IoT SBC server. The SBCs used on this work all boot from eMMC modules and didn't require a micro SD card.
The same hard drive configuration will be used in all scenarios. The operating system is on an SSD (PC) or an eMMC (SBCs), and a group of four SSDs for RAID 5, all disks are Kingston model SA400S3. The home server runs an Intel quad-core 64-Bit i5-4690 CPU and a motherboard Asus B85M-G, running Debian Linux version 11. This will be the operating system used in all configurations as well. The software installed implements a LEMP web server with a Linux operating system, Nginx, MariaDB, and PHP.

A. PINE64 ROCKPro64

The ROCKPro64 is a hexacore 64-Bit processor Rockchip RK3399, composed of a dual ARM Cortex A72 and quad ARM Cortex A53, Fig 7. The model used for this work is

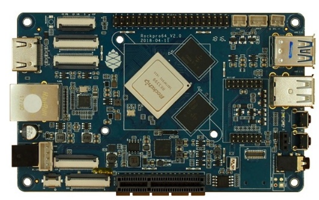

Fig. 7: PINE64 ROCKPro64 SBC

equipped with 4GB RAM and a 64GB eMMC module for the operating system. The board has a PCI-express X4 socket and will be tested with the adapters from sections IV-A and IV-B.

B. ODROID-M1

The ODROID-M1 is a quad-core 64-Bit Rockchip RK3568B2, composed of four ARM Cortex-A55 processors, Fig 8. The model acquired for this work is equipped with 8GB RAM and a 32GB eMMC module for the operating system. The board has (from the specifications page) M.2 NVMe M-Key PCIe3.0 2-Lane socket and will be tested with the adapters from sections IV-C and IV-D.
It should be noted the details of the specifications page for this SBC, with the PCIe version, number of lanes, and a section

Fig. 8: ODROID-M1 SBC

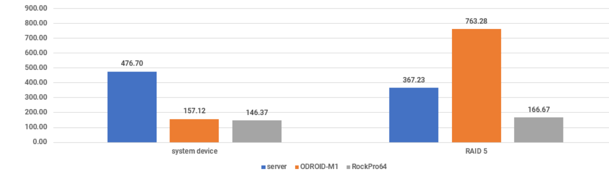

Fig. 9: Storage performance using hdparm

comparing this SBC with the Raspberry Pi Compute Module 4.

VI. Performance and energy consumption metrics and tools

In Portugal, there are periods where the energy prices are cheater, usually during the night [9]. The prices can also vary depending on the person's plan and even the day of the week. Using October 2020, peak prices are around 0,20€/kWh and low 0,10€/kWh; the monthly and annual costs can be estimated. To simplify cost calculations, a bi-time plan will be used. On a 168 hours week, 92 hours is considered a peak hour, the price per kWh is higher, and 76 hours with lower prices. With the average daily consumption (DAC) in kWh, the daily cost can be calculated using the formula:

$$dailycost = \frac{92}{168} * dac * 0.20 + \frac{76}{168} * dac * 0.10$$

There are several tools in the Linux operating system for performance evaluation; comparing them is beyond the scope of this work. The following tools were used:

- Hard drives - hdparm, Fio and a network copy using rsync;
- Memory - sysbench;
- CPU - sysbench and 7zip;
- Network - speedtest-cli;

VII. Performance analysis

The server had five mechanical hard drives, so to have a proper evaluation of performance and energy with the SBCs, the first step was to replace all drives with SSDs. One drive is for the operating system, the remaining four have a RAID 5 array.

A. Hard drives performance

Hard drive performance can be measured in MB/s or Input/Output Operations Per Second (IOPS). On a Linux box, then a very simple built-in IO testing tool is the hdparm command. It is a very simple built-in IO testing tool, that can display disk device statistics and set hardware parameters and statistics about the hard disk, alter writing intervals, acoustic management, and DMA settings [10]. Analyzing the results using hdparm shown in Fig 9, the left side of the chart was expected since it's the main storage drive. On the PC is an SSD, and the SBCs use a slower eMMC storage, so the results are as expected. But the performance of the drive array on the ODROID-M1 was surprising and completely outer performed the PC.

The second tool is Fio which stands for Flexible Input/Output tester. The Flexible IO Tester is a highly configurable benchmark program that allows the user to control the number of I/O jobs to be run concurrently on top of files or raw devices [11]. A set of four different tests will be run on the operating system

Fig. 10: Flexible Input/Output random 4K read and write test

disk and the raid array of disks. The first test is a random 4K read and write test that uses 250MB data, at a ratio of 80% reads to 20% writes, Fig 10. The second test will do a set of random 4K writes, which is the most stressful test for a disk, simulating heavy operations like copying home directories, manipulating email with big files, database operations, and source code trees [12]. The third test is a 16 parallel 64KiB random write process, creating in parallel 16 separate 256MB files to a total o 4GB, and finally, a single 1MB random write process. There are different results from hdparm to fio.

