Red Hat Enterprise Linux 8

Deduplicating and compressing storage

Using VDO to optimize storage capacity in RHEL 8

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Using VDO to optimize storage capacity in RHEL 8

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Abstract

This documentation collection provides instructions on how to use the Virtual Data Optimizer (VDO) to manage deduplicated and compressed storage pools in Red Hat Enterprise Linux 8.

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CHAPTER 1. DEPLOYING VDO

As a system administrator, you can use VDO to create deduplicated and compressed storage pools.

1.1. INTRODUCTION TO VDO

Virtual Data Optimizer (VDO) provides inline data reduction for Linux in the form of deduplication, compression, and thin provisioning. When you set up a VDO volume, you specify a block device on which to construct your VDO volume and the amount of logical storage you plan to present.

- When hosting active VMs or containers, Red Hat recommends provisioning storage at a 10:1 logical to physical ratio: that is, if you are utilizing 1 TB of physical storage, you would present it as 10 TB of logical storage.
- For object storage, such as the type provided by Ceph, Red Hat recommends using a 3:1 logical to physical ratio: that is, 1 TB of physical storage would present as 3 TB logical storage.

In either case, you can simply put a file system on top of the logical device presented by VDO and then use it directly or as part of a distributed cloud storage architecture.

Because VDO is thinly provisioned, the file system and applications only see the logical space in use and are not aware of the actual physical space available. Scripting should be used to monitor the actual available space and generate an alert if use exceeds a threshold: for example, when the VDO volume is 80% full. See Section 2.1, “Managing free space on VDO volumes” for details.

1.2. VDO DEPLOYMENT SCENARIOS

You can deploy VDO in a variety of ways to provide deduplicated storage for:

- both block and file access
- both local and remote storage

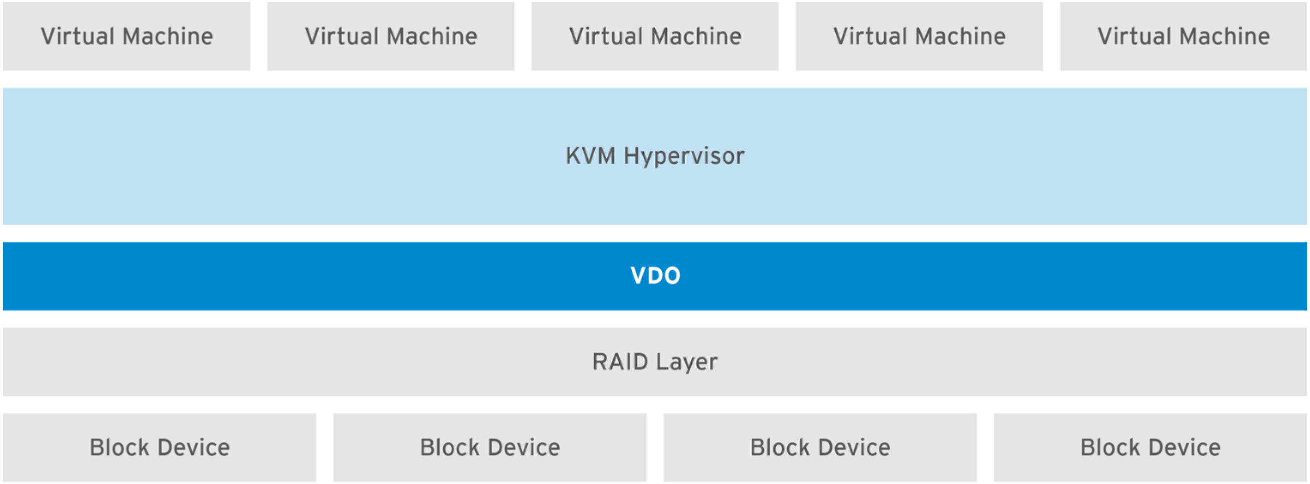
Because VDO exposes its deduplicated storage as a standard Linux block device, you can use it with standard file systems, iSCSI and FC target drivers, or as unified storage.

NOTE

VDO deployment with Ceph Storage is currently not supported.

KVM

You can deploy VDO on a KVM server configured with Direct Attached Storage.



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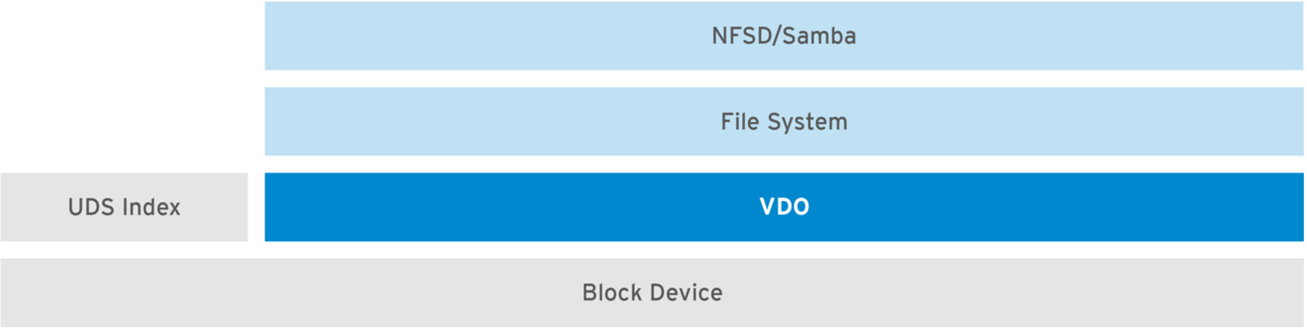
File systems

You can create file systems on top of VDO and expose them to NFS or CIFS users with the NFS server or Samba.



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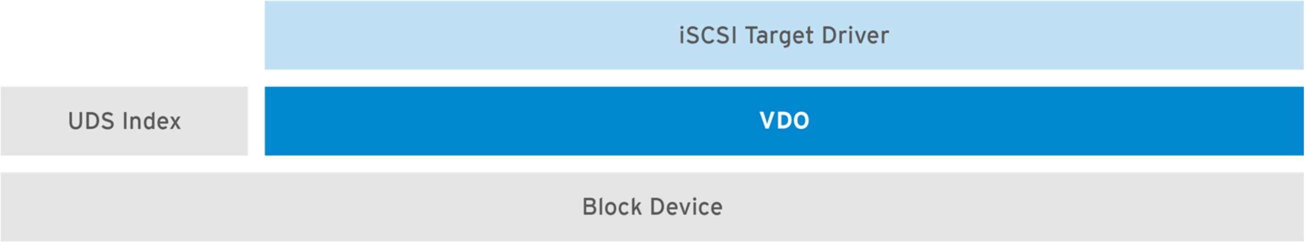
iSCSI target

You can export the entirety of the VDO storage target as an iSCSI target to remote iSCSI initiators.



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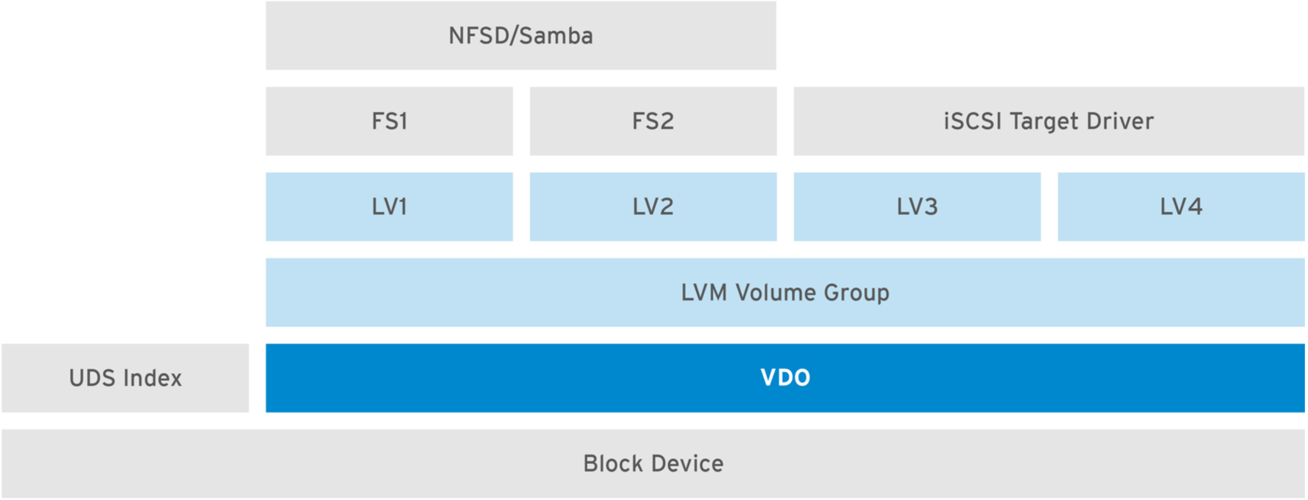
LVM

On more feature-rich systems, you can use LVM to provide multiple logical unit numbers (LUNs) that are all backed by the same deduplicated storage pool.

In the following diagram, the VDO target is registered as a physical volume so that it can be managed by LVM. Multiple logical volumes (*LV1* to *LV4*) are created out of the deduplicated storage pool. In this way, VDO can support multiprotocol unified block or file access to the underlying deduplicated storage pool.



