Michael Lynch

Building a Budget Homelab NAS Server (2022 Edition)

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virtualization • homelab • truenas • tinypilot

This year, I decided to build my first ever home storage server. It's a 32 TB system that stores my personal and business data using open-source software.

The server itself cost $531, and I bought four disks for $732, bringing the total cost to $1,263. It's similar in price to off-the-shelf storage servers, but it offers more power and customizability.

In this post, I'll walk through how I chose the parts, what mistakes I made, and my recommendations for anyone interested in building their own.

Before and after of my 2022 homelab TrueNAS server build

If you'd prefer a video explanation, I recorded one on YouTube.

Background

Why build a NAS server?

NAS stands for network-attached storage. A NAS server's primary job is storing data and making it available to other computers on your network.

So, why have a whole dedicated server for data? After all, every computer stores data.

I find it helpful to decouple data storage from my other systems. I upgrade my main workstation and laptop every two to three years, and migrating my data between computers was always a pain. A dedicated storage server eliminates most data migrations and facilitates sharing files between my systems.

I also have a *lot* of data. I'm a data hoarder, so I keep every digital photo I've ever taken, every email I've sent or received in the last 20 years, and source code for all of my personal projects. The total is currently 8.5 TB.

The biggest data source is my DVD and Blu-Ray collection. I don't like relying on streaming services to keep my favorite content available, so I still buy physical copies of movies and TV shows. As soon as I get a new disc, I rip the raw image and make a streamable video file. Between the raw ISO copy and the streamable MP4s, a single disc can occupy 60 GB of disk space.

I still buy physical DVDs or Blu-Rays for anything I might watch a second time.

What's a homelab?

"Homelab" is a colloquial term that's grown in popularity in the last few years.

A homelab is a place in your home where you can experiment with IT hardware or software that you'd typically find in an office or data center. It can serve as a practice environment for new professional skills, or it can just be a place to play with interesting technology.

Why build your own NAS?

If you're new to the homelab world or have no experience building PCs, I recommend that you **don't build your own NAS**.

There are off-the-shelf solutions that offer similar functionality with a gentler learning curve.

Before building my own homelab NAS, I used a 4-disk Synology DS412+ for seven years. Honestly, I loved my Synology. It was one of the best purchases I ever made. It was a gentle introduction to the world of NAS servers, and it's where I'd recommend you start if you're not sure about the whole NAS thing.

My 10 TB Synology DS412+ has served me well for seven years.

A few months ago, my Synology failed to boot and started making a clicking noise. A chill ran up my spine as I realized how dependent I'd become on this single device. Synology servers are not user-repairable, so if a part breaks after warranty, you have to replace the whole server. And if you're dumb like me, and you've used a Synology-proprietary storage format, ~~you can't access your data without another Synology system~~. (Edit: A commenter on Hacker News

showed me that you can recover a Synology Hybrid RAID volume from a non-Synology system.)

Fortunately, my old Synology recovered after I cleaned it out and reseated the disks, but it was an important wake-up call. I decided to switch to TrueNAS, as it offers an open-source implementation of an open storage format.

TrueNAS and ZFS

TrueNAS (formerly known as FreeNAS) is one of the most popular operating systems for storage servers. It's open-source, and it's been around for almost 20 years, so it seemed like a reliable choice.

TrueNAS uses ZFS, a filesystem designed specifically for storage servers. Traditional filesystems like NTFS or ext4 run on top of a data volume that manages low-level disk I/O. ZFS manages everything in the stack from the file-level logic down to disk I/O. ZFS' comprehensive control gives it more power and performance than other filesystems.

Some neat features of ZFS include:

- Aggregating multiple physical disks into a single filesystem
- Automatically repairing data corruption
- Creating point-in-time snapshots of data on disk (similar to OS X's Time Machine feature)

- Optionally encrypting or compressing data on disk

Before building this system, I had zero experience with ZFS, so I was excited to try it out.

Storage planning

Estimating my storage capacity needs

When I bought my Synology NAS, I initially installed three 4 TB drives and left the fourth slot empty. That gave me a total of 7 TB of usable space with Synology Hybrid Raid. Three years later, I was running out of space, so I added a fourth drive, bringing my total usable space to 10 TB.

I decided to apply the same strategy for my new build. I wanted a system that met my current needs with room to grow. My rough target was to start with 20 TB of usable storage and extra headroom for up to 30 TB if I add disks later.

ZFS doesn't let you add a new drive to an existing pool, but that feature is under active development. Hopefully, by the time I need to expand storage, the feature will be available in TrueNAS.

Many small disks or fewer large disks?

ZFS is designed to survive disk failures, so it stores each block of data redundantly. This feature complicates capacity planning because your total usable storage is not just the sum of each disk's capacity.

ZFS creates filesystems out of "pools" of disks. The more disks in the pool, the more efficiently ZFS can use their storage capacity. For example, if you give ZFS two 10 TB drives, you can only use half of your total disk capacity.

If you instead use five 4 TB drives, ZFS gives you 14 TB of usable storage. Even though your total disk space is the same in either scenario, the five smaller drives give you 40% more usable space.

When you're building a NAS server, you need to decide whether to use a smaller quantity of large disks or a larger quantity of small disks. Smaller drives are usually cheaper in terms of $/TB, but they're more expensive to operate. Two 4 TB drives require twice the electricity of a single 8 TB drive.

I wanted to minimize my server's physical footprint, so I opted for fewer, larger drives.

raidz 1, 2, or 3?

ZFS offers different options for redundancy: raidz1, raidz2, and raidz3. The main difference is in robustness. raidz1 can survive one disk failure without losing data. raidz2 can survive two simultaneous disk failures, and raidz3 can survive three.

What you gain in robustness, you pay for in usable storage. Given five 4 TB hard drives, here's how much usable storage you'd get from each ZFS mode:

ZFS type	Usable storage	% of total capacity
raidz1	15.4 TB	77.2%
raidz2	11.4 TB	57.2%
raidz3	7.7 TB	38.6%

I chose raidz1. With only a handful of disks, the odds of two drives failing simultaneously is fairly low.

Keep in mind that ZFS is not a backup strategy. ZFS can protect you against disk failure, but there are many threats to your data that ZFS won't mitigate, such as accidental deletion, malware, or physical theft. I use restic to replicate everything important to encrypted cloud backups.

The value of ZFS is that I don't have to resort to my cloud backups if one drive dies, but I'll have to recover from backups if two drives fail. That would be a pain, but it's not worth giving up 20% of my server's usable storage for raidz2.

The more physical drives you have, the more defensive you should be about disk failure. If I had a pool of 20 disks, I'd probably use raidz2 or raidz3.

Preventing concurrent disk failures

Naively, the probability of two disks failing at once seems vanishingly small. Based on Backblaze's stats, high-quality disk drives fail at 0.5-4% per year. A 4% risk per year is a 0.08% chance in any given week. Two simultaneous failures would happen once every 30,000 years, so I should be fine, right?

The problem is that disks aren't statistically independent. If one disk fails, its neighbor has a substantially higher risk of dying. This is especially true if the disks are the same model, from the same manufacturing batch, and processed the same workloads.

Further, rebuilding a ZFS pool puts an unusual amount of strain on all of the surviving disks. A disk that would have lasted a few more months under normal usage might die under the additional load of a pool rebuild.

Given these risks, I did what I could to reduce the risk of concurrent disk failures. I chose two different models of disk from two different manufacturers. To reduce the chances of getting disks from the same manufacturing batch, I bought them from different vendors. I can't say how much this matters, but it didn't increase costs significantly, so why not?

I purchased the same model of disk from two different vendors to decrease the chances of getting two disks from the same manufacturing batch.

How I chose parts

Motherboard

The first decision was motherboard size. I've always appreciated my Synology DS412+'s compact form factor. I've never built a computer with a mini-ITX motherboard before, and this seemed like a good opportunity.

I chose the ASUS Prime A320I-K for a few reasons:

- It has four SATA ports, which would allow me to connect four disks directly to the motherboard.
- It supports Radeon graphics, which would spare me from buying a separate graphics card
- It's affordable, at only $98

The ASUS Prime A320I-K supports onboard graphics in a mini-ITX form factor.

Warning: I regret this choice of motherboard. See more discussion below.

I also looked at the B450, which was very similar but almost twice the price. The main advantage seemed to be better overclocking support, which I didn't need.

CPU

From what I had read, ZFS is not very CPU-intensive. I ran a basic test by installing TrueNAS on a cheap Dell OptiPlex 7040 mini PC. It barely used the CPU, so it seemed safe to go with a low-powered option.

My main criteria in a CPU was support for Radeon graphics so that I could use the A320 motherboard's onboard HDMI output.

The AMD Athlon 3000G is inexpensive and has native graphics support.

I settled on the AMD Athlon 3000G. At only $105, it's a good value, it supports Radeon graphics, and it has decent CPU benchmarks.

Case

When I built my last VM server, I used a Fractal Design case. It's my favorite computer case ever, so I returned to Fractal Design on this build.

I went with the Fractal Design Node 304 Black, a compact mini-ITX case. I liked the design because it's closer to a cube than a tower. It has six drive bays, which allows me to start with enough drives and still have room to grow in the future.

The Fractal Design Node 304 Black is a mini-ITX case with space for six disks.

Disk (Data)

With six drive bays available in the case, I decided to start with four 8 TB disks, which translates to 22.5 TB of usable storage under raidz1. When I need to expand in the future, a fifth disk will bring me to 30.9 TB, and a sixth would get me 37 TB.

In the 8 TB range, there aren't many drives below 7200 RPM, but you can go up to 10k RPM. For my NAS, speeds above 7200 RPM wouldn't make a difference because the bottleneck is the network. A 10k RPM drive would be louder and consume more power but offer no practical gain in performance.

I initially tried checking Backblaze's hard drive stats to avoid failure-prone disks, but they use drives on the pricier side. At one point, I was considering $400 drives for their impressively low 0.5% failure rate, but I realized it's irrational to spend twice as much to reduce the failure rate by a few percent.

The last pitfall to avoid is shingled magnetic recording (SMR) technology. ZFS performs poorly on SMR drives, so if you're building a NAS, avoid known SMR drives. If the drive is labeled as CMR, that's conventional magnetic recording, which is fine for ZFS.