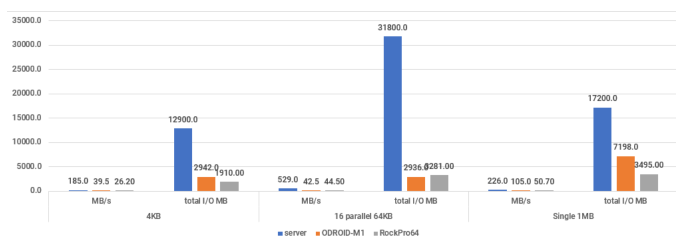

Fig. 11: Flexible Input/Output final tests

Using fio, the raid array performs better on the PC, surpassing the SBCs. Comparing the SBCs, the ODROID-M1 performed better in almost all tests.

After test tests using performance tools, a real-life test was done by copying a Nextcloud file directory with a size of 85.11G bytes. All systems performed identically, as shown in Table I.

B. Memory performance

The tool used for memory benchmarking was Sysbench. Sysbench is a scriptable multi-threaded benchmark tool based

Hardware	Mbytes/sec	Time
PC	11.41	04:30:27
ODROID-M1	11.57	04:26:43
RockPro64	11.26	04:33:24

TABLE I: Nextcloud synchronization using rsync

on LuaJIT. It allows benchmarking beyond other CPU, memory, and threads [13]. Using Sysbench the system will try to allocate blocks of 1MB and keep allocating memory until 10GB, measuring the memory latency. Memory shouldn't be an issue for the requirements of this work. The server and the ODROID-M1 both run on 8 GB of RAM and the RockPro64 4GB, all devices using DDR4 memory, Fig 12.

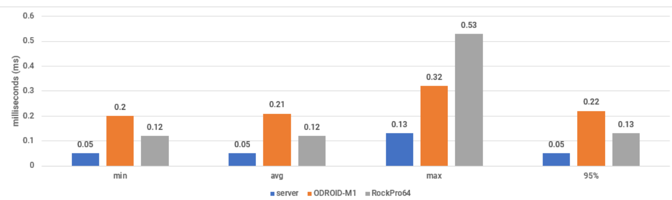

Fig. 12: Memory Speed results - Latency (milliseconds (ms)))

C. Network performance

Testing the network performance wasn't a priority at first glance. But since the network could impact the IoT SBC server, it was also tested. One of the most popular platforms to test network speed is speedtest.net [14]. The platform has a tool to be used via the command line on Linux called speedtest-cli. The PC and ODROID-M1 had similar results,

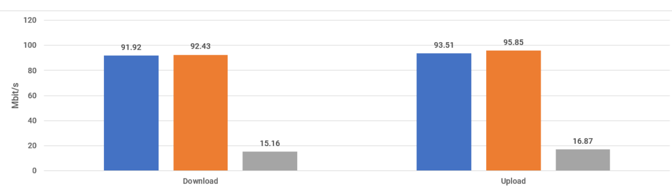

Fig. 13: Network Speed results (Mbit/s)

but the RockPro64 was surprisingly bad, so to confirm that no error was made, all tests were executed several times to explain the RockPro64 behavior. The results are in Fig 13.

D. CPU performance

The Sysbench tool used in section VII-B is also used for CPU performance. The test is done using two threads to perform a multi-threaded benchmark. The results are split into a total of events per second, Fig 14 and latency Fig 15.

All devices had different CPUs and different clock rates. Both the PC and ODROID-M1 (2.0 GHz) run quad-core CPUs, while the RockPro64 runs a hexacore CPU (1.8 GHz), but the i5 on the PC has higher clock rate, 3.90 GHz turbo to 3.50 GHz base. Since the test was done with two threads to minimize the impact of the operating system on the performance evaluation,

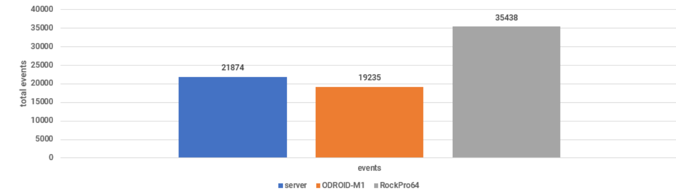

Fig. 14: Total number of events

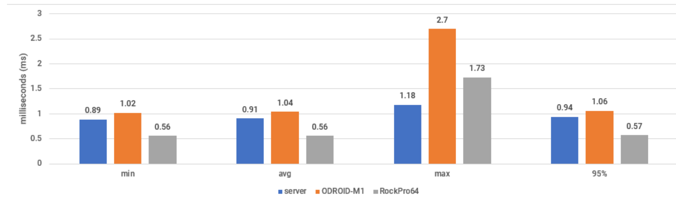

Fig. 15: CPU performance - Latency (milliseconds (ms))

the expectation was that the PC would stand out. While the clock rate has an impact on the ODROID-M1 latency, as expected, the performance of the RockPro64 was impressive, even when compared with the PC.
The second CPU test used the 7-zip tool [15]. 7-Zip is a file compression tool that can do extreme levels of compression on files and store them in a reduced-size 7z archive format. 7-Zip has a built-in option to run LZMA compression benchmarks for measuring CPU performance [14]. Using 7-zip, the results were the expected, with the Intel i5 outer performing the CPU of the SBCs, even when compared with RockPro64 hexacore, Fig 16.

