2000 元的机械硬盘 > 3000 元的固态硬盘?

A.K.A. 镜像站 ZFS 调优实践

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iBug @ USTC

2024 年 8 月 17 日

南京大学 开源软件论坛

USTC Mirrors

- 日均服务量：（2024-05 ~ 2024-06）
  - 出流量 ~36 TiB
  - HTTP 请求数 17M，响应流量 19 TiB
  - Rsync 请求数 147.8K（21.8K），输出流量 10.3 TiB
- 极限情况的仓库容量：
  - HTTP 服务器（XFS）：63.3 TiB / 66.0 TiB (96%, 2023-12-18)
  - Rsync 服务器（ZFS）：42.4 TiB / 43.2 TiB (98%, 2023-11-21)

背景

- HTTP 服务器：
  - 2020 年下半年搭建
  - 10 TB 💿 × 12
  - 2 TB 💾 × 1
  - XFS on LVM on HW RAID
  - 考虑到 XFS 不能缩，VG 留了 free PE
- Rsync 服务器：
  - 2016 年下半年搭建
  - 6 TB 💿 × 12
  - 240 GB 💾 × 2 + 480 GB 💾 × 1 (Optane 900p)
  - RAID-Z3（8 data + 3 parity + 1 hot spare）
  - 全默认参数（除了 `zfs_arc_max`）

硬盘 I/O 日常 > 90%，校内下载 iso 不足 50 MB/s

USTC 镜像站两台服务器在 2024 年 5 月期间的磁盘负载

ZFS

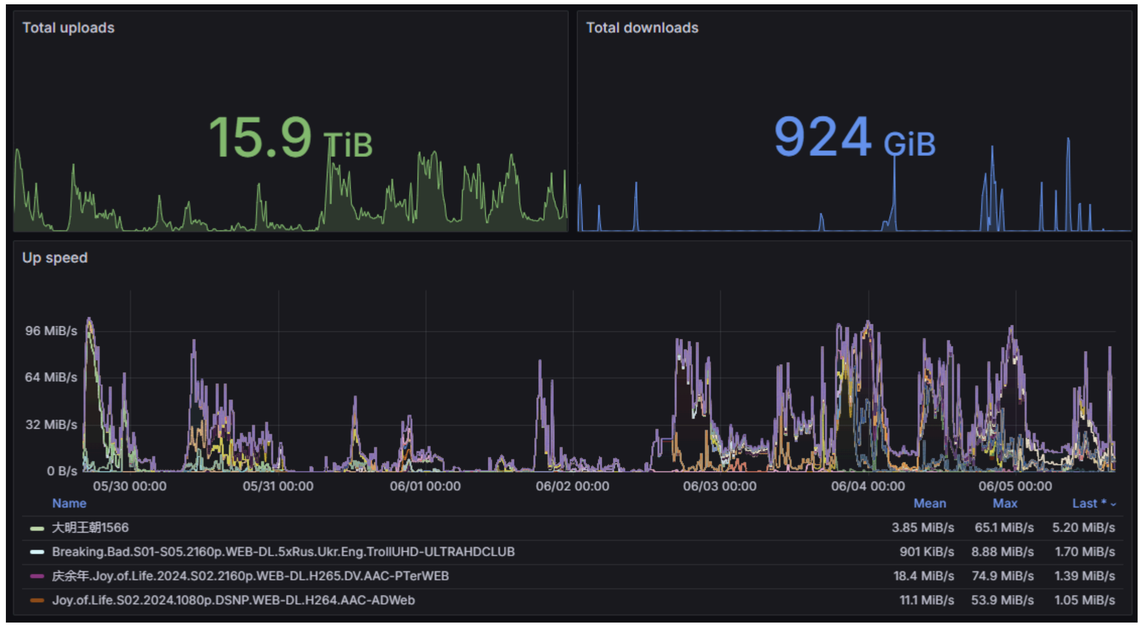
- 单机存储的终极解决方案
- 集 RAID、LVM、FS 于一体
- 所有数据都有 checksum
- ~~Fire and forget~~
- 好多参数啊

前期学习与实验

- ~~从（另一个）老师那嫖子点盘~~装上了 ZFS，用于研究学习
- I/O 负载来源？~~上 PT 站~~
- 练习时长两年半的成果：↑ 1.20 PiB, ↓ 1.83 TiB