I chose the Toshiba N300 and the Seagate IronWolf. I saw positive reviews of both on the TrueNAS forums and reddit. Both models sold for $180-190, which was a good value for the storage space.

Toshiba N300 (left) and Seagate IronWolf (right)

Disk (OS)

TrueNAS needs a dedicated OS disk, but from what I'd read, it doesn't demand much of it. The OS needs at least 2 GB of space, but TrueNAS infrequently reads or writes to the OS disk.

The Kingston A400 is a fantastic value as a 120 GB M.2 SSD for only $32.

I went with the Kingston A400 because it was incredibly inexpensive — $32 for a 120 GB M.2 disk. I love M.2 disks! They don't require any cabling. They just tuck away into the motherboard, take up nearly zero space, and you never have to touch them again.

Memory

In my research, I frequently found references to the "rule" that ZFS requires 1 GB of RAM for every TB of disk space in the system. According to ZFS developer Richard Yao, that rule is a myth. There are some RAM-hungry ZFS features like data deduplication, but ZFS runs fine with constrained memory.

I find memory extremely boring to shop for. I wish I had a more rigorous process for choosing RAM, but I couldn't find trustworthy benchmarks or user reports for RAM. My process was:

1. Review the list of RAM sticks compatible with the ASUS A320I-K motherboard
2. Filter for 32 GB or 64 GB options that used only two sticks
3. Filter for brands I trust (Corsair, Crucial, G.SKILL, Kingston, Samsung, Patriot, Mushkin, HyperX)
4. Filter for options below $150

That process led me to the CORSAIR Vengeance LPX 32GB CMK32GX4M2A2400C14 (2 x 16GB) for $128.

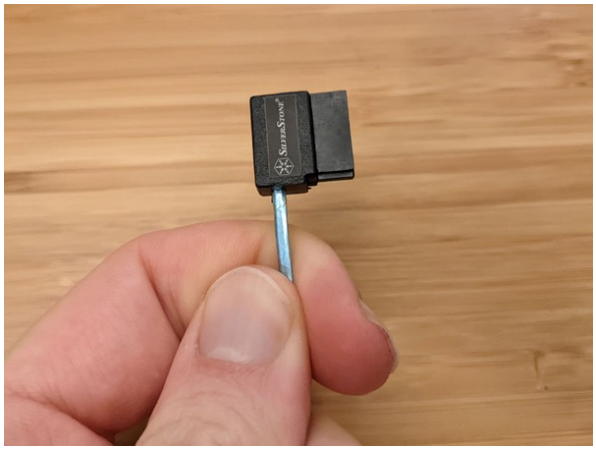
The CORSAIR Vengeance LPX 32GB CMK32GX4M2A2400C14 (2 x 16GB) is compatible with the A320I-K motherboard and is a decent price for 32 GB.

Power supply unit (PSU)

In terms of power capacity, basically any consumer PSU would have been sufficient. According to PCPartPicker, my system only requires 218 W. I would have picked a PSU in the 300-400 W range, but there weren't semi-modular options with lower wattage. I went with the 500 W EVGA 110-BQ-0500-K1.

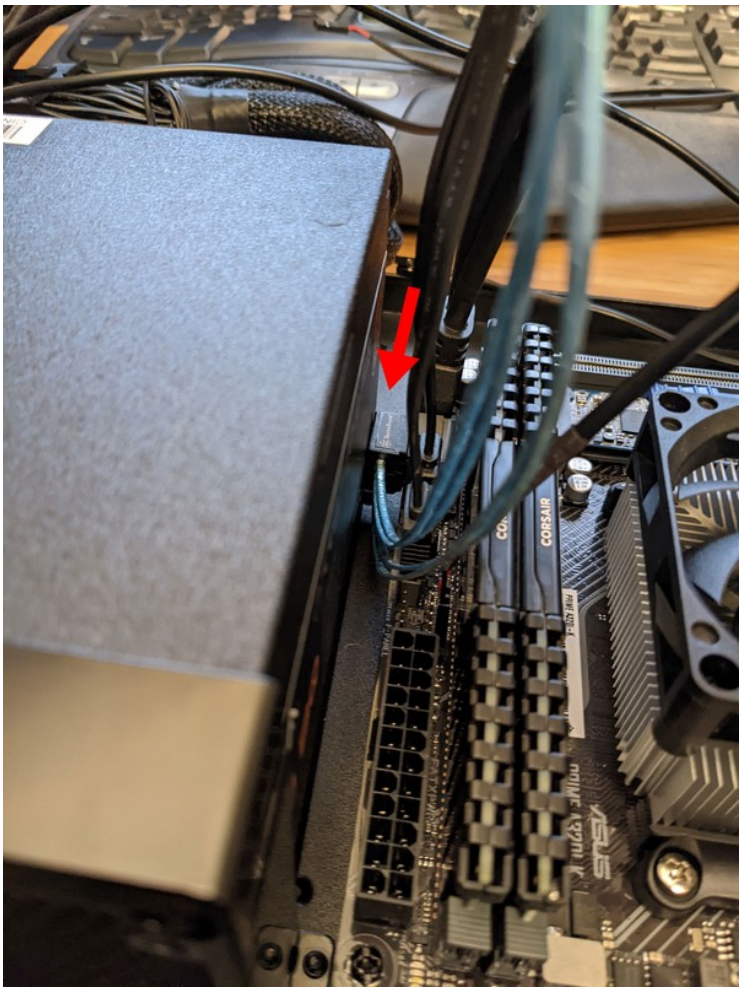
The EVGA 110-BQ-0500-K1 is a semi-modular PSU. At 500 W, it offers more than enough power for my build.

90-degree SATA cables



I needed 90-degree SATA cables to work within the case's space constraints

One item I've never purchased before was a 90-degree SATA cable. I didn't realize I needed them until I saw that there wasn't enough space between my motherboard and PSU to plug in a standard SATA cable. These slim 90-degree cables solved the problem.



It was such a tight squeeze between my PSU and motherboard that I needed 90-degree slim SATA cables.

What's missing?

There are a few components that I intentionally excluded from my build due to price, complexity, or physical space.

Graphics card (GPU)

With scarce physical space and motherboard ports, I didn't want a dedicated graphics card. I chose a motherboard and CPU combination that supports graphics rendering without an external card.

Host bus adaptor (HBA)

Many NAS builds include a host bus adaptor (HBA). An HBA is a chip that goes into the PCI slot of a motherboard and increases the number of disks the motherboard can support.

ZFS requires you to reflash the HBA's firmware in a process that sounds tedious and confusing. I decided to punt on the HBA until I need more storage. The ASUS A320I-K has four SATA ports, which is enough for my initial needs. I made sure to leave a PCI slot empty for a future HBA.

ECC RAM

In researching different TrueNAS builds, I saw several posts claiming that ECC RAM (error correction code RAM) is a must-have to prevent data corruption. I ultimately decided against ECC RAM and just used standard, consumer-grade RAM.

While I obviously don't want my server to corrupt my data in RAM, I've also been using computers for the past 30 years without ECC RAM, and I've never noticed data corruption. If I were building a server for heavy load from multiple users all day, I'd spring for a build with ECC RAM. For home needs, I think simple consumer-grade RAM should be fine.

SLOG disk

Many ZFS builds include a separate, dedicated SSD called the SLOG (separate intent log).

The idea is that writing to an SSD is orders of magnitude faster than writing to multiple spinning disks. When an application writes data, ZFS can quickly write it to the SSD, tell the application that the write succeeded, then asynchronously move the data from the SSD to the storage pool. The SLOG improves write speeds significantly.

I chose not to integrate a SLOG disk because I'm limited by ports and drive bays. Adding a SLOG disk meant either forfeiting my only PCI slot or one of my six drive bays. I'd rather leave myself room to expand capacity later.

Parts list

Category	Component	I paid
CPU	AMD Athlon 3000G	$105.13
Motherboard	ASUS Prime A320I-K*	$97.99
Graphics	None needed — motherboard has native graphics support	$0
Disk (OS)	Kingston A400 120GB	$31.90
Memory	CORSAIR Vengeance LPX 32GB CMK32GX4M2A2400C14 (2 x 16GB)	$127.99
Power	EVGA 110-BQ-0500-K1 500W 80+ Bronze Semi-Modular	$44.99
Case	Fractal Design Node 304 Black	$99.99
SATA cables	Silverstone Tek Ultra Thin Lateral 90 Degree SATA Cables (x2)	$22.30
Total (without disks)		***$530.29***

Category	Component	I paid
Disk (Storage)	Toshiba N300 HDWG480XZSTA 8TB 7200 RPM (x2)	$372.79
Disk (Storage)	Seagate IronWolf 8TB NAS Hard Drive 7200 RPM (x2)	$359.98
Total		**$1,263.06**

* Caveat: This motherboard may not work out of the box with the AMD Athlon 3000G CPU. See details below.

Compared to off-the-shelf products

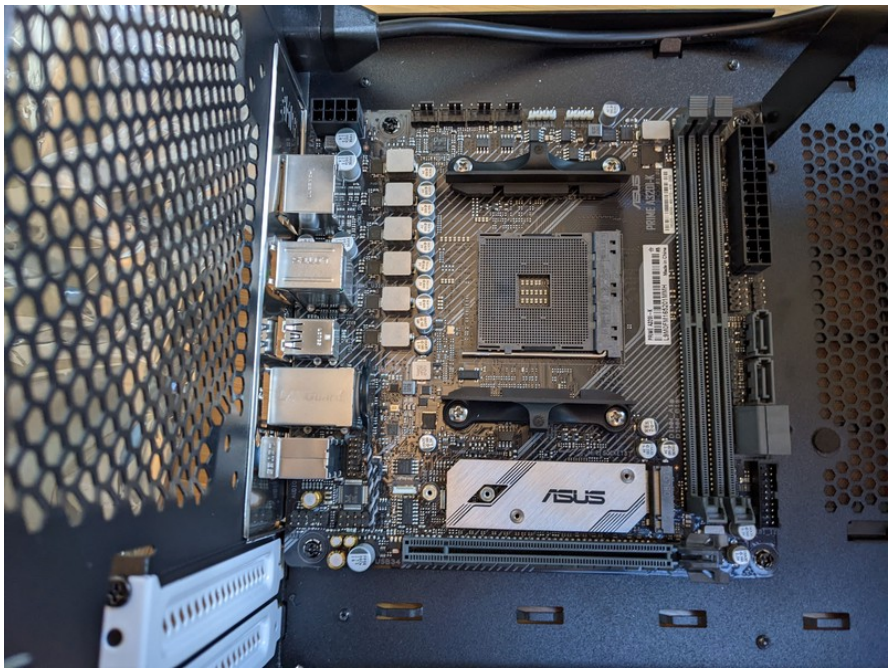
For comparison, here are some off-the-shelf solutions at similar price points.