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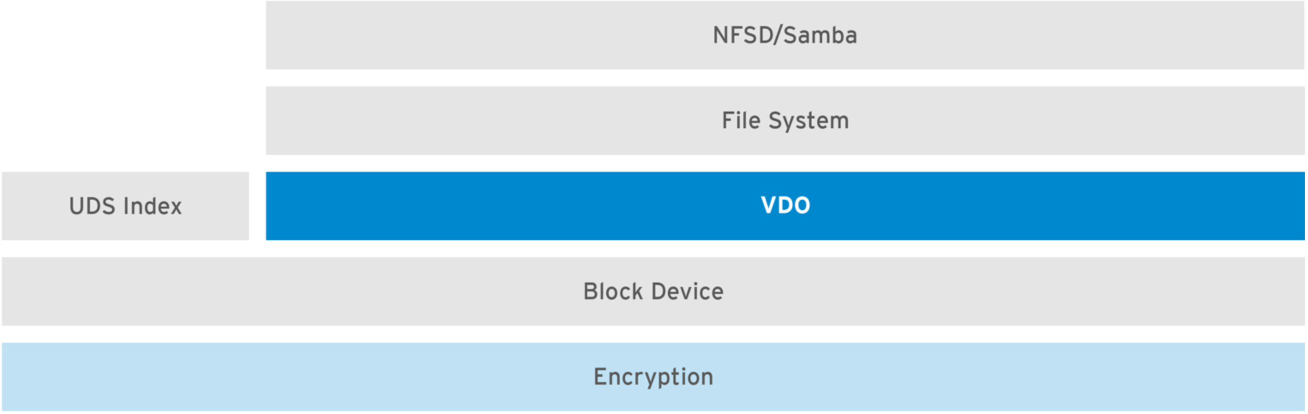
Deduplicated unified storage design enables for multiple file systems to collectively use the same deduplication domain through the LVM tools. Also, file systems can take advantage of LVM snapshot, copy-on-write, and shrink or grow features, all on top of VDO.

Encryption

Device Mapper (DM) mechanisms such as DM Crypt are compatible with VDO. Encrypting VDO volumes helps ensure data security, and any file systems above VDO are still deduplicated.



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IMPORTANT

Applying the encryption layer above VDO results in little if any data deduplication. Encryption makes duplicate blocks different before VDO can deduplicate them.

Always place the encryption layer below VDO.

1.3. VDO REQUIREMENTS

VDO has certain requirements on its placement and your system resources.

1.3.1. Placement of VDO in the storage stack

You should place certain storage layers under VDO and others above VDO.

A VDO volume is a thinly provisioned block device. To prevent running out of physical space, place the volume on top of storage that you can expand at a later time. Examples of such expandable storage are LVM volumes or MD RAID arrays.

You can place thick-provisioned layers on top of VDO, but you cannot rely on the guarantees of thick provisioning in that case. Because the VDO layer is thin-provisioned, the effects of thin provisioning apply to all layers above it. If you do not monitor the VDO device, you might run out of physical space on thick-provisioned volumes above VDO.

Red Hat recommends the following configurations:

Place only under VDO

- DM Multipath
- DM Crypt
- Software RAID (LVM or MD RAID)

Place only above VDO

- LVM cache
- LVM snapshots
- LVM thin provisioning

The following configurations are **not supported**:

- VDO on top of VDO volumes: storage → VDO → LVM → VDO
- VDO on top of LVM snapshots
- VDO on top of LVM cache
- VDO on top of a loopback device
- VDO on top of LVM thin provisioning
- Encrypted volumes on top of VDO: storage → VDO → DM-Crypt
- Partitions on a VDO volume
- RAID (LVM RAID, MD RAID, or any other type) on top of a VDO volume

Additional resources

- For more information on stacking VDO with LVM, see the Stacking LVM volumes article.

1.3.2. VDO memory requirements

Each VDO volume has two distinct memory requirements:

The VDO module
VDO requires 370 MB of RAM plus an additional 268 MB per each 1 TB of physical storage managed by the volume.

The Universal Deduplication Service (UDS) index
UDS requires a minimum of 250 MB of RAM, which is also the default amount that deduplication uses.

The memory required for the UDS index is determined by the index type and the required size of the deduplication window:

Index type	Deduplication window	Note
Dense	1 TB per 1 GB of RAM	A 1 GB dense index is generally sufficient for up to 4 TB of physical storage.
Sparse	10 TB per 1 GB of RAM	A 1 GB sparse index is generally sufficient for up to 40 TB of physical storage.

The UDS Sparse Indexing feature is the recommended mode for VDO. It relies on the temporal locality of data and attempts to retain only the most relevant index entries in memory. With the sparse index, UDS can maintain a deduplication window that is ten times larger than with dense, while using the same amount of memory.

Although the sparse index provides the greatest coverage, the dense index provides more deduplication advice. For most workloads, given the same amount of memory, the difference in deduplication rates between dense and sparse indexes is negligible.

Additional resources

- For concrete examples of UDS index memory requirements, see Section 1.3.4, “Examples of VDO requirements by physical volume size”.

1.3.3. VDO storage space requirements

You can configure a VDO volume to use up to 256 TB of physical storage. Only a certain part of the physical storage is usable to store data. This section provides the calculations to determine the usable size of a VDO-managed volume.

VDO requires storage for two types of VDO metadata and for the UDS index:

- The first type of VDO metadata uses approximately 1 MB for each 4 GB of *physical storage* plus an additional 1 MB per slab.
- The second type of VDO metadata consumes approximately 1.25 MB for each 1 GB of *logical storage*, rounded up to the nearest slab.
- The amount of storage required for the UDS index depends on the type of index and the amount of RAM allocated to the index. For each 1 GB of RAM, a dense UDS index uses 17 GB of storage, and a sparse UDS index will use 170 GB of storage.

Additional resources

- For concrete examples of VDO storage requirements, see Section 1.3.4, “Examples of VDO requirements by physical volume size”.

1.3.4. Examples of VDO requirements by physical volume size

The following tables provide approximate system requirements of VDO based on the size of the underlying physical volume. Each table lists requirements appropriate to the intended deployment, such as primary storage or backup storage.

The exact numbers depend on your configuration of the VDO volume.

Primary storage deployment
In the primary storage case, the UDS index is between 0.01% to 25% the size of the physical volume.

Table 1.1. Storage and memory requirements for primary storage

Physical volume size	RAM usage	Disk usage	Index type
10GB–1TB	250MB	2.5 GB	Dense
2–10TB	1GB	10GB	Dense
	250MB	22GB	Sparse
11–50TB	2GB	170GB	Sparse
51–100TB	3GB	255GB	Sparse
101–256TB	12GB	1020GB	Sparse

Backup storage deployment
In the backup storage case, the UDS index covers the size of the backup set but is not bigger than the physical volume. If you expect the backup set or the physical size to grow in the future, factor this into the index size.

Table 1.2. Storage and memory requirements for backup storage

Physical volume size	RAM usage	Disk usage	Index type
10GB–1TB	250MB	2.5 GB	Dense
2–10TB	2GB	170GB	Sparse
11–50TB	10GB	850GB	Sparse
51–100TB	20GB	1700GB	Sparse
101–256TB	26GB	3400GB	Sparse

1.4. INSTALLING VDO

This procedure installs software necessary to create, mount, and manage VDO volumes.

Procedure

- Install the **vdo** and **kmod-kvdo** packages:

  ```
  # yum install vdo kmod-kvdo
  ```

1.5. CREATING A VDO VOLUME

This procedure creates a VDO volume on a block device.

Prerequisites

- Install the VDO software. See Section 1.4, “Installing VDO”.

- Use expandable storage as the backing block device. For more information, see Section 1.3.1, “Placement of VDO in the storage stack”.

Procedure

In all the following steps, replace *vdo-name* with the identifier you want to use for your VDO volume; for example, **vdo1**. You must use a different name and device for each instance of VDO on the system.

1. Find a persistent name for the block device where you want to create the VDO volume. For more information on persistent names, see Chapter 6, *Overview of persistent naming attributes*. If you use a non-persistent device name, then VDO might fail to start properly in the future if the device name changes.

2. Create the VDO volume:

   ```
   # vdo create \
         --name=vdo-name \
         --device=block-device \
         --vdoLogicalSize=logical-size
   ```

   - Replace *block-device* with the persistent name of the block device where you want to create the VDO volume. For example, **/dev/disk/by-id/scsi-3600508b1001c264ad2af21e903ad031f**.

   - Replace *logical-size* with the amount of logical storage that the VDO volume should present:

     - For active VMs or container storage, use logical size that is **ten** times the physical size of your block device. For example, if your block device is 1TB in size, use **10T** here.

     - For object storage, use logical size that is **three** times the physical size of your block device. For example, if your block device is 1TB in size, use **3T** here.

   - If the physical block device is larger than 16TiB, add the **--vdoSlabSize=32G** option to increase the slab size on the volume to 32GiB.
     Using the default slab size of 2GiB on block devices larger than 16TiB results in the **vdo create** command failing with the following error:

     ```
     vdo: ERROR - vdoformat: formatVDO failed on '/dev/device': VDO Status: Exceeds
     maximum number of slabs supported
     ```

   Example 1.1. Creating VDO for container storage

For example, to create a VDO volume for container storage on a 1TB block device, you might use:

```
# vdo create \
     --name=vdo1 \
     --device=/dev/disk/by-id/scsi-3600508b1001c264ad2af21e903ad031f \
     --vdoLogicalSize=10T
```

IMPORTANT

If a failure occurs when creating the VDO volume, remove the volume to clean up. See Section 2.10.2, “Removing an unsuccessfully created VDO volume” for details.

3. Create a file system on top of the VDO volume:

   - For the XFS file system:

     ```
     # mkfs.xfs -K /dev/mapper/vdo-name
     ```

   - For the ext4 file system:

     ```
     # mkfs.ext4 -E nodiscard /dev/mapper/vdo-name
     ```

4. Use the following command to wait for the system to register the new device node:

   ```
   # udevadm settle
   ```

Next steps

1. Mount the file system. See Section 1.6, “Mounting a VDO volume” for details.

2. Enable the **discard** feature for the file system on your VDO device. See Section 1.7, “Enabling periodic block discard” for details.

Additional resources

- The **vdo(8)** man page

1.6. MOUNTING A VDO VOLUME

This procedure mounts a file system on a VDO volume, either manually or persistently.

Prerequisites

- A VDO volume has been created on your system. For instructions, see Section 1.5, “Creating a VDO volume”.

Procedure

- To mount the file system on the VDO volume manually, use:

```
# mount /dev/mapper/vdo-name mount-point
```

- To configure the file system to mount automatically at boot, add a line to the **/etc/fstab** file:
  - For the XFS file system:

    ```
    /dev/mapper/vdo-name mount-point xfs defaults,_netdev,x-systemd.device-timeout=0,x-systemd.requires=vdo.service 0 0
    ```

  - For the ext4 file system:

    ```
    /dev/mapper/vdo-name mount-point ext4 defaults,_netdev,x-systemd.device-timeout=0,x-systemd.requires=vdo.service 0 0
    ```

Additional resources

- The **vdo(8)** man page

1.7. ENABLING PERIODIC BLOCK DISCARD

This procedure enables a **systemd** timer that regularly discards unused blocks on all supported file systems.