重要学习资料：

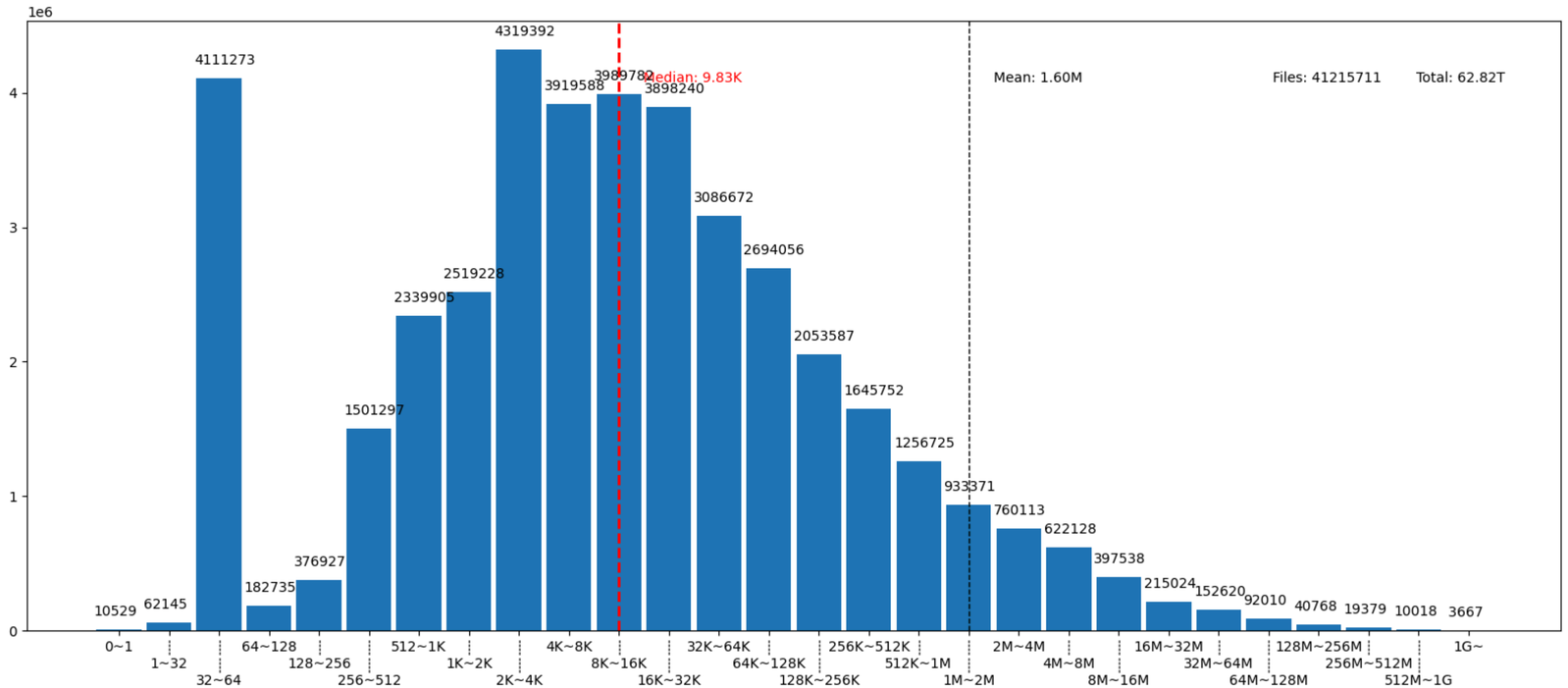
- Chris Siebenmann's blog
- OpenZFS Documentation
- iBug's blog: Understanding ZFS block sizes (ibug.io/p/62)
  - 以及这篇 blog 底下的众多参考文献



好像给什么奇怪的东西加入了 Grafana

镜像站

- 提供文件下载服务
- ~~也提供「家庭宽带上下行流量比例平衡」服务~~
- 读多写少，并且几乎所有操作都是整个文件顺序读写
- 少量的数据损坏没啥不良后果



2024 年 8 月 USTC 镜像仓库内的文件大小分布
其中中位数为 9.83 KiB，平均大小为 1.60 MiB

重建 Rsync 服务器

- RAID-Z3 的 overhead 较高，而且拆成两组 RAID-Z2 = 两倍的 IOPS
- 镜像站调优计划：
  - `recordsize=1M`： 反正都是全文件顺序读
  - `compression=zstd`： 至少可以压掉 > 1M 文件的 padding
    - OpenZFS 2.2 将 early abort 机制推广到了 Zstd 3+，不必担心性能问题
  - `xattr=off`： 谁家镜像需要 xattr?
  - `atime=off`, `setuid=off`, `exec=off`, `devices=off`： 开着干啥?
  - `secondarycache=metadata`： Rsync 就别来消耗固态寿命了
- Danger Zone：
  - `sync=disabled`： 囤到 `zfs_txg_timeout` 再写盘
  - `redundant_metadata=some`： 偶尔坏个文件也没事
- Full version: LUG @ USTC Documentation