Product	2022 Budget NAS	Synology DS920+	QNAP TS-473A-8G-US
Disk bays	6	4	4
RAM	32 GB	4 GB	4 GB
Max RAM	32 GB	8 GB	8 GB
CPU benchmark	4479	3002	4588
Price	$530.29	$549.99	$549

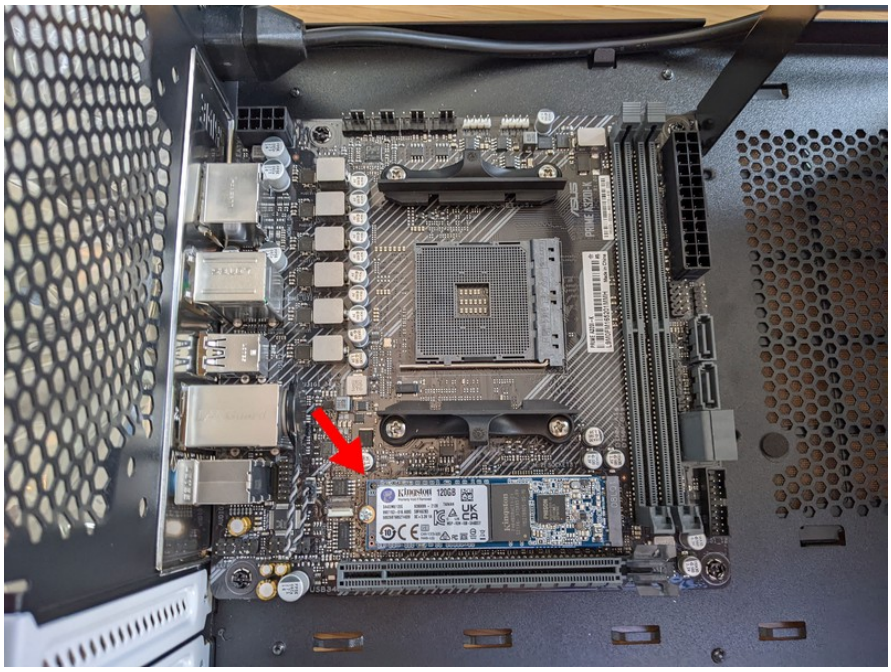
The total cost of my build is similar to off-the-shelf solutions, but I get more value for my money. I have 8x as much RAM, and I'm not locked in to any closed-source, vendor-specific OS platform.

Build photos

All the parts in their retail boxes

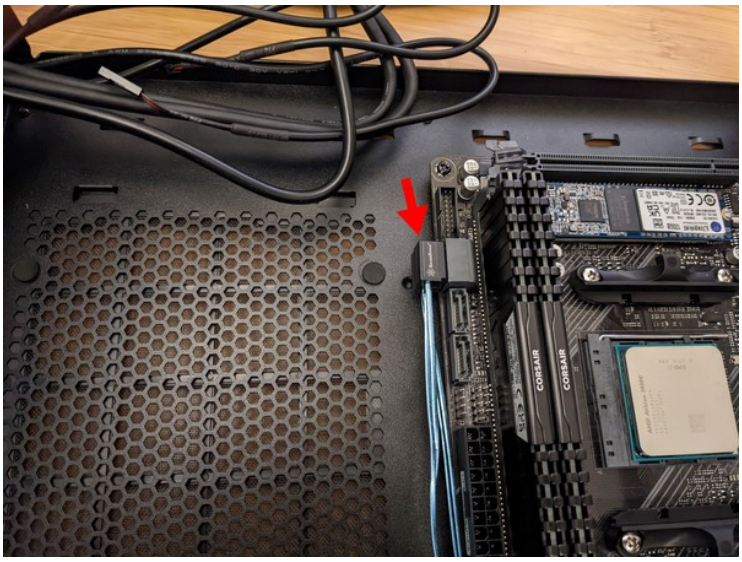


I had no issues installing the motherboard in the Fractal Design mini-ITX case.

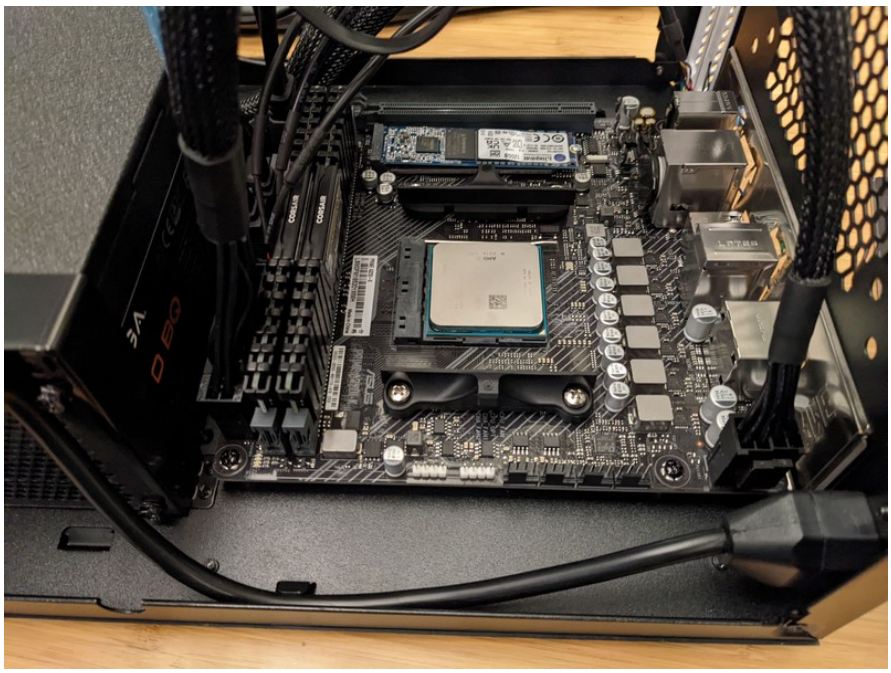


I love installing M.2 SSDs. No wires or rails — one screw, and you're done.

This is the first system I've ever built that doesn't expose the back face of the PSU outside of the case. Instead, the case has a short NEMA extension cable that routes the internal PSU to the case's own external power input.



It was such a tight squeeze between the motherboard's SATA ports and the PSU that I had to buy special 90-degree slim SATA cables.

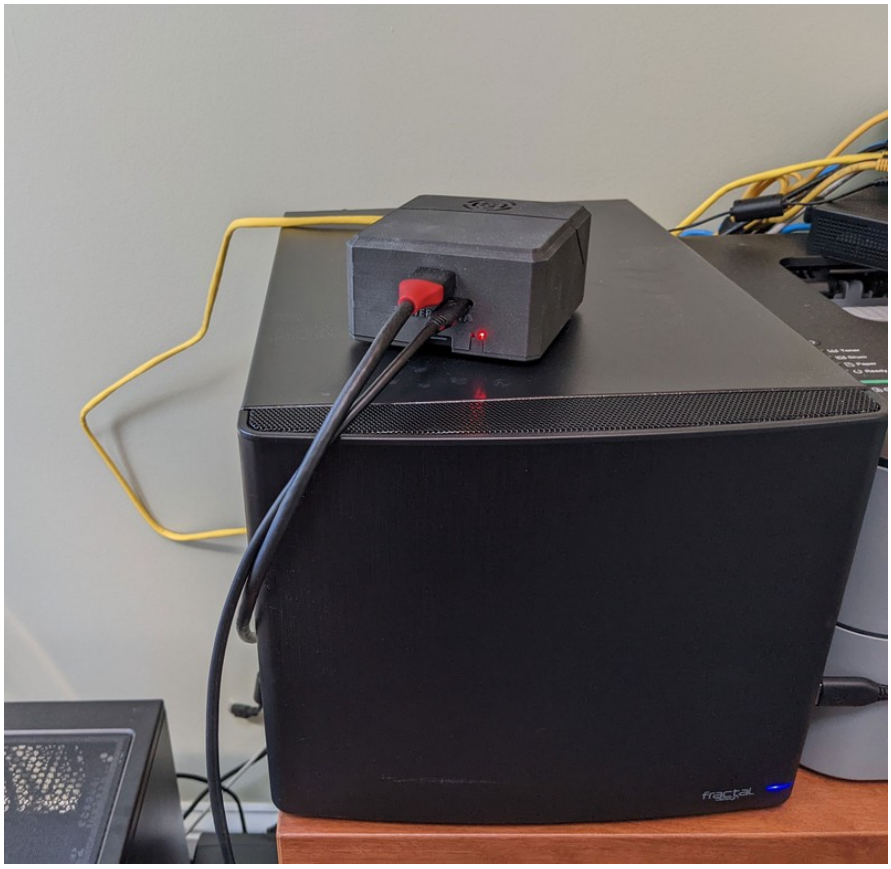


After connecting everything to the motherboard (except for the CPU fan)