Procedure

- Enable and start the **systemd** timer:

  ```
  # systemctl enable --now fstrim.timer
  ```

1.8. MONITORING VDO

This procedure describes how to obtain usage and efficiency information from a VDO volume.

Prerequisites

- Install the VDO software. See Section 1.4, “Installing VDO”.

Procedure

- Use the **vdostats** utility to get information about a VDO volume:

  ```
  # vdostats --human-readable

  Device                   1K-blocks    Used     Available    Use%    Space saving%
  /dev/mapper/node1osd1    926.5G       21.0G    905.5G       2%      73%
  /dev/mapper/node1osd2    926.5G       28.2G    898.3G       3%      64%
  ```

Additional resources

- The **vdostats(8)** man page.

CHAPTER 2. MAINTAINING VDO

After deploying a VDO volume, you can perform certain tasks to maintain or optimize it. Some of the following tasks are required for the correct functioning of VDO volumes.

Prerequisites

- VDO is installed and deployed. See Chapter 1, *Deploying VDO*.

2.1. MANAGING FREE SPACE ON VDO VOLUMES

VDO is a thinly provisioned block storage target. Because of that, you must actively monitor and manage space usage on VDO volumes.

2.1.1. Thin provisioning in VDO

VDO is a thinly provisioned block storage target. The amount of physical space that a VDO volume uses might differ from the size of the volume that is presented to users of the storage. You can make use of this disparity to save on storage costs.

Out-of-space conditions

Take care to avoid unexpectedly running out of storage space, if the data written does not achieve the expected rate of optimization.

Whenever the number of logical blocks (virtual storage) exceeds the number of physical blocks (actual storage), it becomes possible for file systems and applications to unexpectedly run out of space. For that reason, storage systems using VDO must provide you with a way of monitoring the size of the free pool on the VDO volume.

You can determine the size of this free pool by using the **vdostats** utility. The default output of this utility lists information for all running VDO volumes in a format similar to the Linux **df** utility. For example:

```
Device                1K-blocks   Used        Available   Use%
/dev/mapper/vdo-name  211812352   105906176   105906176   50%
```

When the physical storage capacity of a VDO volume is almost full, VDO reports a warning in the system log, similar to the following:

```
Oct  2 17:13:39 system lvm[13863]: Monitoring VDO pool vdo-name.
Oct  2 17:27:39 system lvm[13863]: WARNING: VDO pool vdo-name is now 80.69% full.
Oct  2 17:28:19 system lvm[13863]: WARNING: VDO pool vdo-name is now 85.25% full.
Oct  2 17:29:39 system lvm[13863]: WARNING: VDO pool vdo-name is now 90.64% full.
Oct  2 17:30:29 system lvm[13863]: WARNING: VDO pool vdo-name is now 96.07% full.
```

NOTE

These warning messages appear only when the **lvm2-monitor** service is running. It is enabled by default.

How to prevent out-of-space conditions

If the size of free pool drops below a certain level, you can take action by:

- Deleting data. This reclaims space whenever the deleted data is not duplicated. Deleting data frees the space only after discards are issued.

- Adding physical storage

IMPORTANT

Monitor physical space on your VDO volumes to prevent out-of-space situations. Running out of physical blocks might result in losing recently written, unacknowledged data on the VDO volume.

Thin provisioning and the TRIM and DISCARD commands

To benefit from the storage savings of thin provisioning, the physical storage layer needs to know when data is deleted. File systems that work with thinly provisioned storage send **TRIM** or **DISCARD** commands to inform the storage system when a logical block is no longer required.

Several methods of sending the **TRIM** or **DISCARD** commands are available:

- With the **discard** mount option, the file systems can send these commands whenever a block is deleted.

- You can send the commands in a controlled manner by using utilities such as **fstrim**. These utilities tell the file system to detect which logical blocks are unused and send the information to the storage system in the form of a **TRIM** or **DISCARD** command.

The need to use **TRIM** or **DISCARD** on unused blocks is not unique to VDO. Any thinly provisioned storage system has the same challenge.

2.1.2. Monitoring VDO

This procedure describes how to obtain usage and efficiency information from a VDO volume.

Prerequisites

- Install the VDO software. See Section 1.4, “Installing VDO”.

Procedure

- Use the **vdostats** utility to get information about a VDO volume:

```
# vdostats --human-readable

Device                1K-blocks   Used    Available   Use%   Space saving%
/dev/mapper/node1osd1   926.5G    21.0G    905.5G      2%      73%
/dev/mapper/node1osd2   926.5G    28.2G    898.3G      3%      64%
```

Additional resources

- The **vdostats(8)** man page.

2.1.3. Reclaiming space for VDO on file systems

This procedure reclaims storage space on a VDO volume that hosts a file system.

VDO cannot reclaim space unless file systems communicate that blocks are free using the **DISCARD**, **TRIM**, or **UNMAP** commands.

Procedure

- If the file system on your VDO volume supports discard operations, enable them. See *Chapter 5, Discarding unused blocks*.
- For file systems that do not use **DISCARD**, **TRIM**, or **UNMAP**, you can manually reclaim free space. Store a file consisting of binary zeros and then delete that file.

2.1.4. Reclaiming space for VDO without a file system

This procedure reclaims storage space on a VDO volume that is used as a block storage target without a file system.

Procedure

- Use the **blkdiscard** utility.
  For example, a single VDO volume can be carved up into multiple subvolumes by deploying LVM on top of it. Before deprovisioning a logical volume, use the **blkdiscard** utility to free the space previously used by that logical volume.

  LVM supports the **REQ_DISCARD** command and forwards the requests to VDO at the appropriate logical block addresses in order to free the space. If you use other volume managers, they also need to support **REQ_DISCARD**, or equivalently, **UNMAP** for SCSI devices or **TRIM** for ATA devices.

Additional resources

- The **blkdiscard(8)** man page

2.1.5. Reclaiming space for VDO on Fibre Channel or Ethernet network

This procedure reclaims storage space on VDO volumes (or portions of volumes) that are provisioned to hosts on a Fibre Channel storage fabric or an Ethernet network using SCSI target frameworks such as LIO or SCST.

Procedure

- SCSI initiators can use the **UNMAP** command to free space on thinly provisioned storage targets, but the SCSI target framework needs to be configured to advertise support for this command. This is typically done by enabling thin provisioning on these volumes.
  Verify support for **UNMAP** on Linux-based SCSI initiators by running the following command:

  ```
  # sg_vpd --page=0xb0 /dev/device
  ```

  In the output, verify that the *Maximum unmap LBA count* value is greater than zero.

2.2. STARTING OR STOPPING VDO VOLUMES

You can start or stop a given VDO volume, or all VDO volumes, and their associated UDS indexes.

2.2.1. Started and activated VDO volumes

During the system boot, the **vdo systemd** unit automatically *starts* all VDO devices that are configured as *activated*.

The **vdo systemd** unit is installed and enabled by default when the **vdo** package is installed. This unit automatically runs the **vdo start --all** command at system startup to bring up all activated VDO volumes.

You can also create a VDO volume that does not start automatically by adding the **--activate=disabled** option to the **vdo create** command.

The starting order

Some systems might place LVM volumes both above VDO volumes and below them. On these systems, it is necessary to start services in the right order:

1. The lower layer of LVM must start first. In most systems, starting this layer is configured automatically when the LVM package is installed.

2. The **vdo systemd** unit must start then.

3. Finally, additional scripts must run in order to start LVM volumes or other services on top of the running VDO volumes.

How long it takes to stop a volume

Stopping a VDO volume takes time based on the speed of your storage device and the amount of data that the volume needs to write:

- The volume always writes around 1GiB for every 1GiB of the UDS index.

- With a sparse UDS index, the volume additionally writes the amount of data equal to the block map cache size plus up to 8MiB per slab.

2.2.2. Starting a VDO volume

This procedure starts a given VDO volume or all VDO volumes on your system.

Procedure

- To start a given VDO volume, use:

  ```
  # vdo start --name=my-vdo
  ```

- To start all VDO volumes, use:

  ```
  # vdo start --all
  ```

Additional resources

- The **vdo(8)** man page

2.2.3. Stopping a VDO volume

This procedure stops a given VDO volume or all VDO volumes on your system.

Procedure

1. Stop the volume.

   - To stop a given VDO volume, use:

     ```
     # vdo stop --name=my-vdo
     ```

   - To stop all VDO volumes, use:

     ```
     # vdo stop --all
     ```

2. Wait for the volume to finish writing data to the disk.

Additional resources

- The **vdo(8)** man page

2.2.4. Related information

- If restarted after an unclean shutdown, VDO performs a rebuild to verify the consistency of its metadata and repairs it if necessary. See Section 2.5, “Recovering a VDO volume after an unclean shutdown” for more information on the rebuild process.

2.3. AUTOMATICALLY STARTING VDO VOLUMES AT SYSTEM BOOT

You can configure VDO volumes so that they start automatically at system boot. You can also disable the automatic start.

2.3.1. Started and activated VDO volumes

During the system boot, the **vdo systemd** unit automatically *starts* all VDO devices that are configured as *activated*.

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- The volume always writes around 1GiB for every 1GiB of the UDS index.
- With a sparse UDS index, the volume additionally writes the amount of data equal to the block map cache size plus up to 8MiB per slab.

2.3.2. Activating a VDO volume

This procedure activates a VDO volume to enable it to start automatically.

Procedure

- To activate a specific volume:

  ```
  # vdo activate --name=my-vdo
  ```

- To activate all volumes:

  ```
  # vdo activate --all
  ```

Additional resources

- The **vdo(8)** man page

2.3.3. Deactivating a VDO volume

This procedure deactivates a VDO volume to prevent it from starting automatically.

Procedure

- To deactivate a specific volume:

  ```
  # vdo deactivate --name=my-vdo
  ```

- To deactivate all volumes:

  ```
  # vdo deactivate --all
  ```

Additional resources

- The **vdo(8)** man page

2.4. SELECTING A VDO WRITE MODE

You can configure write mode for a VDO volume, based on what the underlying block device requires. By default, VDO selects write mode automatically.