ZFS 参数

- 290+ 参数不能个个都学习嘛（感谢 Aron Xu @ BFSU）
- ARC 容量：

```
# Set ARC size to 160-200 GiB, keep 16 GiB free for OS
options zfs zfs_arc_max=214748364800
options zfs zfs_arc_min=171798691840
options zfs zfs_arc_sys_free=17179869184
```

- ARC 内容：

```
# Favor metadata to data by 20x (OpenZFS 2.2+)
options zfs zfs_arc_meta_balance=2000

# Allow up to 80% of ARC to be used for dnodes
options zfs zfs_arc_dnode_limit_percent=80
```

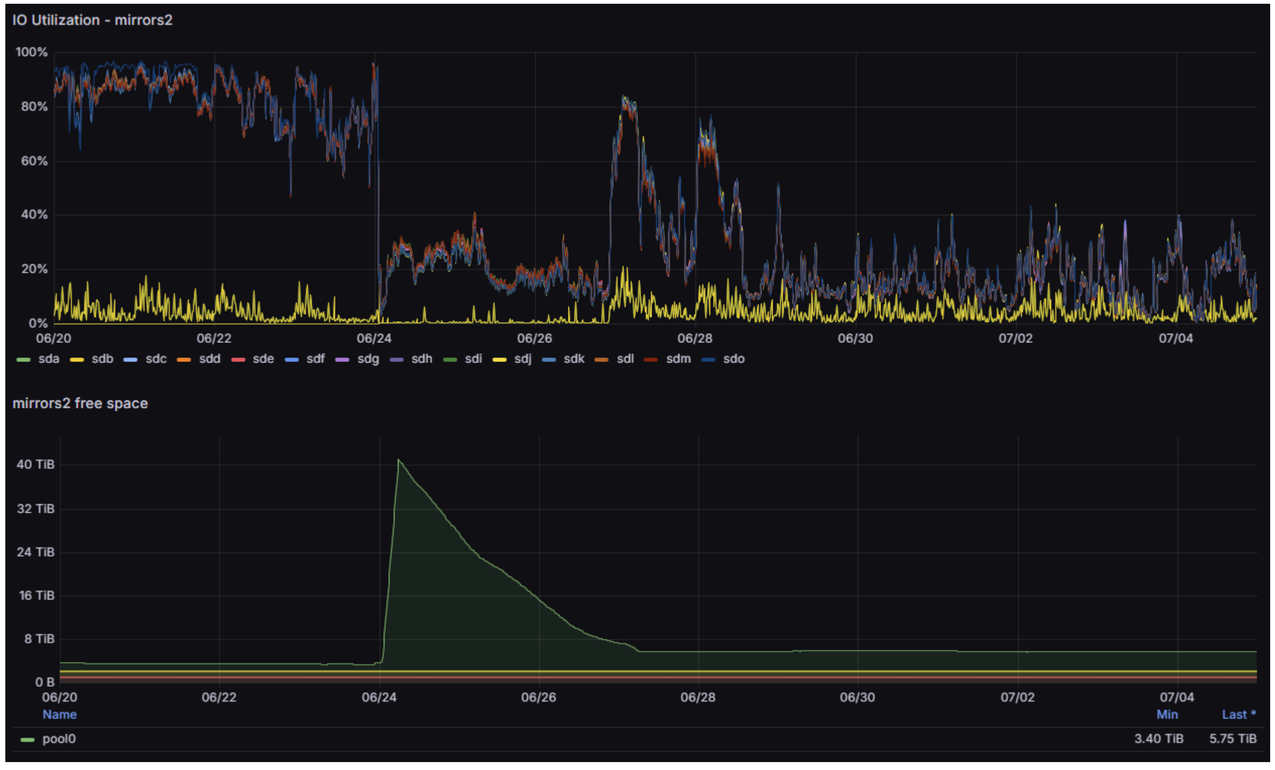
- I/O 队列深度：

```
# See man page section "ZFS I/O Scheduler"
options zfs zfs_vdev_async_read_max_active=8
options zfs zfs_vdev_async_read_min_active=2
options zfs zfs_vdev_scrub_max_active=5
options zfs zfs_vdev_max_active=20000
```