The completed build

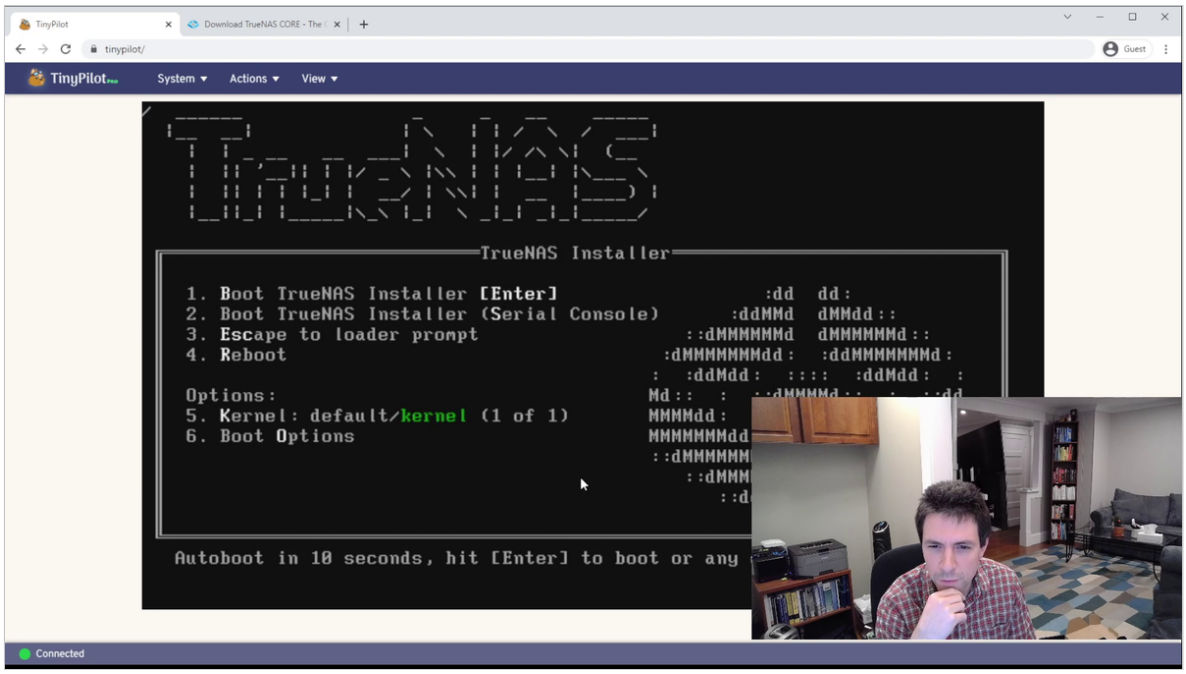
Building the server with TinyPilot

Longtime readers of this blog may recall that I used the Raspberry Pi to create a tool specifically for building and managing servers. It's called TinyPilot. This was the third server I've built with TinyPilot and the first I built with the new TinyPilot Voyager 2.



Instead of connecting a keyboard, mouse, and monitor to the TrueNAS server, I managed the installation with a TinyPilot Voyager 2.

I'm obviously biased, but building this server with the Voyager 2 was a lot of fun! I never had to connect a keyboard or monitor to the server. I could see video output, boot to BIOS, and mount the TrueNAS installer image all from my web browser.



TinyPilot allows me to mount the TrueNAS installer ISO without plugging in a flash drive, keyboard, or monitor.

The one gap I ran into was in upgrading the BIOS. TinyPilot can mount disk images like `.img` and `.iso` files, but it doesn't yet know how to share raw files with the target computer. When I needed to load the `.CAP` file for the ASUS BIOS upgrade, I shamefully put them on a USB thumb drive instead of keeping it a pure TinyPilot build. I hope to add support for that scenario soon so that TinyPilot can handle my next BIOS upgrade.

Is this BIOS version incompatible? Or am I an idiot?

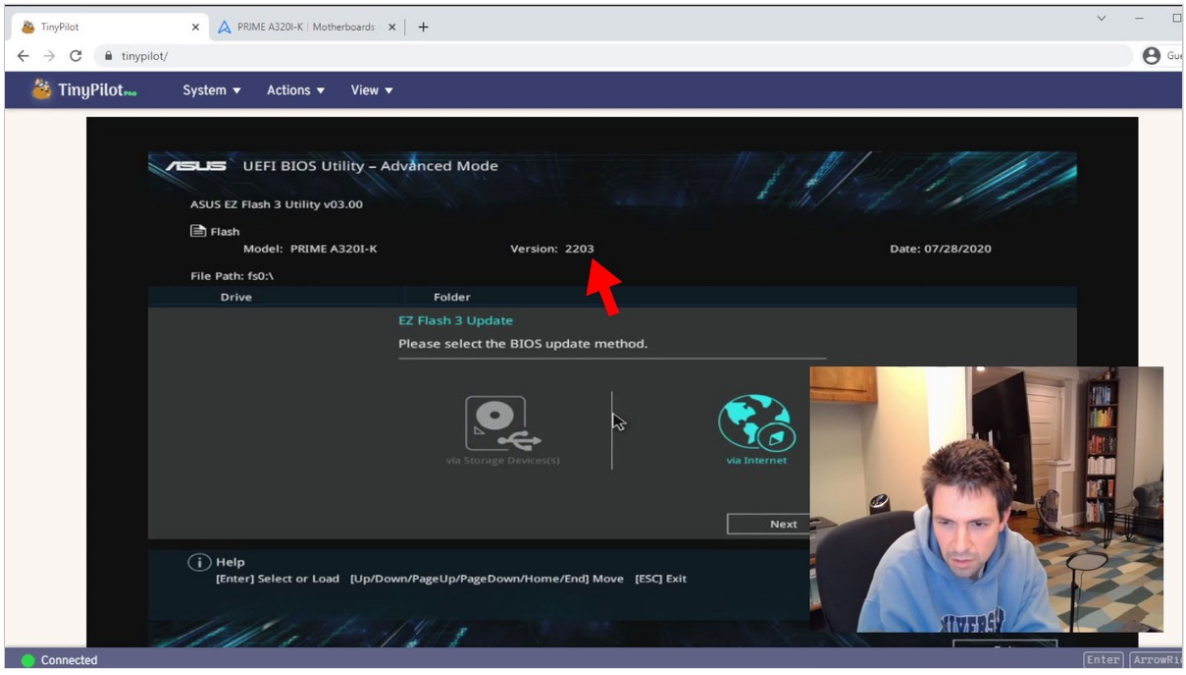
When I got all the components installed, the system powered on, but there was no video display.

Oh no! Did I misunderstand the motherboard's onboard video requirements? I did all the usual diagnostics: reseated the RAM, reseated the CPU, and checked all the cables — same result.

After some panicked Googling, I saw mentions that the ASUS Prime A320I-K requires a BIOS upgrade before it can work with the Athlon 3000G. I recalled seeing that warning when I was selecting parts and breezing right by it. "I've done BIOS updates," I thought. "They're no big deal!"

I didn't consider how I'd upgrade my BIOS *without a CPU*.

Luckily, the Ryzen 7 CPU from my 2017 homelab VM server was compatible with the ASUS Prime A320. I borrowed the CPU and GPU from that server, and I got my new NAS server to boot!

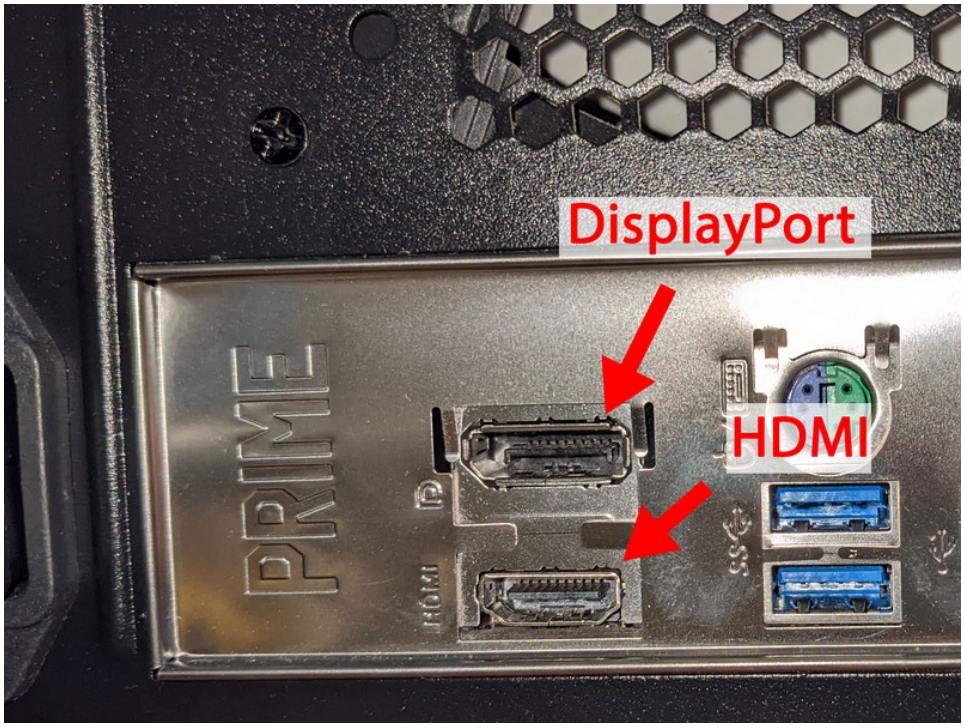


I was able to use parts from my old 2017 homelab VM server to upgrade the BIOS.

Strangely, even after I got the system to boot with borrowed parts, the motherboard reported that it was running BIOS version 2203, which ASUS claims *is* compatible with the AMD Athlon 3000G CPU. But I updated to the latest BIOS, which was 5862.

The ASUS Prime A320I-K CPU compatibility page claims it's compatible with the Athlon 3000G starting at BIOS version 2203.

After upgrading to 5862, I *still* couldn't get a boot. Then, I realized that I was plugging my HDMI cable into the server's DisplayPort output.