2.4.1. VDO write modes

VDO supports the following write modes:

sync

When VDO is in **sync** mode, the layers above it assume that a write command writes data to persistent storage. As a result, it is not necessary for the file system or application, for example, to issue FLUSH or force unit access (FUA) requests to cause the data to become persistent at critical points.

VDO must be set to **sync** mode only when the underlying storage guarantees that data is written to persistent storage when the write command completes. That is, the storage must either have no volatile write cache, or have a write through cache.

async

When VDO is in **async** mode, VDO does not guarantee that the data is written to persistent storage when a write command is acknowledged. The file system or application must issue FLUSH or FUA requests to ensure data persistence at critical points in each transaction.

VDO must be set to **async** mode if the underlying storage does not guarantee that data is written to persistent storage when the write command completes; that is, when the storage has a volatile write back cache.

> **WARNING**
>
> When VDO is running in **async** mode, it is not compliant with Atomicity, Consistency, Isolation, Durability (ACID). When there is an application or a file system that assumes ACID compliance on top of the VDO volume, **async** mode might cause unexpected data loss.

auto

The **auto** mode automatically selects **sync** or **async** based on the characteristics of each device. This is the default option.

2.4.2. The internal processing of VDO write modes

This section provides details on how the **sync** and **async** VDO write modes operate.

If the **kvdo** module is operating in synchronous mode:

1. It temporarily writes the data in the request to the allocated block and then acknowledges the request.

2. Once the acknowledgment is complete, an attempt is made to deduplicate the block by computing a MurmurHash-3 signature of the block data, which is sent to the VDO index.

3. If the VDO index contains an entry for a block with the same signature, **kvdo** reads the indicated block and does a byte-by-byte comparison of the two blocks to verify that they are identical.

4. If they are indeed identical, then **kvdo** updates its block map so that the logical block points to the corresponding physical block and releases the allocated physical block.

5. If the VDO index did not contain an entry for the signature of the block being written, or the indicated block does not actually contain the same data, **kvdo** updates its block map to make the temporary physical block permanent.

If **kvdo** is operating in asynchronous mode:

1. Instead of writing the data, it will immediately acknowledge the request.

2. It will then attempt to deduplicate the block in same manner as described above.

3. If the block turns out to be a duplicate, **kvdo** updates its block map and releases the allocated block. Otherwise, it writes the data in the request to the allocated block and updates the block map to make the physical block permanent.

2.4.3. Checking the write mode on a VDO volume

This procedure lists the active write mode on a selected VDO volume.

Procedure

- Use the following command to see the write mode used by a VDO volume:

  ```
  # vdo status --name=my-vdo
  ```

  The output lists:

  - The *configured write policy*, which is the option selected from **sync**, **async**, or **auto**

  - The *write policy*, which is the particular write mode that VDO applied, that is either **sync** or **async**

2.4.4. Checking for a volatile cache

This procedure determines if a block device has a volatile cache or not. You can use the information to choose between the **sync** and **async** VDO write modes.

Procedure

1. Use either of the following methods to determine if a device has a writeback cache:

   - Read the **/sys/block/*block-device*/device/scsi_disk/*identifier*/cache_type sysfs** file. For example:

     ```
     $ cat '/sys/block/sda/device/scsi_disk/7:0:0:0/cache_type'

     write back
     ```

     ```
     $ cat '/sys/block/sdb/device/scsi_disk/1:2:0:0/cache_type'

     None
     ```

   - Alternatively, you can find whether the above mentioned devices have a write cache or not in the kernel boot log:

```
sd 7:0:0:0: [sda] Write cache: enabled, read cache: enabled, doesn't support DPO or
FUA
sd 1:2:0:0: [sdb] Write cache: disabled, read cache: disabled, supports DPO and FUA
```

2. In the previous examples:

   - Device **sda** indicates that it *has* a writeback cache. Use **async** mode for it.

   - Device **sdb** indicates that it *does not have* a writeback cache. Use **sync** mode for it.

   You should configure VDO to use the **sync** write mode if the **cache_type** value is **None** or **write through**.

2.4.5. Setting a VDO write mode

This procedure sets a write mode for a VDO volume, either for an existing one or when creating a new volume.

IMPORTANT

Using an incorrect write mode might result in data loss after a power failure, a system crash, or any unexpected loss of contact with the disk.

Prerequisites

- Determine which write mode is correct for your device. See Section 2.4.4, "Checking for a volatile cache".

Procedure

- You can set a write mode either on an existing VDO volume or when creating a new volume:

  - To modify an existing VDO volume, use:

    ```
    # vdo changeWritePolicy --writePolicy=sync|async|auto \
                           --name=vdo-name
    ```

  - To specify a write mode when creating a VDO volume, add the **--writePolicy=*sync|async|auto*** option to the **vdo create** command.

2.5. RECOVERING A VDO VOLUME AFTER AN UNCLEAN SHUTDOWN

You can recover a VDO volume after an unclean shutdown to enable it to continue operating. The task is mostly automated. Additionally, you can clean up after a VDO volume was unsuccessfully created because of a failure in the process.

2.5.1. VDO write modes

VDO supports the following write modes:

sync

When VDO is in **sync** mode, the layers above it assume that a write command writes data to persistent storage. As a result, it is not necessary for the file system or application, for example, to issue FLUSH or force unit access (FUA) requests to cause the data to become persistent at critical points.

VDO must be set to **sync** mode only when the underlying storage guarantees that data is written to persistent storage when the write command completes. That is, the storage must either have no volatile write cache, or have a write through cache.

async

When VDO is in **async** mode, VDO does not guarantee that the data is written to persistent storage when a write command is acknowledged. The file system or application must issue FLUSH or FUA requests to ensure data persistence at critical points in each transaction.

VDO must be set to **async** mode if the underlying storage does not guarantee that data is written to persistent storage when the write command completes; that is, when the storage has a volatile write back cache.

WARNING

When VDO is running in **async** mode, it is not compliant with Atomicity, Consistency, Isolation, Durability (ACID). When there is an application or a file system that assumes ACID compliance on top of the VDO volume, **async** mode might cause unexpected data loss.

auto

The **auto** mode automatically selects **sync** or **async** based on the characteristics of each device. This is the default option.

2.5.2. VDO volume recovery

When a VDO volume restarts after an unclean shutdown, VDO performs the following actions:

- Verifies the consistency of the metadata on the volume.
- Rebuilds a portion of the metadata to repair it if necessary.

Rebuilds are automatic and do not require user intervention.

VDO might rebuild different writes depending on the active write mode:

sync

If VDO was running on synchronous storage and write policy was set to **sync**, all data written to the volume are fully recovered.

async

If the write policy was **async**, some writes might not be recovered if they were not made durable. This is done by sending VDO a **FLUSH** command or a write I/O tagged with the FUA (force unit access) flag. You can accomplish this from user mode by invoking a data integrity operation like **fsync**, **fdatasync**, **sync**, or **umount**.

In either mode, some writes that were either unacknowledged or not followed by a flush might also be rebuilt.

Automatic and manual recovery

When a VDO volume enters **recovering** operating mode, VDO automatically rebuilds the unclean VDO volume after the it comes back online. This is called *online recovery*.

If VDO cannot recover a VDO volume successfully, it places the volume in **read-only** operating mode that persists across volume restarts. You need to fix the problem manually by forcing a rebuild.

Additional resources

- For more information on automatic and manual recovery and VDO operating modes, see Section 2.5.3, “VDO operating modes”.

2.5.3. VDO operating modes

This section describes the modes that indicate whether a VDO volume is operating normally or is recovering from an error.

You can display the current operating mode of a VDO volume using the **vdostats --verbose *device*** command. See the *Operating mode* attribute in the output.

normal

This is the default operating mode. VDO volumes are always in **normal** mode, unless either of the following states forces a different mode. A newly created VDO volume starts in **normal** mode.

recovering

When a VDO volume does not save all of its metadata before shutting down, it automatically enters **recovering** mode the next time that it starts up. The typical reasons for entering this mode are sudden power loss or a problem from the underlying storage device.
In **recovering** mode, VDO is fixing the references counts for each physical block of data on the device. Recovery usually does not take very long. The time depends on how large the VDO volume is, how fast the underlying storage device is, and how many other requests VDO is handling simultaneously. The VDO volume functions normally with the following exceptions:

- Initially, the amount of space available for write requests on the volume might be limited. As more of the metadata is recovered, more free space becomes available.

- Data written while the VDO volume is recovering might fail to deduplicate against data written before the crash if that data is in a portion of the volume that has not yet been recovered. VDO can compress data while recovering the volume. You can still read or overwrite compressed blocks.

- During an online recovery, certain statistics are unavailable: for example, *blocks in use* and *blocks free*. These statistics become available when the rebuild is complete.

- Response times for reads and writes might be slower than usual due to the ongoing recovery work

You can safely shut down the VDO volume in **recovering** mode. If the recovery does not finish before shutting down, the device enters **recovering** mode again the next time that it starts up.

The VDO volume automatically exits **recovering** mode and moves to **normal** mode when it has fixed all the reference counts. No administrator action is necessary. For details, see Section 2.5.4, “Recovering a VDO volume online”.

read-only

When a VDO volume encounters a fatal internal error, it enters **read-only** mode. Events that might cause **read-only** mode include metadata corruption or the backing storage device becoming read-only. This mode is an error state.
In **read-only** mode, data reads work normally but data writes always fail. The VDO volume stays in **read-only** mode until an administrator fixes the problem.

You can safely shut down a VDO volume in **read-only** mode. The mode usually persists after the VDO volume is restarted. In rare cases, the VDO volume is not able to record the **read-only** state to the backing storage device. In these cases, VDO attempts to do a recovery instead.

Once a volume is in read-only mode, there is no guarantee that data on the volume has not been lost or corrupted. In such cases, Red Hat recommends copying the data out of the read-only volume and possibly restoring the volume from backup.

If the risk of data corruption is acceptable, it is possible to force an offline rebuild of the VDO volume metadata so the volume can be brought back online and made available. The integrity of the rebuilt data cannot be guaranteed. For details, see Section 2.5.5, “Forcing an offline rebuild of a VDO volume metadata”.

2.5.4. Recovering a VDO volume online

This procedure performs an online recovery on a VDO volume to recover metadata after an unclean shutdown.