- Full version: LUG @ USTC Documentation

重建成果

- 略感惊喜的压缩率：39.5T / 37.1T = 1.07x
  - 正确用法： `zfs list -po name,logicalused,used`
  - 实际压缩率：1 + 6.57%（-2.67 TB / -2.43 TiB）
  - ~~等于删了 9 份微信数据~~
- 合理的磁盘 I/O



重建前后 Rsync 服务器的磁盘负载与空闲空间比较

HTTP 服务器

- 硬件 RAID + LVM + XFS + Kernel page cache（开箱即用？）
- SSD？LVMCache！
  - 1M extents? Block size? Algorithm?
  - 💀 GRUB2
  - 💀 "oldssd"
- XFS 不能缩，所以 VG 和 FS 两层都要留空间备用

重建前 HTTP 服务器采用的 LVMcache 方案的命中率

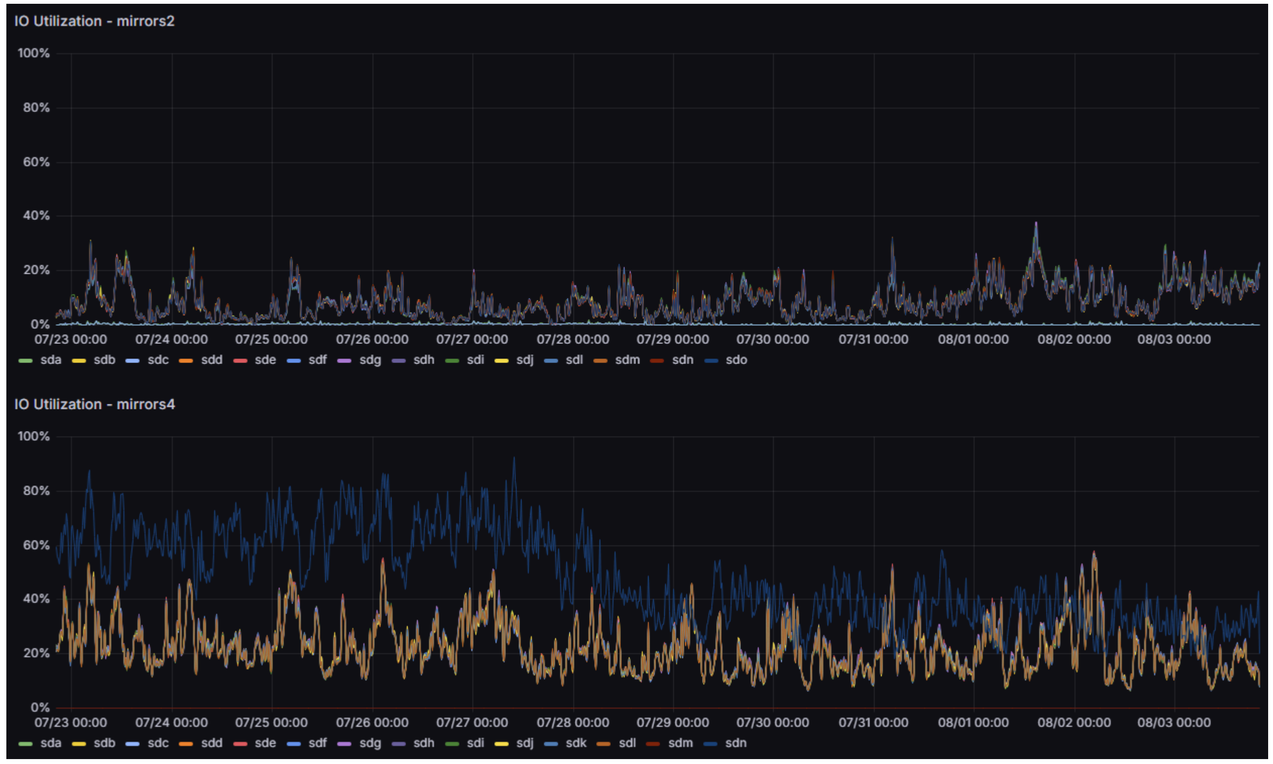
如法炮制

- 体验一下更加先进的 kernel：`6.8.8-3-pve`（无需 DKMS 哦）
- 重建为两组 RAID-Z2，开压缩
  - 面向 HTTP 用户的服务器，所以 `secondarycache=all`（放着不动）
  - 更好的 CPU，所以 `compression=zstd-8`
- 更快的 `zfs send -Lcp`：36 小时倒完 50+ TiB 仓库
- 压缩率：1 + 3.93%（-2.42 TB / -2.20 TiB）