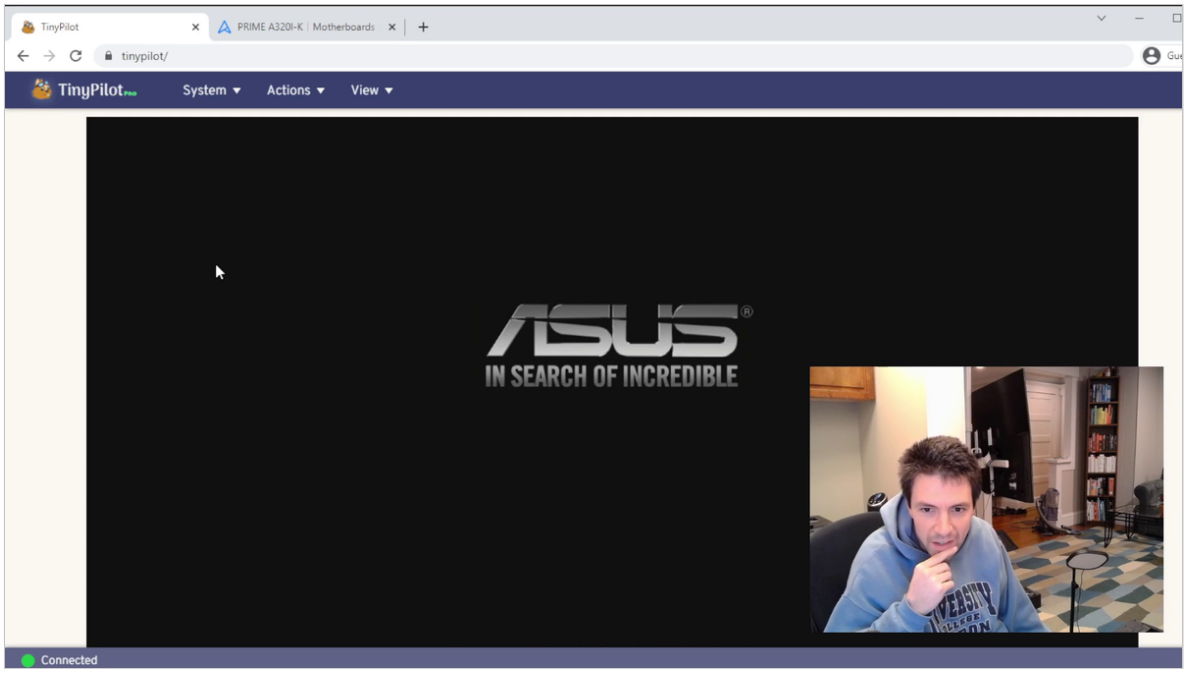
> Why did the DisplayPort designers make it so easy to plug in HDMI cables by mistake?

Was this whole parts-borrowing rigamarole even necessary? There are two possibilities:

- I'm dumb and didn't notice my HDMI cable plugged into the motherboard's DisplayPort output until after I upgraded the BIOS.

- ASUS is dumb, and they incorrectly listed the Athlon 3000G as compatible with BIOS version 2203 when it isn't.

Normally, I'd accept the blame, but the ASUS BIOS was so flaky that the problem might have been on the ASUS side. In any case, I was relieved to finally boot the NAS without any borrowed parts.



The moment I finally got a boot screen with the Athlon 3000G installed

Performance benchmarks

One of the surprises to me in writing this up was that I couldn't find any good benchmarking tools for measuring NAS performance. There are tools that run on the NAS itself to benchmark local disk I/O, but that doesn't reflect real-world usage. Most of my usage is over the network, so a local disk benchmark will completely miss bottlenecks in the networking stack.

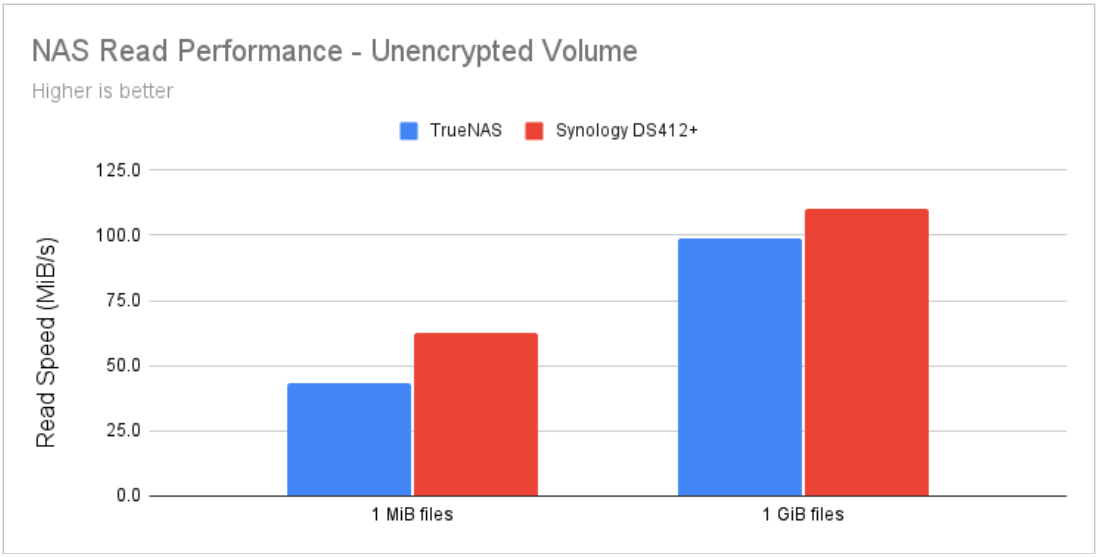
I just made up my own rudimentary benchmark. I generated two sets of random file data and then used robocopy to measure read and write speeds between my main desktop and my NAS. This was by no means a rigorous test

— I didn't do it on an isolated network, and I didn't shut down all other processes on my desktop while running the test. I ran the same tests against my old Synology DS412+ as a comparison.

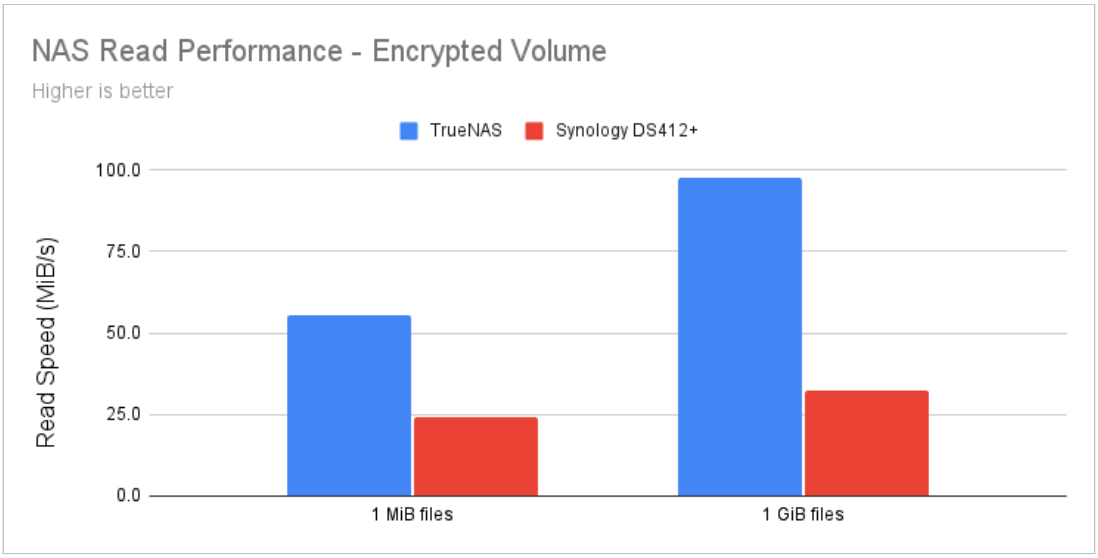
The first file set was 20 GiB of 1 GiB files, and the other was 3 GiB of 1 MiB files. I took the average of three trials over both encrypted volumes and unencrypted volumes.

Performance topped out at 111 MiB/s (931 Mbps), which is suspiciously close to 1 Gbps. This suggests that the limiting factor is my networking hardware, as my switch, my desktop, and the NAS servers all have 1 Gbps Ethernet ports.

Read performance

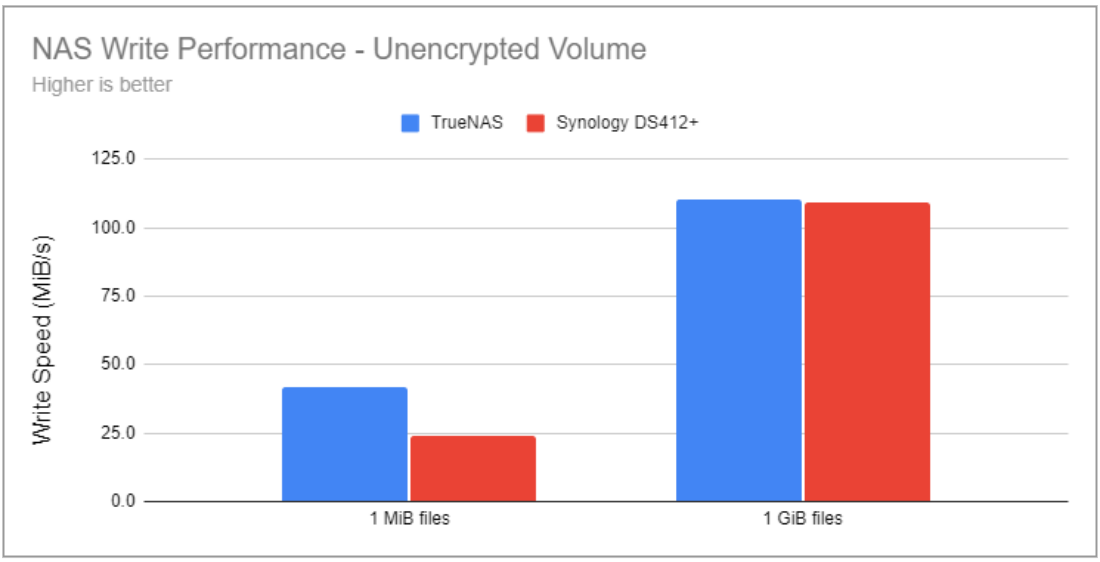


For unencrypted volumes, I was surprised to see my rusty, 7-year-old Synology outperform my shiny, new TrueNAS build. Synology was 31% faster at reading small files and 10% faster on large files.