Procedure

1. If the VDO volume is not already started, start it:

   ```
   # vdo start --name=my-vdo
   ```

   No additional steps are necessary. The recovery runs in the background.

2. If you rely on volume statistics like *blocks in use* and *blocks free*, wait until they are available.

2.5.5. Forcing an offline rebuild of a VDO volume metadata

This procedure performs a forced offline rebuild of a VDO volume metadata to recover after an unclean shutdown.

> **WARNING**
>
> This procedure might cause data loss on the volume.

Prerequisites

- The VDO volume is started.

Procedure

1. Check if the volume is in read-only mode. See the *operating mode* attribute in the command output:

   ```
   # vdo status --name=my-vdo
   ```

   If the volume is not in read-only mode, it is not necessary to force an offline rebuild. Perform an online recovery as described in Section 2.5.4, “Recovering a VDO volume online” .

2. Stop the volume if it is running:

   ```
   # vdo stop --name=my-vdo
   ```

3. Restart the volume with the **--forceRebuild** option:

   ```
   # vdo start --name=my-vdo --forceRebuild
   ```

2.5.6. Removing an unsuccessfully created VDO volume

This procedure cleans up a VDO volume in an intermediate state. A volume is left in an intermediate state if a failure occurs when creating the volume. This might happen when, for example:

- The system crashes
- Power fails
- The administrator interrupts a running **vdo create** command

Procedure

- To clean up, remove the unsuccessfully created volume with the **--force** option:

  ```
  # vdo remove --force --name=my-vdo
  ```

  The **--force** option is required because the administrator might have caused a conflict by changing the system configuration since the volume was unsuccessfully created.

  Without the **--force** option, the **vdo remove** command fails with the following message:

  ```
  [...]
  A previous operation failed.
  Recovery from the failure either failed or was interrupted.
  Add '--force' to 'remove' to perform the following cleanup.
  Steps to clean up VDO my-vdo:
  umount -f /dev/mapper/my-vdo
  udevadm settle
  dmsetup remove my-vdo
  vdo: ERROR - VDO volume my-vdo previous operation (create) is incomplete
  ```

2.6. OPTIMIZING THE UDS INDEX

You can configure certain settings of the UDS index to optimize it on your system.

IMPORTANT

You cannot change the properties of the UDS index *after* creating the VDO volume.

2.6.1. The UDS index

VDO uses a high-performance deduplication index called UDS to detect duplicate blocks of data as they are being stored.

The UDS index provides the foundation of the VDO product. For each new piece of data, it quickly determines if that piece is identical to any previously stored piece of data. If the index finds match, the storage system can then internally reference the existing item to avoid storing the same information more than once.

The UDS index runs inside the kernel as the **uds** kernel module.

The *deduplication window* is the number of previously written blocks that the index remembers. The size of the deduplication window is configurable. For a given window size, the index requires a specific amount of RAM and a specific amount of disk space. The size of the window is usually determined by specifying the size of the index memory using the **--indexMem=size** option. VDO then determines the amount of disk space to use automatically.

The UDS index consists of two parts:

- A compact representation is used in memory that contains at most one entry per unique block.
- An on-disk component that records the associated block names presented to the index as they occur, in order.

UDS uses an average of 4 bytes per entry in memory, including cache.

The on-disk component maintains a bounded history of data passed to UDS. UDS provides deduplication advice for data that falls within this deduplication window, containing the names of the most recently seen blocks. The deduplication window allows UDS to index data as efficiently as possible while limiting the amount of memory required to index large data repositories. Despite the bounded nature of the deduplication window, most datasets which have high levels of deduplication also exhibit a high degree of temporal locality — in other words, most deduplication occurs among sets of blocks that were written at about the same time. Furthermore, in general, data being written is more likely to duplicate data that was recently written than data that was written a long time ago. Therefore, for a given workload over a given time interval, deduplication rates will often be the same whether UDS indexes only the most recent data or all the data.

Because duplicate data tends to exhibit temporal locality, it is rarely necessary to index every block in the storage system. Were this not so, the cost of index memory would outstrip the savings of reduced storage costs from deduplication. Index size requirements are more closely related to the rate of data ingestion. For example, consider a storage system with 100 TB of total capacity but with an ingestion rate of 1 TB per week. With a deduplication window of 4 TB, UDS can detect most redundancy among the data written within the last month.

2.6.2. Recommended UDS index configuration

This section describes the recommended options to use with the UDS index, based on your intended use case.

In general, Red Hat recommends using a **sparse** UDS index for all production use cases. This is an extremely efficient indexing data structure, requiring approximately one-tenth of a byte of RAM per block in its deduplication window. On disk, it requires approximately 72 bytes of disk space per block. The minimum configuration of this index uses 256 MB of RAM and approximately 25 GB of space on disk.

To use this configuration, specify the **--sparseIndex=enabled --indexMem=0.25** options to the **vdo create** command. This configuration results in a deduplication window of 2.5 TB (meaning it will remember a history of 2.5 TB). For most use cases, a deduplication window of 2.5 TB is appropriate for deduplicating storage pools that are up to 10 TB in size.

The default configuration of the index, however, is to use a **dense** index. This index is considerably less efficient (by a factor of 10) in RAM, but it has much lower (also by a factor of 10) minimum required disk space, making it more convenient for evaluation in constrained environments.

In general, a deduplication window that is one quarter of the physical size of a VDO volume is a recommended configuration. However, this is not an actual requirement. Even small deduplication windows (compared to the amount of physical storage) can find significant amounts of duplicate data in many use cases. Larger windows may also be used, but it in most cases, there will be little additional benefit to doing so.

Additional resources

- Speak with your Red Hat Technical Account Manager representative for additional guidelines on tuning this important system parameter.

2.7. ENABLING OR DISABLING DEDUPLICATION IN VDO

In some instances, you might want to temporarily disable deduplication of data being written to a VDO volume while still retaining the ability to read to and write from the volume. Disabling deduplication prevents subsequent writes from being deduplicated, but the data that was already deduplicated remains so.

2.7.1. Deduplication in VDO

Deduplication is a technique for reducing the consumption of storage resources by eliminating multiple copies of duplicate blocks.

Instead of writing the same data more than once, VDO detects each duplicate block and records it as a reference to the original block. VDO maintains a mapping from logical block addresses, which are used by the storage layer above VDO, to physical block addresses, which are used by the storage layer under VDO.

After deduplication, multiple logical block addresses can be mapped to the same physical block address. These are called shared blocks. Block sharing is invisible to users of the storage, who read and write blocks as they would if VDO were not present.

When a shared block is overwritten, VDO allocates a new physical block for storing the new block data to ensure that other logical block addresses that are mapped to the shared physical block are not modified.

2.7.2. Enabling deduplication on a VDO volume

This procedure restarts the associated UDS index and informs the VDO volume that deduplication is active again.

NOTE

Deduplication is enabled by default.

Procedure

- To restart deduplication on a VDO volume, use the following command:

```
# vdo enableDeduplication --name=my-vdo
```

2.7.3. Disabling deduplication on a VDO volume

This procedure stops the associated UDS index and informs the VDO volume that deduplication is no longer active.

Procedure

- To stop deduplication on a VDO volume, use the following command:

```
# vdo disableDeduplication --name=my-vdo
```

- You can also disable deduplication when creating a new VDO volume by adding the **--deduplication=disabled** option to the **vdo create** command.

2.8. ENABLING OR DISABLING COMPRESSION IN VDO

VDO provides data compression. You can disable it to maximize performance or to speed processing of data that is unlikely to compress, or re-enable it to increase space savings.

2.8.1. Compression in VDO

In addition to block-level deduplication, VDO also provides inline block-level compression using the HIOPS Compression™ technology.

VDO volume compression is on by default.

While deduplication is the optimal solution for virtual machine environments and backup applications, compression works very well with structured and unstructured file formats that do not typically exhibit block-level redundancy, such as log files and databases.

Compression operates on blocks that have not been identified as duplicates. When VDO sees unique data for the first time, it compresses the data. Subsequent copies of data that have already been stored are deduplicated without requiring an additional compression step.

The compression feature is based on a parallelized packaging algorithm that enables it to handle many compression operations at once. After first storing the block and responding to the requestor, a best-fit packing algorithm finds multiple blocks that, when compressed, can fit into a single physical block. After it is determined that a particular physical block is unlikely to hold additional compressed blocks, it is written to storage and the uncompressed blocks are freed and reused.

By performing the compression and packaging operations after having already responded to the requestor, using compression imposes a minimal latency penalty.

2.8.2. Enabling compression on a VDO volume

This procedure enables compression on a VDO volume to increase space savings.

NOTE

Compression is enabled by default.

Procedure

- To start it again, use the following command:

```
# vdo enableCompression --name=my-vdo
```

2.8.3. Disabling compression on a VDO volume

This procedure stops compression on a VDO volume to maximize performance or to speed processing of data that is unlikely to compress.

Procedure

- To stop compression on an existing VDO volume, use the following command:

```
# vdo disableCompression --name=my-vdo
```

- Alternatively, you can disable compression by adding the **--compression=disabled** option to the **vdo create** command when creating a new volume.

2.9. INCREASING THE SIZE OF A VDO VOLUME

You can increase the physical size of a VDO volume to utilize more underlying storage capacity, or the logical size to provide more capacity on the volume.

2.9.1. Thin provisioning in VDO

VDO is a thinly provisioned block storage target. The amount of physical space that a VDO volume uses might differ from the size of the volume that is presented to users of the storage. You can make use of this disparity to save on storage costs.

Out-of-space conditions

Take care to avoid unexpectedly running out of storage space, if the data written does not achieve the expected rate of optimization.

Whenever the number of logical blocks (virtual storage) exceeds the number of physical blocks (actual storage), it becomes possible for file systems and applications to unexpectedly run out of space. For that reason, storage systems using VDO must provide you with a way of monitoring the size of the free pool on the VDO volume.