重建前后两台服务器的磁盘负载比较

左边为重建前，中间为仅 Rsync 服务器重建后，右边为两台服务器均重建后的负载

两台服务器的 ZFS ARC 命中率



两台服务器重建后稳定的磁盘利用率

杂项

ZFS 压缩率

NAME	LUSED	USED	RATIO
pool0/repo/crates.io-index	2.19G	1.65G	3.01x
pool0/repo/elpa	3.35G	2.32G	1.67x
pool0/repo/rfc	4.37G	3.01G	1.56x
pool0/repo/debian-cdimage	1.58T	1.04T	1.54x
pool0/repo/tldp	4.89G	3.78G	1.48x
pool0/repo/loongnix	438G	332G	1.34x
pool0/repo/rosdistro	32.2M	26.6M	1.31x

我数学不好：openzfs/zfs#7639

ZFS 压缩量

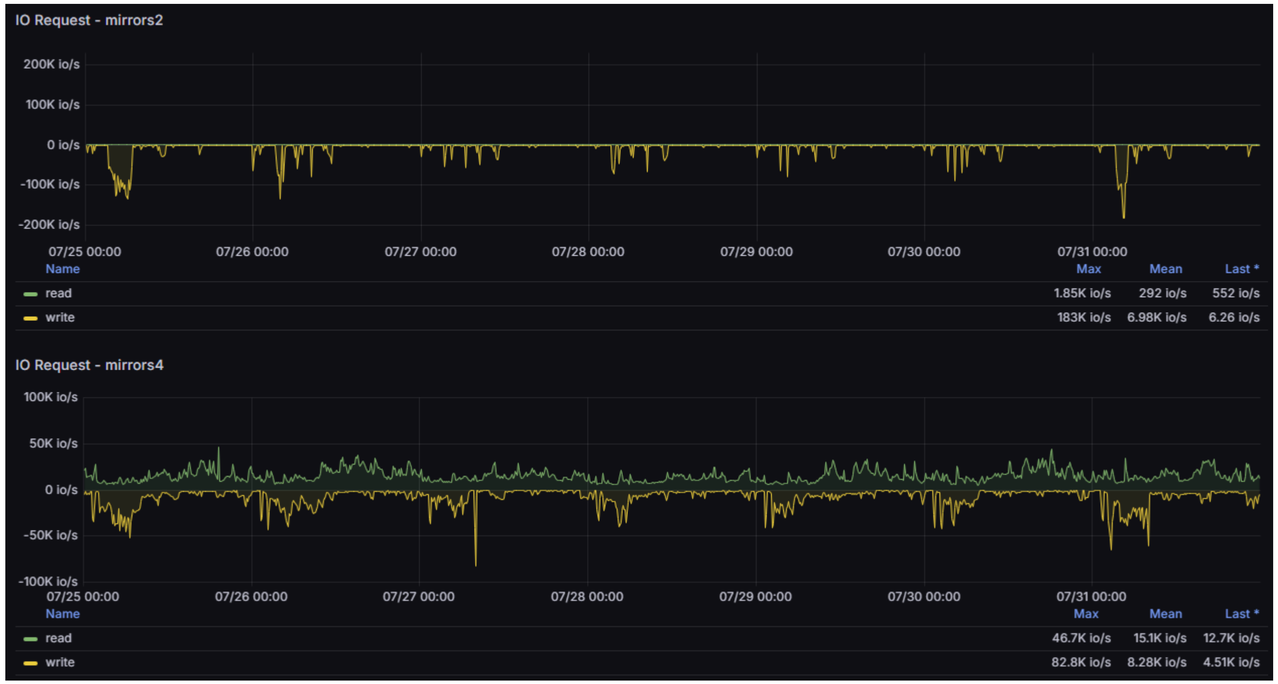
NAME	LUSED	USED	DIFF
pool0/repo	58.3T	56.1T	2.2T
pool0/repo/debian-cdimage	1.6T	1.0T	549.6G
pool0/repo/opensuse	2.5T	2.3T	279.7G
pool0/repo/turnkeylinux	1.2T	1.0T	155.2G
pool0/repo/loongnix	438.2G	331.9G	106.3G
pool0/repo/alpine	3.0T	2.9T	103.9G
pool0/repo/openwrt	1.8T	1.7T	70.0G