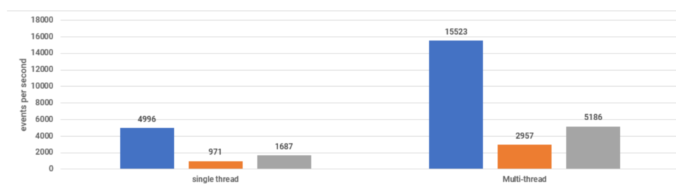

Fig. 16: 7-zip CPU performance

VIII. Energy consumption

All the devices use a voltage and current sensing module PZEM-004T, connected to a D1 mini Pro (ESP-8266EX). The PZEM-004T sends the measured voltage, current, active power, and accumulative power consumption to ESP8266EX via UART communication. The measured data values from each power meter module are forwarded to the data server over Wi-Fi [15]. The server has several web pages that generate charts with the results. As stated in Section VII, the first step was to replace all drives with SSDs. After the system was reinstalled, it was possible to measure the energy consumption and evaluate the changes only by replacing the disks, Fig 17. With thirty days results, a second chart was created to compare all the different scenarios, shown on Fig 18. With the data, it can calculate the daily consumption average. The

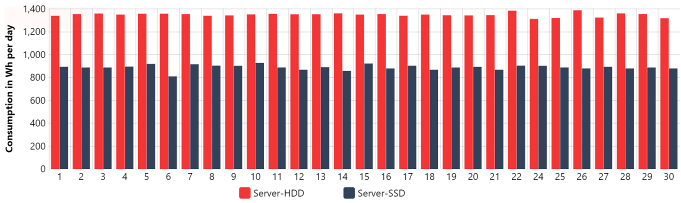

Fig. 17: Server energy consumption HDD vs SSD

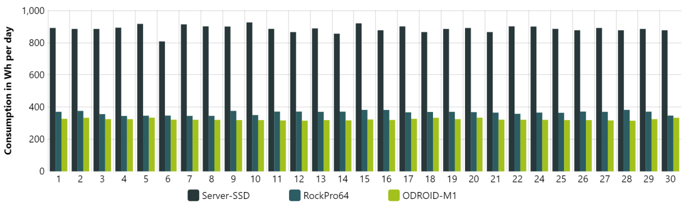

Fig. 18: Energy consumption month

SBCs consume less than half of the home server per day, and the SBC with the best efficiency is the ODOID-M1, consuming almost one-third of the server, as it can be shown in Table II.

Finally, using the current energy costs and the daily plan from the energy provider refereed in Section VI, we can estimate the energy costs per day, month, and year III. From the values calculated, we can observe that the SBCs have better efficiency, and the ODOID-M1 is the device that spends less power.

IX. Conclusion

The last decade has seen significant technological advancements, particularly in the development of mobile phones. These advancements have created faster, more efficient, and better-performing components used in small single-board devices. These devices, known as SBCs, now rival personal computers in terms of processing power and memory performance but are limited in storage capacity. SBCs can now run operating systems like Linux and Windows using flash eMMC components that serve as small personal computers or servers. Tests have shown that SBCs can function as home servers with a Linux OS, Nginx web server, PHP, MariaDB database engine, and NextCloud private cloud service. Regarding performance, SBCs can match home servers in memory and CPU but lag in network speed. However, they have a significant advantage in power consumption, using less than half the power of a home server and potentially saving more with a smaller power supply. Testing with the Raspberry Pi Compute Module 4 and IO Board was not possible due to the unavailability of a model with 4GB RAM and 32GB eMMC.

Home server (HDD)	Home server (SSD)	ODROID-M1	RockPro64
1344	884	319	361

TABLE II: Consumption average watts/day

	Home server (HDDs)	Home server (SSDs)	ODROID-M1	RockPro64
day	0.21 €	0.14 €	0.05 €	0.06 €
month	6.45 €	4.24 €	1.53 €	1.73 €
year	75.92 €	49.94 €	18.02 €	20.39 €

TABLE III: Consumption costs

Acknowledgment

This work is partially funded by National Funds through the FCT - Foundation for Science and Technology, I.P., within the scope of the projects UIDB/00308/2020, UIDB/05583/2020 and MANaGER (POCI-01-0145-FEDER-028040). Furthermore, we would like to thank INESC Coimbra, the Research Centre in Digital Services (CISeD) and the Polytechnics of Viseu and Coimbra for their support.

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