You can determine the size of this free pool by using the **vdostats** utility. The default output of this utility lists information for all running VDO volumes in a format similar to the Linux **df** utility. For example:

```
Device              1K-blocks   Used       Available   Use%
/dev/mapper/vdo-name  211812352   105906176   105906176   50%
```

When the physical storage capacity of a VDO volume is almost full, VDO reports a warning in the system log, similar to the following:

```
Oct  2 17:13:39 system lvm[13863]: Monitoring VDO pool vdo-name.
Oct  2 17:27:39 system lvm[13863]: WARNING: VDO pool vdo-name is now 80.69% full.
Oct  2 17:28:19 system lvm[13863]: WARNING: VDO pool vdo-name is now 85.25% full.
Oct  2 17:29:39 system lvm[13863]: WARNING: VDO pool vdo-name is now 90.64% full.
Oct  2 17:30:29 system lvm[13863]: WARNING: VDO pool vdo-name is now 96.07% full.
```

NOTE

These warning messages appear only when the **lvm2-monitor** service is running. It is enabled by default.

How to prevent out-of-space conditions

If the size of free pool drops below a certain level, you can take action by:

- Deleting data. This reclaims space whenever the deleted data is not duplicated. Deleting data frees the space only after discards are issued.
- Adding physical storage

IMPORTANT

Monitor physical space on your VDO volumes to prevent out-of-space situations. Running out of physical blocks might result in losing recently written, unacknowledged data on the VDO volume.

Thin provisioning and the TRIM and DISCARD commands

To benefit from the storage savings of thin provisioning, the physical storage layer needs to know when data is deleted. File systems that work with thinly provisioned storage send **TRIM** or **DISCARD** commands to inform the storage system when a logical block is no longer required.

Several methods of sending the **TRIM** or **DISCARD** commands are available:

- With the **discard** mount option, the file systems can send these commands whenever a block is deleted.
- You can send the commands in a controlled manner by using utilities such as **fstrim**. These utilities tell the file system to detect which logical blocks are unused and send the information to the storage system in the form of a **TRIM** or **DISCARD** command.

The need to use **TRIM** or **DISCARD** on unused blocks is not unique to VDO. Any thinly provisioned storage system has the same challenge.

2.9.2. Increasing the logical size of a VDO volume

This procedure increases the logical size of a given VDO volume. It enables you to initially create VDO volumes that have a logical size small enough to be safe from running out of space. After some period of time, you can evaluate the actual rate of data reduction, and if sufficient, you can grow the logical size of the VDO volume to take advantage of the space savings.

It is not possible to decrease the logical size of a VDO volume.

Procedure

- To grow the logical size, use:

  ```
  # vdo growLogical --name=my-vdo \
                  --vdoLogicalSize=new-logical-size
  ```

  When the logical size increases, VDO informs any devices or file systems on top of the volume of the new size.

2.9.3. Increasing the physical size of a VDO volume

This procedure increases the amount of physical storage available to a VDO volume.

It is not possible to shrink a VDO volume in this way.

Prerequisites

- The underlying block device has a larger capacity than the current physical size of the VDO volume.
  If it does not, you can attempt to increase the size of the device. The exact procedure depends on the type of the device. For example, to resize an MBR or GPT partition, see the Resizing a partition section in the *Managing storage devices* guide.

Procedure

- Add the new physical storage space to the VDO volume:

  ```
  # vdo growPhysical --name=my-vdo
  ```

2.10. REMOVING VDO VOLUMES

You can remove an existing VDO volume on your system.

2.10.1. Removing a working VDO volume

This procedure removes a VDO volume and its associated UDS index.

Procedure

1. Unmount the file systems and stop the applications that are using the storage on the VDO volume.

2. To remove the VDO volume from your system, use:

   ```
   # vdo remove --name=my-vdo
   ```

2.10.2. Removing an unsuccessfully created VDO volume

This procedure cleans up a VDO volume in an intermediate state. A volume is left in an intermediate state if a failure occurs when creating the volume. This might happen when, for example:

- The system crashes
- Power fails
- The administrator interrupts a running **vdo create** command

Procedure

- To clean up, remove the unsuccessfully created volume with the **--force** option:

  ```
  # vdo remove --force --name=my-vdo
  ```

  The **--force** option is required because the administrator might have caused a conflict by changing the system configuration since the volume was unsuccessfully created.

  Without the **--force** option, the **vdo remove** command fails with the following message:

  ```
  [...]
  A previous operation failed.
  Recovery from the failure either failed or was interrupted.
  Add '--force' to 'remove' to perform the following cleanup.
  Steps to clean up VDO my-vdo:
  umount -f /dev/mapper/my-vdo
  udevadm settle
  dmsetup remove my-vdo
  vdo: ERROR - VDO volume my-vdo previous operation (create) is incomplete
  ```

2.11. RELATED INFORMATION

- You can use the **Ansible** tool to automate VDO deployment and administration. For details, see:
  - Ansible documentation: https://docs.ansible.com/
  - VDO Ansible module documentation: https://docs.ansible.com/ansible/latest/modules/vdo_module.html

CHAPTER 3. TESTING VDO SPACE SAVINGS

You can perform a series of tests to determine how much storage space you can save by using VDO.

Prerequisites

- One or more physical block devices are available.
- The target block device is larger than 512 GiB.
- VDO is installed.

3.1. THE PURPOSE AND OUTCOMES OF TESTING VDO

VDO tests provided by Red Hat help produce an assessment of the integration of VDO into existing storage devices. They are intended to augment, not replace, your internal evaluation efforts.

The test results help Red Hat engineers to assist you in understanding VDO behavior in specific storage environments. Original equipment manufacturers (OEMs) can learn how to design their deduplication and compression capable devices, and how their customers can tune their applications for those devices.

Goals

- Identify configuration settings that elicit optimal responses from the test device.
- Explain basic tuning parameters to help avoid product misconfigurations.
- Create a reference of performance results to compare with real use cases.
- Identify how different workloads affect performance and data efficiency.
- Shorten the time to market with VDO implementations.

The test plan and test conditions

The VDO tests provide conditions under which VDO can be most realistically evaluated. Altering test procedures or parameters might invalidate results. Red Hat sales engineers can guide you when modifying test plans.

For an effective test plan, you must study the VDO architecture and explore these items:

- The performance in high-load environments
- The configurable properties of VDO for performance tuning end-user applications
- The impact of VDO being a native 4 KiB block device
- The response to access patterns and distributions of deduplication and compression
- The value of cost versus capacity versus performance for a given application

3.2. THIN PROVISIONING IN VDO

VDO is a thinly provisioned block storage target. The amount of physical space that a VDO volume uses might differ from the size of the volume that is presented to users of the storage. You can make use of this disparity to save on storage costs.

Out-of-space conditions

Take care to avoid unexpectedly running out of storage space, if the data written does not achieve the expected rate of optimization.

Whenever the number of logical blocks (virtual storage) exceeds the number of physical blocks (actual storage), it becomes possible for file systems and applications to unexpectedly run out of space. For that reason, storage systems using VDO must provide you with a way of monitoring the size of the free pool on the VDO volume.

You can determine the size of this free pool by using the **vdostats** utility. The default output of this utility lists information for all running VDO volumes in a format similar to the Linux **df** utility. For example:

```
Device                1K-blocks   Used        Available   Use%
/dev/mapper/vdo-name  211812352   105906176   105906176   50%
```

When the physical storage capacity of a VDO volume is almost full, VDO reports a warning in the system log, similar to the following:

```
Oct  2 17:13:39 system lvm[13863]: Monitoring VDO pool vdo-name.
Oct  2 17:27:39 system lvm[13863]: WARNING: VDO pool vdo-name is now 80.69% full.
Oct  2 17:28:19 system lvm[13863]: WARNING: VDO pool vdo-name is now 85.25% full.
Oct  2 17:29:39 system lvm[13863]: WARNING: VDO pool vdo-name is now 90.64% full.
Oct  2 17:30:29 system lvm[13863]: WARNING: VDO pool vdo-name is now 96.07% full.
```

NOTE

These warning messages appear only when the **lvm2-monitor** service is running. It is enabled by default.

How to prevent out-of-space conditions

If the size of free pool drops below a certain level, you can take action by:

- Deleting data. This reclaims space whenever the deleted data is not duplicated. Deleting data frees the space only after discards are issued.
- Adding physical storage

IMPORTANT

Monitor physical space on your VDO volumes to prevent out-of-space situations. Running out of physical blocks might result in losing recently written, unacknowledged data on the VDO volume.

Thin provisioning and the TRIM and DISCARD commands

To benefit from the storage savings of thin provisioning, the physical storage layer needs to know when data is deleted. File systems that work with thinly provisioned storage send **TRIM** or **DISCARD** commands to inform the storage system when a logical block is no longer required.

Several methods of sending the **TRIM** or **DISCARD** commands are available:

- With the **discard** mount option, the file systems can send these commands whenever a block is deleted.

- You can send the commands in a controlled manner by using utilities such as **fstrim**. These utilities tell the file system to detect which logical blocks are unused and send the information to the storage system in the form of a **TRIM** or **DISCARD** command.

The need to use **TRIM** or **DISCARD** on unused blocks is not unique to VDO. Any thinly provisioned storage system has the same challenge.

3.3. INFORMATION TO RECORD BEFORE EACH VDO TEST

You must record the following information at the start of each test to ensure that the test environment is fully understood. You can capture much of the required information by using the **sosreport** utility.

Required information

- The used Linux build, including the kernel build number
- The complete list of installed packages, as obtained from the **rpm -qa** command
- Complete system specifications
  - CPU type and quantity; available in the **/proc/cpuinfo** file
  - Installed memory and the amount available after the rase OS is running; available in the **/proc/meminfo** file
  - Types of used drive controllers
  - Types and quantity of used disks
- A complete list of running processes; available from the **ps aux** command or a similar listing
- Name of the physical volume and the volume group created for use with VDO; available from the **pvs** and **vgs** commands
- File system used when formatting the VDO volume, if any
- Permissions on the mounted directory
- Content of the **/etc/vdoconf.yaml** file
- Location of the VDO files

3.4. CREATING A VDO TEST VOLUME

This procedure creates a VDO volume with a logical size of 1 TiB on a 512 GiB physical volume for testing purposes.

Procedure

1. Create a VDO volume:

```
# vdo create --name=vdo-test \
             --device=/dev/sdb \
             --vdoLogicalSize=1T \
            --writePolicy=policy \
            --verbose
```

- Replace ***/dev/sdb*** with the path to a block device.
- To test the VDO **async** mode on top of asynchronous storage, create an asynchronous volume using the **--writePolicy=async** option.
- To test the VDO **sync** mode on top of synchronous storage, create a synchronous volume using the **--writePolicy=sync** option.