Grafana I/O 统计

```
SELECT
  non_negative_derivative(sum("reads"), 1s) AS "read",
  non_negative_derivative(sum("writes"), 1s) AS "write"
FROM (
  SELECT
    first("reads") AS "reads",
    first("writes") AS "writes"
  FROM "zfs_pool"
  WHERE ("host" = 'taokystrong' AND "pool" = 'pool0') AND $timeFilter
  GROUP BY time($interval), "host"::tag, "pool"::tag, "dataset"::tag fill(null)
)
WHERE $timeFilter
GROUP BY time($interval), "pool"::tag fill(linear)
```

跑得有点慢（毕竟要先 `GROUP BY` 每个 ZFS dataset 再一起 `sum`）

I/O 带宽：把里层的 `reads` 和 `writes` 换成 `nread` 和 `nwritten` 即可



- 如何用机械盘跑出平均 15K、最高 50K 的 IOPS?
- ~~把 ARC hit 算进去~~

灵车时间

Proxmox Kernel

- ≈ Ubuntu Kernel
- 💀 Rsync 容器
- `security/apparmor/af_unix.c` ???
- LUG Documentation: AppArmor

```
dpkg-divert --package lxc-pve --rename --divert /usr/share/apparmor-features/features.stock --add /usr/share/apparmor-features/features
wget -O /usr/share/apparmor-features/features https://github.com/proxmox/lxc/raw/master/debian/features
```

```
/srv/zerotier/redhat/el/8:
repodata                                zerotier-one-1.8.6-1.el8.ppc64le.rpm   zerotier-one-1.8.10-1.el8.ppc64le.rpm  zerotier-one-1.10.2-1.el8.ppc64le.rpm  zerotier-one-1.10.5-1.el8.ppc64le.rpm  zerotier-one-1.12.1-1.el8.ppc64le.rpm
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zerotier-one-1.6.6-1.el8.ppc64le.rpm    zerotier-one-1.8.6-1.el8.x86_64.rpm    zerotier-one-1.8.10-1.el8.x86_64.rpm   zerotier-one-1.10.2-1.el8.x86_64.rpm   zerotier-one-1.10.5-1.el8.x86_64.rpm   zerotier-one-1.12.1-1.el8.x86_64.rpm
zerotier-one-1.8.2-1.el8.ppc64le.rpm    zerotier-one-1.8.7-1.el8.aarch64.rpm   zerotier-one-1.10.0-1.el8.aarch64.rpm  zerotier-one-1.10.3-1.el8.aarch64.rpm  zerotier-one-1.10.6-1.el8.aarch64.rpm  zerotier-one-1.12.2-1.el8.aarch64.rpm
zerotier-one-1.8.3-1.el8.ppc64le.rpm    zerotier-one-1.8.7-1.el8.ppc64le.rpm   zerotier-one-1.10.0-1.el8.ppc64le.rpm  zerotier-one-1.10.3-1.el8.ppc64le.rpm  zerotier-one-1.10.6-1.el8.ppc64le.rpm  zerotier-one-1.12.2-1.el8.ppc64le.rpm
zerotier-one-1.8.4-1.el8.ppc64le.rpm    zerotier-one-1.8.7-1.el8.x86_64.rpm    zerotier-one-1.10.0-1.el8.x86_64.rpm   zerotier-one-1.10.3-1.el8.x86_64.rpm   zerotier-one-1.10.6-1.el8.x86_64.rpm   zerotier-one-1.12.2-1.el8.x86_64.rpm
zerotier-one-1.8.5-1.el8.aarch64.rpm    zerotier-one-1.8.9-1.el8.aarch64.rpm   zerotier-one-1.10.1-1.el8.aarch64.rpm  zerotier-one-1.10.4-1.el8.aarch64.rpm  zerotier-one-1.12.0-1.el8.aarch64.rpm  zerotier-one-1.14.0-1.el8.aarch64.rpm
zerotier-one-1.8.5-1.el8.ppc64le.rpm    zerotier-one-1.8.9-1.el8.ppc64le.rpm   zerotier-one-1.10.1-1.el8.ppc64le.rpm  zerotier-one-1.10.4-1.el8.ppc64le.rpm  zerotier-one-1.12.0-1.el8.ppc64le.rpm  zerotier-one-1.14.0-1.el8.ppc64le.rpm
zerotier-one-1.8.5-1.el8.x86_64.rpm     zerotier-one-1.8.9-1.el8.x86_64.rpm    zerotier-one-1.10.1-1.el8.x86_64.rpm   zerotier-one-1.10.4-1.el8.x86_64.rpm   zerotier-one-1.12.0-1.el8.x86_64.rpm   zerotier-one-1.14.0-1.el8.x86_64.rpm
zerotier-one-1.8.6-1.el8.aarch64.rpm    zerotier-one-1.8.10-1.el8.aarch64.rpm  zerotier-one-1.10.2-1.el8.aarch64.rpm  zerotier-one-1.10.5-1.el8.aarch64.rpm  zerotier-one-1.12.1-1.el8.aarch64.rpm

/srv/zerotier/redhat/el/8.3:
repodata                                zerotier-one-1.8.6-1.el8.ppc64le.rpm   zerotier-one-1.8.10-1.el8.ppc64le.rpm  zerotier-one-1.10.2-1.el8.ppc64le.rpm  zerotier-one-1.10.5-1.el8.ppc64le.rpm  zerotier-one-1.12.1-1.el8.ppc64le.rpm
zerotier-one-1.6.6-1.el8.ppc64le.rpm    zerotier-one-1.8.6-1.el8.x86_64.rpm    zerotier-one-1.8.10-1.el8.x86_64.rpm   zerotier-one-1.10.2-1.el8.x86_64.rpm   zerotier-one-1.10.5-1.el8.x86_64.rpm   zerotier-one-1.12.1-1.el8.x86_64.rpm