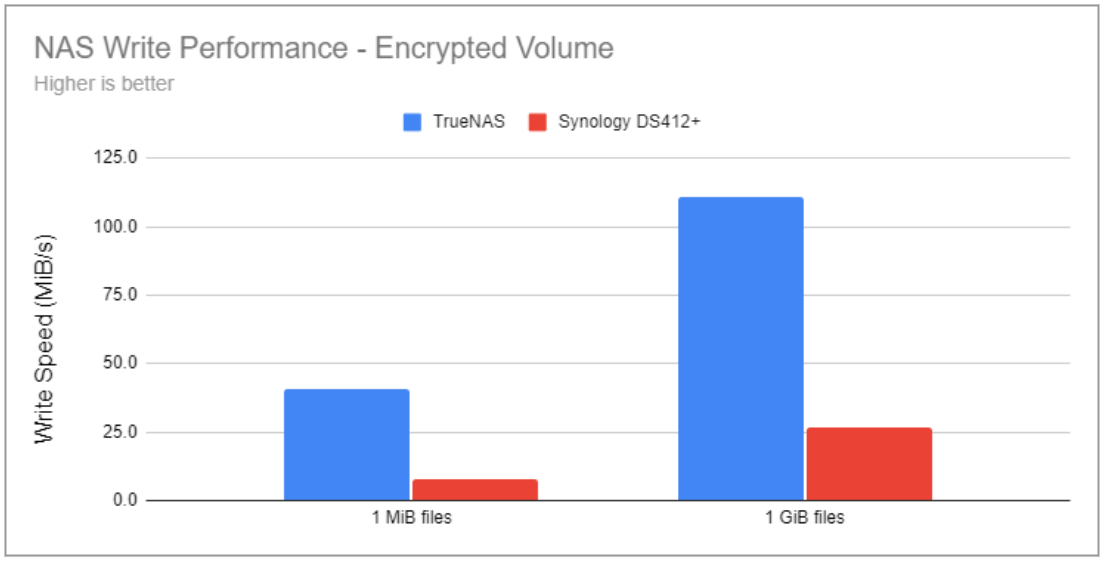


Synology's glory was short-lived, as it completely choked on encryption. Synology's read speeds dropped by 67-75% on encrypted volumes, whereas encryption had no effect on TrueNAS. That allowed TrueNAS to outperform Synology by 2.3x for small files and 3x for large files on an encrypted volume. I keep most of my data on encrypted volumes, so this test more accurately represents my typical usage.

Write performance



Although my old Synology managed to outshine TrueNAS on reads, this was not the case for writes. Even on an unencrypted volume, TrueNAS was 77% faster on small files, and the two systems performed similarly on 1 GiB files.



Again, bringing encryption into the mix obliterates Synology's write performance. With encryption enabled, TrueNAS was 5.2x faster on small files and 3.2x faster on large files.

Power consumption

I used a [Kill A Watt P4460 meter] to measure power consumption on both my old Synology and the new TrueNAS server:

	Synology DS412+	2022 NAS
Idle	38 W	60 W
Load	43 W	67 W

The new server uses 60% more power than my old Synology, which is a bit surprising. I pay about $0.17/kWh, so the server costs around $7.20/month to run.

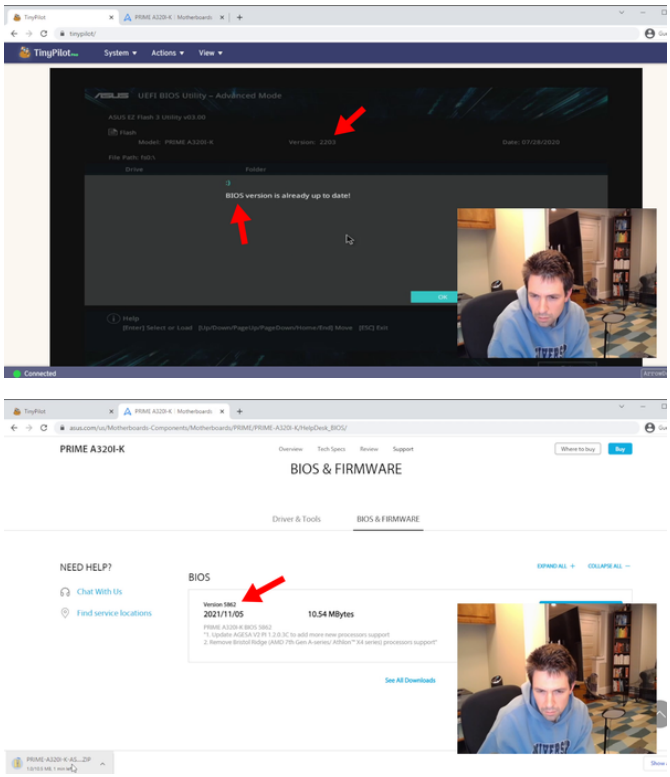
I don't know much about what factors drive up the power draw, but one possibility is the PSU. Synology probably has a PSU that's perfectly sized to its other components, whereas my 500 W PSU is likely inefficient at powering a system that requires only 15% of its capacity.

Final thoughts

Motherboard

My biggest complaint about the ASUS Prime A320I-K was its limited compatibility, but it's possible that I'm mistaken.

Beyond that, I wasn't crazy about the BIOS. Its upgrade utility was completely broken. It's supposed to be able to download and install the latest BIOS versions, but when I tried upgrading, it kept telling me that I had the latest BIOS when I didn't. I had to upgrade manually by downloading the files and loading them on a thumb drive.



The ASUS EZ Flash utility claimed I had the latest BIOS at version 2203. The ASUS website offered BIOS version 5862, so I had to update manually.

I also missed that the A320I-K supports a maximum of 32 GB of RAM. I'm not sure if I'll ever need to expand memory, but it would have been good to

give myself some more breathing room.

Fixing the Realtek networking driver

I noticed that the motherboard's Ethernet adaptor would sometimes die when my system was under heavy network load, and /u/trevaar on reddit helpfully explained why. Apparently, the FreeBSD driver for the A320I-K's Realtek NIC has stability issues, but it's possible to load the official driver with the following workaround:

1. From the TrueNAS web dashboard, go to System > Tunables
2. Add the following two settings:

Variable	Value	Type
`if_re_load`	`YES`	loader
`if_re_name`	`/boot/modules/if_re.ko`	loader

Case

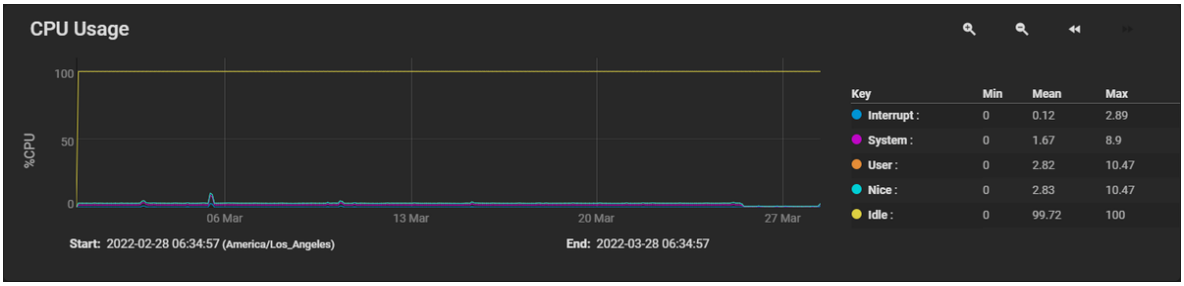
I was disappointed in the Fractal Design Node 304. When I built my VM server with the Fractal Design Meshify C, the case kept delighting me with features I'd never seen on other cases. On this build, it was the opposite. I kept thinking, "Why is this a problem in this case when this has never been a problem for me before?"

It looks nice on the outside, but I found it awkward to work in. There was barely any documentation, and some of the case mechanisms weren't obvious.

It's my first mini-ITX build, and I know the case designers have to make sacrifices in the name of minimizing size, so maybe I'm judging it too harshly.

CPU

I'm happy with the Athlon 3000G, but it turned out to be massively overpowered for my needs. My TrueNAS dashboard reports that CPU load has been 99% idle for the past month of usage:



TrueNAS barely uses any CPU capacity.

The most important thing about the CPU was that it supported AMD's Radeon video technology, which saved me from needing a GPU. For $105, it was a great deal.

Disk (Data)

It's a bit too early to judge disks, so check back in about five years to see how I'm liking them. So far, so good.

My biggest worry was that the disks would be too noisy, but I never hear them at all. The only time I've heard them was while running the performance benchmarks. Interestingly, they were noisiest not during reads or writes but when I was deleting files between tests.

Power supply unit (PSU)

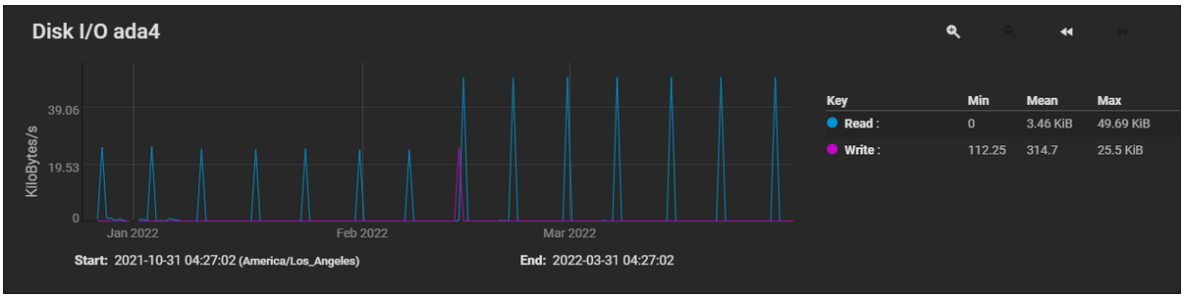
After seeing that the system idles at 60 W, I'm wondering if I should have put more effort into a lower-capacity power supply. 500 W is more than double the

capacity I need, so maybe I could have reduced my server's idle power draw with a PSU in the 300-400 W range.

Disk (OS)

The Kingston A400 is working fine. TrueNAS puts such a minimal load on the OS disk that there isn't much for it to do. It has 90 GB free, so I could have used an even smaller drive.

There's almost zero disk activity in TrueNAS' reporting. There's a tiny I/O read every week as part of a default scheduled task for error checking, but that's it.