2. Format the new volume with an XFS or ext4 file system.
   - For XFS:

     ```
     # mkfs.xfs -K /dev/mapper/vdo-test
     ```

   - For ext4:

     ```
     # mkfs.ext4 -E nodiscard /dev/mapper/vdo-test
     ```

3. Mount the formatted volume:

   ```
   # mkdir /mnt/vdo-test

   # mount /dev/mapper/vdo-test /mnt/vdo-test && \
     chmod a+rwx /mnt/vdo-test
   ```

3.5. TESTING THE VDO TEST VOLUME

This procedure tests whether reading and writing to the VDO test volume works.

Prerequisites

- A newly created VDO test volume is mounted. For details, see Section 3.4, “Creating a VDO test volume”.

Procedure

1. Write 32 GiB of random data to the VDO volume:

   ```
   $ dd if=/dev/urandom of=/mnt/vdo-test/testfile bs=4096 count=8388608
   ```

2. Read the data from the VDO volume and write it to another volume:

   ```
   $ dd if=/mnt/vdo-test/testfile of=another-location/testfile bs=4096
   ```

   - Replace *another-location* with any directory where you have write access that is not on the VDO test volume. For example, you can use your home directory.

3. Compare the two files:

   ```
   $ diff --report-identical-files /mnt/vdo-test/testfile another-location/testfile
   ```

The command should report that the files are the same.

4. Copy the file back to a new location on the VDO volume:

```
$ dd if=another-location/testfile of=/mnt/vdo-test/testfile2 bs=4096
```

5. Compare the third file to the second file:

```
$ diff --report-identical-files /mnt/vdo-test/testfile2 another-location/testfile
```

The command should report that the files are the same.

Cleanup steps

- Remove the VDO test volume as described in Section 3.6, "Cleaning up the VDO test volume".

3.6. CLEANING UP THE VDO TEST VOLUME

This procedure removes the VDO volume used for testing VDO efficiency from the system.

Prerequisites

- A VDO test volume is mounted.

Procedure

1. Unmount the file system created on the VDO volume:

```
# umount /mnt/vdo-test
```

2. Remove the VDO test volume from the system:

```
# vdo remove --name=vdo-test
```

Verification steps

- Verify that the volume has been removed:

```
# vdo list --all | grep vdo-test
```

The command should not list the VDO test partition.

3.7. MEASURING VDO DEDUPLICATION

This procedure tests the efficiency of VDO data deduplication on a VDO test volume.

Prerequisites

- A newly created VDO test volume is mounted. For details, see Section 3.4, "Creating a VDO test volume".

Procedure

1. Prepare a table where you can record the test results:

Statistic	Bare file system	After seed	After 10 copies
File system used size			
VDO data used			
VDO logical used			

2. Create 10 directories on the VDO volume to hold 10 copies of the test data set:

```
$ mkdir /mnt/vdo-test/vdo{01..10}
```

3. Examine the disk usage reported by the file system:

```
$ df --human-readable /mnt/vdo-test
```

Example 3.1. Disk usage

```
Filesystem            Size  Used Avail Use% Mounted on
/dev/mapper/vdo-test  1.5T  198M  1.4T   1% /mnt/vdo-test
```

4. Record the following values:

```
# vdostats --verbose | grep "blocks used"
```

Example 3.2. Used blocks

```
data blocks used                : 1090
overhead blocks used              : 538846
logical blocks used             : 6059434
```

- The **data blocks used** value is the number of blocks used by user data after optimization on the physical device running under VDO.

- The **logical blocks used** value is the number of blocks used before optimization. It will be used as the starting point for measurements.

5. Create a data source file on the VDO volume:

```
$ dd if=/dev/urandom of=/mnt/vdo-test/sourcefile bs=4096 count=1048576

4294967296 bytes (4.3 GB) copied, 540.538 s, 7.9 MB/s
```

6. Re-examine the amount of used physical disk space:

```
$ df --human-readable /mnt/vdo-test
```

Example 3.3. Disk usage with the data source file

```
Filesystem            Size  Used Avail Use% Mounted on
/dev/mapper/vdo-test  1.5T  4.2G  1.4T   1% /mnt/vdo-test
```

```
# vdostats --verbose | grep "blocks used"
```

Example 3.4. Used blocks with the data source file

```
data blocks used                : 1050093  # Increased by 4GiB
overhead blocks used            : 538846   # Did not significantly change
logical blocks used             : 7108036  # Increased by 4GiB
```

This command should show an increase in the number of blocks used, corresponding to the size of the written file.

7. Copy the file to each of the 10 subdirectories:

```
$ for i in {01..10}; do
  cp /mnt/vdo-test/sourcefile /mnt/vdo-test/vdo$i
  done
```

8. Re-examine the amount of used physical disk space:

```
$ df -h /mnt/vdo-test
```

Example 3.5. Disk usage after copying the file

```
Filesystem            Size  Used Avail Use% Mounted on
/dev/mapper/vdo-test  1.5T   45G  1.3T   4% /mnt/vdo-test
```

```
# vdostats --verbose | grep "blocks used"
```

Example 3.6. Used blocks after copying the file

```
data blocks used                : 1050836   # Increased by 3 MiB
overhead blocks used            : 538846
logical blocks used             : 17594127  # Increased by 41 GiB
```

The **data blocks used** value should be similar to the result of the earlier listing, with only a slight increase due to file system journaling and metadata.

9. Subtract this new value of the space used by the file system from the value found before writing the test data. This is the amount of space consumed by this test from the perspective of the file system.

10. Observe the space savings in your recorded statistics:

Example 3.7. Recorded values

Statistic	Bare file system	After seed	After 10 copies
File system used size	198 MiB	4.2 GiB	45 GiB
VDO data used	4 MiB	4.1 GiB	4.1 GiB
VDO logical used	23.6 GiB *(file system overhead for 1.6 TiB formatted drive)*	27.8 GiB	68.7 GiB

NOTE

In the table, values have been converted to MiB or GiB. Blocks in the **vdostats** output are 4,096 B in size.

Cleanup steps

- Remove the VDO test volume as described in Section 3.6, "Cleaning up the VDO test volume".

3.8. MEASURING VDO COMPRESSION

This procedure tests the efficiency of VDO data compression on a VDO test volume.

Prerequisites

- A newly created VDO test volume is mounted. For details, see Section 3.4, "Creating a VDO test volume".

Procedure

1. Disable deduplication and enable compression on the VDO test volume:

```
# vdo disableDeduplication --name=vdo-test
# vdo enableCompression --name=vdo-test
```

2. Synchronize the VDO volume to complete any unfinished compression:

```
# sync && dmsetup message vdo-test 0 sync-dedupe
```

3. Inspect VDO statistics before the transfer:

```
# vdostats --verbose | grep "blocks used"
```

Make note of the **data blocks used** and **logical blocks used** values.

4. VDO optimizes file system overhead as well as actual user data. Calculate the number of 4 KiB blocks saved by compression for the empty file system as **logical blocks used** minus **data blocks used**.

5. Copy the content of the **/lib** directory to the VDO volume:

   ```
   # cp --verbose --recursive /lib /mnt/vdo-test

   ...
   sent 152508960 bytes  received 60448 bytes  61027763.20 bytes/sec
   total size is 152293104  speedup is 1.00
   ```

   Record the total size of the copied data.

6. Synchronize Linux caches and the VDO volume:

   ```
   # sync && dmsetup message vdo-test 0 sync-dedupe
   ```

7. Inspect VDO statistics again:

   ```
   # vdostats --verbose | grep "blocks used"
   ```

   Observe the **logical blocks used** and **data blocks used** values.

8. Calculate the amount of bytes saved by compression using the following formula:

   ```
   saved_bytes = (logical_blocks_used - data_blocks_used) * 4096
   ```

Cleanup steps

- Remove the VDO test volume as described in Section 3.6, “Cleaning up the VDO test volume”.

3.9. MEASURING TOTAL VDO SPACE SAVINGS

This procedure tests the combined efficiency of VDO data deduplication and compression on a VDO test volume.

Procedure

1. Create and mount a VDO volume as described in Section 3.4, “Creating a VDO test volume” .

2. Perform the tests described in] and xref:measuring-vdo-compression_testing-vdo-space-savings[on the same volume without removing it. Observe changes to space savings in the **vdostats** output.

3. Experiment with your own datasets.

3.10. TESTING THE EFFECT OF TRIM AND DISCARD ON VDO

This procedure tests whether the **TRIM** and **DISCARD** commands properly free up blocks from deleted files on a VDO test volume. It demonstrates that discards inform VDO that the space is no longer used.

Prerequisites

- A newly created VDO test volume is mounted. For details, see Section 3.4, "Creating a VDO test volume".

Procedure

1. Prepare a table where you can record the test results:

Step	File space used (MB)	Data blocks used	Logical blocks used
Initial			
Add 1 GiB file			
Run **fstrim**			
Delete 1 GiB file			
Run **fstrim**			

2. Trim the file system to remove unneeded blocks:

```
# fstrim /mnt/vdo-test
```

The command might take a long time.

3. Record the initial space usage in the file system:

```
$ df -m /mnt/vdo-test
```

4. See how many physical and logical data blocks the VDO volume uses:

```
# vdostats --verbose | grep "blocks used"
```

5. Create a 1 GiB file with non-duplicate data on the VDO volume:

```
$ dd if=/dev/urandom of=/mnt/vdo-test/file bs=1M count=1K
```

6. Record the space usage again:

```
$ df -m /mnt/vdo-test

# vdostats --verbose | grep "blocks used"
```

The file system should use an additional 1 GiB. The **data blocks used** and **logical blocks used** values should increase similarly.

7. Trim the file system again:

```
# fstrim /mnt/vdo-test
```

8. Inspect the space usage again to confirm that the trim had no impact on the physical volume usage:

   ```
   $ df -m /mnt/vdo-test

   # vdostats --verbose | grep "blocks used"
   ```

9. Delete the 1 GiB file:

   ```
   $ rm /mnt/vdo-test/file
   ```

10. Check and record the space usage again:

    ```
    $ df -m /mnt/vdo-test

    # vdostats --verbose | grep "blocks used"
    ```

    The file system is aware that a file has been deleted, but there is no change to the number of physical or logical blocks because the file deletion has not been communicated to the underlying storage.