zerotier-one-1.8.2-1.el8.ppc64le.rpm    zerotier-one-1.8.7-1.el8.aarch64.rpm   zerotier-one-1.10.0-1.el8.aarch64.rpm  zerotier-one-1.10.3-1.el8.aarch64.rpm  zerotier-one-1.10.6-1.el8.aarch64.rpm  zerotier-one-1.12.2-1.el8.aarch64.rpm
zerotier-one-1.8.3-1.el8.ppc64le.rpm    zerotier-one-1.8.7-1.el8.ppc64le.rpm   zerotier-one-1.10.0-1.el8.ppc64le.rpm  zerotier-one-1.10.3-1.el8.ppc64le.rpm  zerotier-one-1.10.6-1.el8.ppc64le.rpm  zerotier-one-1.12.2-1.el8.ppc64le.rpm
zerotier-one-1.8.4-1.el8.ppc64le.rpm    zerotier-one-1.8.7-1.el8.x86_64.rpm    zerotier-one-1.10.0-1.el8.x86_64.rpm   zerotier-one-1.10.3-1.el8.x86_64.rpm   zerotier-one-1.10.6-1.el8.x86_64.rpm   zerotier-one-1.12.2-1.el8.x86_64.rpm
zerotier-one-1.8.5-1.el8.aarch64.rpm    zerotier-one-1.8.9-1.el8.aarch64.rpm   zerotier-one-1.10.1-1.el8.aarch64.rpm  zerotier-one-1.10.4-1.el8.aarch64.rpm  zerotier-one-1.12.0-1.el8.aarch64.rpm  zerotier-one-1.14.0-1.el8.aarch64.rpm
zerotier-one-1.8.5-1.el8.ppc64le.rpm    zerotier-one-1.8.9-1.el8.ppc64le.rpm   zerotier-one-1.10.1-1.el8.ppc64le.rpm  zerotier-one-1.10.4-1.el8.ppc64le.rpm  zerotier-one-1.12.0-1.el8.ppc64le.rpm  zerotier-one-1.14.0-1.el8.ppc64le.rpm
zerotier-one-1.8.5-1.el8.x86_64.rpm     zerotier-one-1.8.9-1.el8.x86_64.rpm    zerotier-one-1.10.1-1.el8.x86_64.rpm   zerotier-one-1.10.4-1.el8.x86_64.rpm   zerotier-one-1.12.0-1.el8.x86_64.rpm   zerotier-one-1.14.0-1.el8.x86_64.rpm
zerotier-one-1.8.6-1.el8.aarch64.rpm    zerotier-one-1.8.10-1.el8.aarch64.rpm  zerotier-one-1.10.2-1.el8.aarch64.rpm  zerotier-one-1.10.5-1.el8.aarch64.rpm  zerotier-one-1.12.1-1.el8.aarch64.rpm

/srv/zerotier/redhat/el/8.4:
repodata                                zerotier-one-1.8.6-1.el8.ppc64le.rpm   zerotier-one-1.8.10-1.el8.ppc64le.rpm  zerotier-one-1.10.2-1.el8.ppc64le.rpm  zerotier-one-1.10.5-1.el8.ppc64le.rpm  zerotier-one-1.12.1-1.el8.ppc64le.rpm
zerotier-one-1.6.6-1.el8.ppc64le.rpm    zerotier-one-1.8.6-1.el8.x86_64.rpm    zerotier-one-1.8.10-1.el8.x86_64.rpm   zerotier-one-1.10.2-1.el8.x86_64.rpm   zerotier-one-1.10.5-1.el8.x86_64.rpm   zerotier-one-1.12.1-1.el8.x86_64.rpm
zerotier-one-1.8.2-1.el8.ppc64le.rpm    zerotier-one-1.8.7-1.el8.aarch64.rpm   zerotier-one-1.10.0-1.el8.aarch64.rpm  zerotier-one-1.10.3-1.el8.aarch64.rpm  zerotier-one-1.10.6-1.el8.aarch64.rpm  zerotier-one-1.12.2-1.el8.aarch64.rpm
zerotier-one-1.8.3-1.el8.ppc64le.rpm    zerotier-one-1.8.7-1.el8.ppc64le.rpm   zerotier-one-1.10.0-1.el8.ppc64le.rpm  zerotier-one-1.10.3-1.el8.ppc64le.rpm  zerotier-one-1.10.6-1.el8.ppc64le.rpm  zerotier-one-1.12.2-1.el8.ppc64le.rpm
zerotier-one-1.8.4-1.el8.ppc64le.rpm    zerotier-one-1.8.7-1.el8.x86_64.rpm    zerotier-one-1.10.0-1.el8.x86_64.rpm   zerotier-one-1.10.3-1.el8.x86_64.rpm   zerotier-one-1.10.6-1.el8.x86_64.rpm   zerotier-one-1.12.2-1.el8.x86_64.rpm
zerotier-one-1.8.5-1.el8.aarch64.rpm    zerotier-one-1.8.9-1.el8.aarch64.rpm   zerotier-one-1.10.1-1.el8.aarch64.rpm  zerotier-one-1.10.4-1.el8.aarch64.rpm  zerotier-one-1.12.0-1.el8.aarch64.rpm  zerotier-one-1.14.0-1.el8.aarch64.rpm
zerotier-one-1.8.5-1.el8.ppc64le.rpm    zerotier-one-1.8.9-1.el8.ppc64le.rpm   zerotier-one-1.10.1-1.el8.ppc64le.rpm  zerotier-one-1.10.4-1.el8.ppc64le.rpm  zerotier-one-1.12.0-1.el8.ppc64le.rpm  zerotier-one-1.14.0-1.el8.ppc64le.rpm
zerotier-one-1.8.5-1.el8.x86_64.rpm     zerotier-one-1.8.9-1.el8.x86_64.rpm    zerotier-one-1.10.1-1.el8.x86_64.rpm   zerotier-one-1.10.4-1.el8.x86_64.rpm   zerotier-one-1.12.0-1.el8.x86_64.rpm   zerotier-one-1.14.0-1.el8.x86_64.rpm
```