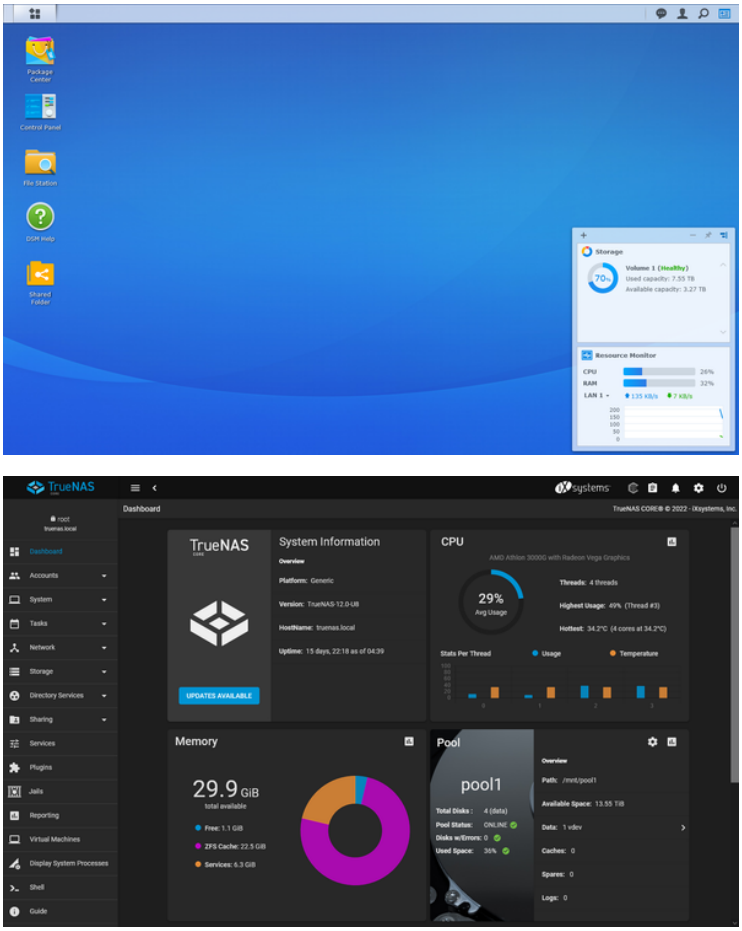
TrueNAS rarely touches its OS disk after booting.

TrueNAS

I'm running TrueNAS Core 13, which is the more mature FreeBSD version. The other option is TrueNAS Scale, which is based on Debian, which has wider hardware and software compatibility.

Coming into TrueNAS, I knew my Synology's web UI would be hard to beat. It's the most elegant and intuitive interface I've ever seen for a network appliance. They did a great job of building a clean UI that spares the end-user from technical details of the underlying filesystem.

TrueNAS has its hacker charm, but I find it a huge usability downgrade from Synology. The interface seems like it was designed by someone with disdain for anything outside of the command line.



The Synology web interface (left) is leaps and bounds ahead of TrueNAS (right).

On TrueNAS, it took me several tries to create a new volume and share it on my network. You have to jump between several disconnected menus, and there aren't any hints about what action you need to perform next. With Synology, there's a smooth UI flow that guides you through all the required settings.

I found third-party apps *much* harder to install on TrueNAS. I use Plex Media Server to stream my movie and TV collection, and Plex is a pre-configured plugin on TrueNAS. It should be one of the easiest apps to install, but it took me an hour of fiddling and searching through documentation. By comparison,

installing Plex on Synology takes about two minutes of clicking through a wizard.

I'm sticking with TrueNAS because I care more about platform lock-in than almost anything else, and I like supporting open-source software. If I were recommending a NAS to a friend who wasn't as ideologically driven, I'd suggest Synology.

ZFS

ZFS is cool, but I haven't found a need for most of its features beyond RAID.

I see people talking about snapshotting, but I haven't found a need for it. I already have snapshots in my restic backup solution. They're not especially convenient, but I've been using restic for two years, and I only recall needing to recover data from a snapshot once.

One interesting feature is encrypted snapshots. You can take snapshots of a data volume without having to decrypt it. I have some data that I want to keep encrypted, but I don't need to access it very often, so being able to back it up regularly without decrypting it would be handy.

Overall

Overall, I'm enjoying my new NAS, and I learned a lot from this build. If this had been my first experience with a NAS, I'd be miserable and confused, but starting with my Synology gave me a gentle introduction to the technologies involved. I feel like the training wheels are off, and I'm ready to tinker with the power features of ZFS and TrueNAS.

Video

Thanks to the members of the [Blogging for Devs Community] for providing early feedback on this post.

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35 comments Log In

K kejsarmakten May 24, 2022

The link explaining why you regret the motherboard doesn't work (links http://blog:1313/budget-nas/#motherboard-1 (http://blog:1313/budget-nas/#motherboard-1))

 **Michael Lynch** @michael May 24, 2022

Fixed, thanks!

@ddmls May 24, 2022

That was interesting, you give me ideas! I appreciate the details.

 **Michael Lynch** @michael May 24, 2022

Thanks for reading! Glad it was helpful.

Steve Webb @scumola May 24, 2022

Smart buying drives that weren't from the same production run. ZFS features that you can use - run proxmox w/ ZFS, then mirror the ZFS snapshots to the truenas. ZFS dedupe is awesome.

Brant Robinette @Kiaser May 24, 2022

A few notes:

1. Being that small of a NAS, without a dedicated GPU it may have been better to go with a Intel Core i3 CPU that has Quick Sync as well as ECC support (Core i3 is the only consumer one that currently supports both, but the 13th Gen Intel consumer chips coming out soon will have both on Core i5, i7, and i9's). This would give you ability for Plex transcoding using the excellent Intel Quick Sync process that's perfect for a local/home network, as well as the ECC support that ZFS ABSOLUTELY needs.
2. ECC. Yes, you need it. ZFS uses ECC intensely in it's file integrity checks. It is an imperative, IMO, a truly integral part of ZFS. You'll be missing out some of the primary reasons to use ZFS at all, without ECC. You may think you haven't had an issue using consumer RAM in the past, but it's likely you just didn't see the SYMPTOMS of using it. Also, this NAS will be doing functions far different than your regular home PC, and will be far more prone to hitting issues that ECC could've prevented than a regular home-use PC would ever experience. I think the Athlon 3000G supports it, but if it's anything like the Ryzen 3000/5000 series it's going to be quite hard to find a motherboard that supports it properly.
3. RAID/redundancy is just a small benefit of ZFS. Physical hardware redundancy is always something needed, but what people don't realize is that FILE redundancy/integrity is just as, if not more, important that physical. With ZFS, you're getting storage device AND file level redundancy/integrity checks. Plus the additional functions inside ZFS that let you expand and create better caching than a hardware RAID solution is key for future upgrading/needs.
4. RAIDZ1 is okay in your scenario, as long as you have backups. Keep in mind, any parity configuration (such as RAIDZ1 and above) is going to require resilvering the ENTIRE array when a drive is replaced. Being you went with higher capacity drives, you COULD be looking at days upon days of 100% disk usage to resilver the array. This leads to a much higher chance of a second drive failure, but also likely days of pitiful if not unusuable performance. If you end up going bigger or adding more later, RAIDZ2 at the least should be considered, if not switching over to a pool of multiple mirrors (expensive per GB, but fast and it only ever has to rebuild the one drive space if one drive fails, so it repairs extremely fast).
5. ZFS will and SHOULD use plenty of RAM, even without deduplication. ZFS will use nearly as much RAM as you can throw at it for a sort of pre-fetch cache and so that it can eventually write to the physical array in a more uniform way for faster future performance. Even with a smaller array like yours, you really still would likely benefit from 64GB or even 128GB of system RAM for ZFS to be able to do it's thing.
6. HBA. It's fine not to have one for now. But you're mistaken about flashing the firmware. Only cards that are RAID cards would need to be flashed into IT-mode, regular HBA cards are already set to pass-through as it is so no flashing is required. And with every device you have (motherboard, drives, etc) you should be at least flashing to the newest revision. Doing that with HBA's, if needed, is nearly an identical process as the rest.
7. SLOG, it's fine for your situation not to have one, even if you had the space. If/when it comes time for upgrades, and you REALLY want to dig into ZFS performance, I'd recommend not just a SSD mirror SLOG array but also a NVME SSD mirror Special Device/Metadata thrown into the mix.
8. How did you manage to physically put a HDMI into the DisplayPort, did it damage it? Check those pins close to see if anything is bent

or close to shorting out.

9. Testing, you can actually run DD or badblocks to an array, not just the single hard drives. You can do this directly from TrueNAS shell or the CLI itself if needed.

Michael Lynch @michael May 25, 2022

Thanks for reading! I'm still new to TrueNAS and ZFS, so I appreciate the additional info!

> ECC. Yes, you need it. ZFS uses ECC intensely in it's file integrity checks. It is an imperative, IMO, a truly integral part of ZFS. You'll be missing out some of the primary reasons to use ZFS at all, without ECC.

I'm still not clear on why it's a necessity for ZFS, and I think it's because I haven't really found any concrete measures of risk. Is it like one bitflip for every 500 TB written or is it more like once every 5 TB?

> You may think you haven't had an issue using consumer RAM in the past, but it's likely you just didn't see the SYMPTOMS of using it.

Yes, it's definitely possible that RAM has corrupted my data in the past, but my intuition is that if I've never noticed it, it's likely very rare. What would be the effects of memory corruption that I'm not noticing?

> Only cards that are RAID cards would need to be flashed into IT-mode, regular HBA cards are already set to pass-through as it is so no flashing is required.

Oh, interesting! That makes them much more appealing. The one I saw recommended most frequently was the IBM M1015 which I guess is a RAID card rather than a regular HBA. I didn't realize there was a distinction until now.

G gac Jun 28, 2022

Matthew Ahrens `(https://arstechnica.com/civis/viewtopic.php?p=26303271#p26303271)` (one of the original Sun ZFS team members) and Jim Salter `(https://arstechnica.com/civis/viewtopic.php?p=26304459#p26304459)` (aka mercenarysysadmin in a few places) have both historically said that you *should* use ECC if it's an option, as you should with all filesystems. But there's nothing about ZFS that makes it *worse* to run without ECC than, say, ext4 or any other common filesystem.