Dedup!

```
zfs create -o dedup=on pool0/repo/zerotier
```

```
# zdb -DDD pool0
dedup = 4.93, compress = 1.23, copies = 1.00, dedup * compress / copies = 6.04
```

效果倒是不错，但是不想像 ZFS dedup 这么灵怎么办?

jdupes

```
# post-sync.sh
# Do file-level deduplication for select repos
case "$NAME" in
  docker-ce|influxdata|nginx|openresty|proxmox|salt|tailscale|zerotier)
    jdupes -L -Q -r -q "$DIR" ;;
esac
```

jdupes 效果

Name	Orig	Dedup	Diff	Ratio
proxmox	395.4G	162.6G	232.9G	2.43x
docker-ce	539.6G	318.2G	221.4G	1.70x
influxdata	248.4G	54.8G	193.6G	4.54x
salt	139.0G	87.2G	51.9G	1.59x
nginx	94.9G	59.7G	35.2G	1.59x
zerotier	29.8G	6.1G	23.7G	4.88x
mysql-repo	647.8G	632.5G	15.2G	1.02x
openresty	65.1G	53.4G	11.7G	1.22x
tailscale	17.9G	9.0G	9.0G	2.00x

只要 ZFS 用得好

- 妈妈再也不用担心我的硬盘分区
- 机械硬盘 ~~比西方的固态硬盘跑得还快~~
- 成为第一个不再**羡慕** TUNA 全闪的镜像站
- 免费的额外容量
  - Dedup 会员红包
- 碎片率?

谢谢！

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