I run ECC because I have boxes that do it. If I didn't, I probably wouldn't sweat it too much, but I would make sure I have good backups (which you should be doing anyway), make sure I buy reliable, quality components (which you should be doing anyway), and so on.

Georgi Danov @Gdanov May 25, 2022

Some random remarks

- zfs composing is drives -> vdevs -> pool -> filesystem
- you can put your slog on your os drive by using a file as vdev or re-partitionig. That would speed up sync writes only however. And will give you trouble if the os drive goes kaput
- zfs uses memory aggressively, but doesn't require much for a Nas use case. You could be over provisioning BTW, but who cares at that cost
- there are number of growth strategies other than the feature everyone at reddit is waiting for. The most trivial is to change all disks with bigger ones. The more complicated is to add new vdev.
- someone correctly advised you smaller disks are better. For that reason I opted to go with 6 smaller disks for my last build

Michael Lynch @michael May 27, 2022

> you can put your slog on your os drive by using a file as vdev or re-partitionig. That would speed up sync writes only however. And will give you trouble if the os drive goes kaput

Can you share more details about this? Would this be something I have to do through the CLI? I'm not seeing many options in the web UI for doing anything with my OS drive.

I'm confused when people say that the SLOG helps *only* with sync writes. Aren't most writes synchronous?

Georgi Danov @Gdanov May 27, 2022

I use only CLIs for sysadmin. just check the zpool manual and use a preallocated file path instead of device path.

I don't know if most writes are (a)sync in your use case. Must be measured. There isn't rule of thumb or something.

Async writes return immediately so obviously you can't make them faster. Of course that's the perceived time. In reality monitor your disk's io queue and performance

your disk's IO queue and performance.

Casper S @BitesizedLion May 26, 2022

Interesting build, considering building a NAS myself, also have you considered adding 10Gig at all?

Also your comment system is strange... it allows question marks in the full name field but not dots?

Michael Lynch @michael May 27, 2022

> Interesting build, considering building a NAS myself, also have you considered adding 10Gig at all?

I was jealous of Michael Stapelberg's (https://michael.stapelberg.ch/posts/2021-05-16-home-network-fiber-10-gbits-upgrade/) 10 Gig setup, but I keep putting it off. All of my equipment is 1 Gbps, so I'd have to do a lot of upgrading.

> Also your comment system is strange... it allows question marks in the full name field but not dots?

Oh, interesting. Thanks for letting me know. I use the open-source TalkYard commenting system (https://github.com/debiki/talkyard), so I've just submitted a fix (https://github.com/debiki/talkyard/pull/240) to them.

1 Like

J

JJMcgee May 29, 2022

Great writeup. I am planning to do a NAS build soon and this was very informative. One point worth mentioning in your disk failure section is the chance a cascading failure situation. Array rebuilds after a disk failure put a huge stress on the remaining disks and if all of the disks in the array are of a similar age, even if they are not from the same manufacturer or lot, the added stress can greatly increase the likelihood of further disk failures. This is an additional reason people sometimes choose raidz2 or raidz3 over raidz1.

Michael Lynch @michael May 31, 2022

Thanks, I didn't think about that! I've updated the post to add that note:

https://github.com/mtlynch/mtlynch.io/pull/921/files (https://github.com/mtlynch/mtlynch.io/pull/921/files)

C

Curious Bystander May 30, 2022

If you wanted a TrueNAS server, why not purchase one? https://www.truenas.com/truenas-mini/# (https://www.truenas.com/truenas-mini/) is even on Amazon...

Michael Lynch @michael May 31, 2022

I find it fun to build servers myself. It allows me to customize it for the things I care about.

The Mini X looks nice, but it costs twice as much as my build, and it has half the RAM.

Carson Yang @yangchuansheng Jun 3, 2022

Great and inspiring post! I've translated it into Chinese (https://hackmd.io/@yangchuansheng/rJ7ZbZv_5) for local community study, is it okay to retweet this article?

Michael Lynch @michael Jun 3, 2022

Thanks for translating! It's licensed under Creative Commons (http://creativecommons.org/licenses/by/4.0/), so you can translate and publish as long as you give attribution back to the original (preferably with a link).

Noted @Jeremy Jun 3, 2022

Awesome post Michael! I built one similar using Open Media Vault recently.

Michael Lynch @michael Jun 3, 2022

Nice! I'd love to see more about your build process if you decide to a writeup on your blog.

G2 gilot Jun 17, 2022

Built my own FreeNAS server back in 2016. I strongly sugget you to read the community hardware recommendations:
https://www.truenas.com/community/resources/hardware-recommendations-guide.12/
`(https://www.truenas.com/community/resources/hardware-recommendations-guide.12/)`
It was last updated in 2021-01-24.

F Fanhao Jul 25, 2022

Great article Michael!

A minor question: could you elaborate what you mean by this?

> A 4% risk per year is a 2% chance in any given week.

 **Michael Lynch** @michael Jul 25, 2022

This is my own amateur statistics, so correct me if I'm wrong, but I calculate that if the odds of a failure in one year is 4%, then to calculate the odds of failure in a given week, we solve the equation:

```
(1-x)^52=0.04
```

Solving the equation gives x=0.0175, which I rounded to 2%.

J2 Jason Aug 5, 2022

You want to solve

```
1-x^52 = 0.04
```

In this case, `x` is the probability of not failing in any week. `x^52` is the probability of no failures in any week if the events are independent. And `1 - x^52` is the probability of *at least one* failure in a year. So, the probability of not failing in a week must be at least 99.92% in order for the probability of failure in a year to be 4%. You can also solve this with the cumulative distribution function of the binomial distribution. And a quick check on your result would be using the expected number of failures in a year from the binomial if the failure rate is 2% is `52 * 0.02 = 1.04` which is much too high if the probability of failure in a year is only 4%. As you said, this is only if the events are independent in time which is unlikely.

 **Michael Lynch** @michael Aug 8, 2022

Ah, thanks! That makes sense. I've updated it to correct the probability.

Andre Fontes @arkantospt Sep 20, 2022

Sorry for my ignorance... but what is the difference of having the disks on main computer and wake it up whenever you need to access the disks remotely?
In my perspective, you just bought a new shity PC to fit the ITX size, to have a extra enclosed box containing the disks, instead of in the main computer.

 **Michael Lynch** @michael Sep 21, 2022

Thanks for reading!

The main reason is that it uncouples storage from my main desktop. I don't think my main PC has room for four extra HDDs and SATA cables, but even if it did, I'm stuck with that restriction every time I upgrade my main desktop, which I do every 2-3 years. I upgrade my storage server much less frequently (I kept my last one for 7 years), so it's nice to just upgrade my desktop and not have to worry about storage beyond a good SSD for the OS drive.

The other reason is that ZFS has a lot of features that aren't available on a Windows system, and my main desktop is Windows.

It's also nice to have a central storage server that all of my devices use. My main desktop, my laptop, and my VM server all use the storage server. Granted, I could have set up SMB shares on my Windows desktop, but it's not as convenient as having an always-on server that all the other devices share.

D djh Nov 26, 2022

Thanks for taking the time to write this up.

I was thinking about doing something similar but those power consumption figures concern me a lot. Unfortunately here in the UK power is around £0.34 p/KwH (around $0.41) so those watts really make a difference.

Think I'll stick with an off the shelf solution for this reason, as much as it pains me!

 **Michael Lynch** @michael Nov 26, 2022

Thanks for reading! Glad to hear it was helpful.

1 Like

Rohit Pai @rodude123 Jan 25

Probably a stupid question but you don't have to install free nas you can install anything on this. I'm considering upgrading my setup and currently have everything running of Ubuntu 22.04

Theo Carvalho @Theodecarvalho Feb 16

Thats so nice process! I'm in the same path, to build my own NAS. Let me ask you: Did you think about using OpenMediaVault instead a TrueNas? Due the needs, that is closer to mine, I think that is a most compatible choise. Using ext4 and not need ecc RAM for ZFS filesystem... Even for realtek NIC. Im choosing my parts thinking exactly on both o.s. to run on it. Cheers.

@hyper_focused_guy Jun 6

Awesome guide. I will look into this more closer.
I need to set something like this up in the future. I have used OneDrive for a long time. But I don't like the fact that I have not 100% control of my data, and what I have heard is that they can shut down your account, if they discover the "wrong type of data".

This is why I'm also against buying a pre-built system and still be forced to use their software. I will not have full control then. I need my own NAS as now. Thanks for this.

Some disagree with this:

M Maurice Moss May 26, 2022

[Being a landlord/Building a NAS] is worthwhile if you value your time at $0-$10/hr.

This is a real-life caricature of IT Crowd: "We swapped the unit you can buy in the store for a dozen parts + fringe OS + NASA level file system combination that only a unix guru can run!! We saved company money by spending 2 weeks building rather than 1 day buying and setting up!".

Brant's comment highlights the number of massively stupid pitfalls in your path (they not wrong - aligns with my own decade+ of building/contributing to NAS space); the specific items may or may not bite you, but it goes to show the even a reasonably researched effort is gonna produce a result here that is shotgun partially loaded at any given time. The difference is with Synology they tend to have a specialist piece the compromises/risks into weighted holistic package, where as you are cherry picking items left and right (e.g. ECC: No, Z1: yes, SLOG, HW parts etc).

Society jokes about people slaving away at day jobs to pay for their sports car and boat, but yet engineers un-ironically spend thousands (if not 10s of thousands) dollars of labor to build a Baja truck equivalent of a grocery getter (instead of a Toyota). Lets call this what it is: pig (engineer) rolling around in mud making fun.

I reckon buy the Toyota/Synology and move on to bigger and better things in your life. I'm chalking this toward the KB washing column, infinitely more so now that you actually are managing/running more impactful things. This strikes me as a detour in the wrong direction, and I'm bit horrified with the conclusion ("ready to start tinkering with your production data instance" Bruh... Don't deprive yourself of NAS services - streaming, storage, etc - while you have NAS physically or digitally disassembled in the garage)

2 Disagree

 **Michael Lynch** @michael May 26, 2022

Thanks for reading!

As I said in the post, I'm choosing TrueNAS for ideological reasons and not optimizing for convenience. I agree that Synology would save me time, but tinkering with technology is time I enjoy spending, so I don't see that as an issue.

1 Like

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