11. Trim the file system again:

    ```
    # fstrim /mnt/vdo-test
    ```

12. Check and record the space usage again:

    ```
    $ df -m /mnt/vdo-test

    # vdostats --verbose | grep "blocks used"
    ```

    The **fstrim** utility looks for free blocks in the file system and sends a **TRIM** command to the VDO volume for unused addresses, which releases the associated logical blocks. VDO processes the **TRIM** command to release the underlying physical blocks.

Additional resources

- For more information on the **TRIM** and **DISCARD** commands, the **fstrim** utility, and the **discard** mount option, see Chapter 5, *Discarding unused blocks*

CHAPTER 4. TESTING VDO PERFORMANCE

You can perform a series of tests to measure VDO performance, obtain a performance profile of your system with VDO, and determine which applications perform well with VDO.

Prerequisites

- One or more Linux physical block devices are available.
- The target block device (for example, **/dev/sdb**) is larger than 512 GiB.
- Flexible I/O Tester (**fio**) is installed.
- VDO is installed.

4.1. PREPARING AN ENVIRONMENT FOR VDO PERFORMANCE TESTING

Before testing VDO performance, you must consider the host system configuration, VDO configuration, and the workloads that will be used during testing. These choices affect the benchmarking of space efficiency, bandwidth, and latency.

To prevent one test from affecting the results of another, you must create a new VDO volume for each iteration of each test.

4.1.1. Considerations before testing VDO performance

The following conditions and configurations affect the VDO test results:

System configuration

- Number and type of CPU cores available. You can list this information using the **taskset** utility.
- Available memory and total installed memory
- Configuration of storage devices
- Active disk scheduler
- Linux kernel version
- Packages installed

VDO configuration

- Partitioning scheme
- File systems used on VDO volumes
- Size of the physical storage assigned to a VDO volume
- Size of the logical VDO volume created
- Sparse or dense UDS indexing

- UDS Index in memory size
- VDO thread configuration

Workloads

- Types of tools used to generate test data
- Number of concurrent clients
- The quantity of duplicate 4 KiB blocks in the written data
- Read and write patterns
- The working set size

4.1.2. Special considerations for testing VDO read performance

You must consider these additional factors before testing VDO read performance:

- If a 4 KiB block has never been written, VDO does not read from the storage and immediately responds with a zero block.
- If a 4 KiB block has been written but contains all zeros, VDO does not read from the storage and immediately responds with a zero block.

This behavior results in very fast read performance when there is no data to read. This is why read tests must prefill the volume with actual data.

4.1.3. Preparing the system for testing VDO performance

This procedure configures system settings to achieve optimal VDO performance during testing.

IMPORTANT

Testing beyond the bounds listed in any particular test might result in the loss of testing time due to abnormal results.

For example, the VDO tests describe a test that conducts random reads over a 100 GiB address range. To test a working set of 500 GiB, you must increase the amount of RAM allocated for the VDO block map cache accordingly.

Procedure

1. Ensure that your CPU is running at its highest performance setting.
2. If possible, disable CPU frequency scaling using the BIOS configuration or the Linux **cpupower** utility.
3. If possible, enable dynamic processor frequency adjustment (Turbo Boost or Turbo Core) for the CPU. This feature introduces some variability in the test results, but improves overall performance.
4. File systems might have unique impacts on performance. They often skew performance measurements, making it harder to isolate the impact of VDO on the results.

If reasonable, measure performance on the raw block device. If this is not possible, format the device using the file system that VDO will use in the target implementation.

4.2. CREATING A VDO VOLUME FOR PERFORMANCE TESTING

This procedure creates a VDO volume with a logical size of 1 TiB on a 512 GiB physical volume for testing VDO performance.

Procedure

- Create a VDO volume:

  ```
  # vdo create --name=vdo-test \
               --device=/dev/sdb \
               --vdoLogicalSize=1T \
               --writePolicy=policy \
               --verbose
  ```

  - Replace ***/dev/sdb*** with the path to a block device.
  - To test the VDO **async** mode on top of asynchronous storage, create an asynchronous volume using the **--writePolicy=async** option.
  - To test the VDO **sync** mode on top of synchronous storage, create a synchronous volume using the **--writePolicy=sync** option.

4.3. CLEANING UP THE VDO PERFORMANCE TESTING VOLUME

This procedure removes the VDO volume used for testing VDO performance from the system.

Prerequisites

- A VDO test volume exists on the system.

Procedure

- Remove the VDO test volume from the system:

  ```
  # vdo remove --name=vdo-test
  ```

Verification steps

- Verify that the volume has been removed:

  ```
  # vdo list --all | grep vdo-test
  ```

  The command should not list the VDO test partition.

4.4. TESTING THE EFFECTS OF I/O DEPTH ON VDO PERFORMANCE

These tests determine the I/O depth that produces the optimal throughput and the lowest latency for your VDO configuration. I/O depth represents the number of I/O requests that the **fio** tool submits at a time.

Because VDO uses a 4 KiB sector size, the tests perform four-corner testing at 4 KiB I/O operations, and I/O depth of 1, 8, 16, 32, 64, 128, 256, 512, and 1024.

4.4.1. Testing the effect of I/O depth on sequential 100% reads in VDO

This test determines how sequential 100% read operations perform on a VDO volume at different I/O depth values.

Procedure

1. Create a new VDO volume.
   For details, see Section 4.2, "Creating a VDO volume for performance testing" .
2. Prefill any areas that the test might access by performing a write **fio** job on the test volume:

```
# fio --rw=write \
      --bs=8M \
      --name=vdo \
      --filename=/dev/mapper/vdo-test \
      --ioengine=libaio \
      --thread \
      --direct=1 \
      --scramble_buffers=1
```

3. Record the reported throughput and latency for sequential 100% reads:

```
# for depth in 1 2 4 8 16 32 64 128 256 512 1024 2048; do
  fio --rw=read \
      --bs=4096 \
      --name=vdo \
      --filename=/dev/mapper/vdo-test \
      --ioengine=libaio \
      --numjobs=1 \
      --thread \
      --norandommap \
      --runtime=300 \
      --direct=1 \
      --iodepth=$depth \
      --scramble_buffers=1 \
      --offset=0 \
      --size=100g
  done
```

4. Remove the VDO test volume.
   For details, see Section 4.3, "Cleaning up the VDO performance testing volume" .

4.4.2. Testing the effect of I/O depth on sequential 100% writes in VDO

This test determines how sequential 100% write operations perform on a VDO volume at different I/O depth values.

Procedure

1. Create a new VDO test volume.

For details, see Section 4.2, “Creating a VDO volume for performance testing” .

2. Prefill any areas that the test might access by performing a write **fio** job:

```
# fio --rw=write \
      --bs=8M \
      --name=vdo \
      --filename=/dev/mapper/vdo-test \
      --ioengine=libaio \
      --thread \
      --direct=1 \
      --scramble_buffers=1
```

3. Record the reported throughput and latency for sequential 100% writes:

```
# for depth in 1 2 4 8 16 32 64 128 256 512 1024 2048; do
  fio --rw=write \
      --bs=4096 \
      --name=vdo \
      --filename=/dev/mapper/vdo-test \
      --ioengine=libaio \
      --numjobs=1 \
      --thread \
      --norandommap \
      --runtime=300 \
      --direct=1 \
      --iodepth=$depth \
      --scramble_buffers=1 \
      --offset=0 \
      --size=100g
  done
```

4. Remove the VDO test volume.
For details, see Section 4.3, “Cleaning up the VDO performance testing volume” .

4.4.3. Testing the effect of I/O depth on random 100% reads in VDO

This test determines how random 100% read operations perform on a VDO volume at different I/O depth values.

Procedure

1. Create a new VDO test volume.
For details, see Section 4.2, “Creating a VDO volume for performance testing” .

2. Prefill any areas that the test might access by performing a write **fio** job:

```
# fio --rw=write \
      --bs=8M \
      --name=vdo \
      --filename=/dev/mapper/vdo-test \
      --ioengine=libaio \
      --thread \
      --direct=1 \
      --scramble_buffers=1
```

3. Record the reported throughput and latency for random 100% reads:

```
# for depth in 1 2 4 8 16 32 64 128 256 512 1024 2048; do
  fio --rw=randread \
      --bs=4096 \
      --name=vdo \
      --filename=/dev/mapper/vdo-test \
      --ioengine=libaio \
      --numjobs=1 \
      --thread \
      --norandommap \
      --runtime=300 \
      --direct=1 \
      --iodepth=$depth \
      --scramble_buffers=1 \
      --offset=0 \
      --size=100g
  done
```

4. Remove the VDO test volume.
   For details, see Section 4.3, “Cleaning up the VDO performance testing volume” .

4.4.4. Testing the effect of I/O depth on random 100% writes in VDO

This test determines how random 100% write operations perform on a VDO volume at different I/O depth values.

IMPORTANT

You must recreate the VDO volume between each I/O depth test run.

Procedure

Perform the following series of steps separately for the I/O depth values of 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, and 2048:

1. Create a new VDO test volume.
   For details, see Section 4.2, “Creating a VDO volume for performance testing” .

2. Prefill any areas that the test might access by performing a write **fio** job:

```
# fio --rw=write \
      --bs=8M \
      --name=vdo \
      --filename=/dev/mapper/vdo-test \
      --ioengine=libaio \
      --thread \
      --direct=1 \
      --scramble_buffers=1
```

3. Record the reported throughput and latency for random 100% writes:

```
# fio --rw=randwrite \
    --bs=4096 \
    --name=vdo \
    --filename=/dev/mapper/vdo-test \
    --ioengine=libaio \
    --numjobs=1 \
    --thread \
    --norandommap \
    --runtime=300 \
    --direct=1 \
    --iodepth=depth-value
    --scramble_buffers=1 \
    --offset=0 \
    --size=100g
done
```

4. Remove the VDO test volume.
   For details, see Section 4.3, “Cleaning up the VDO performance testing volume” .

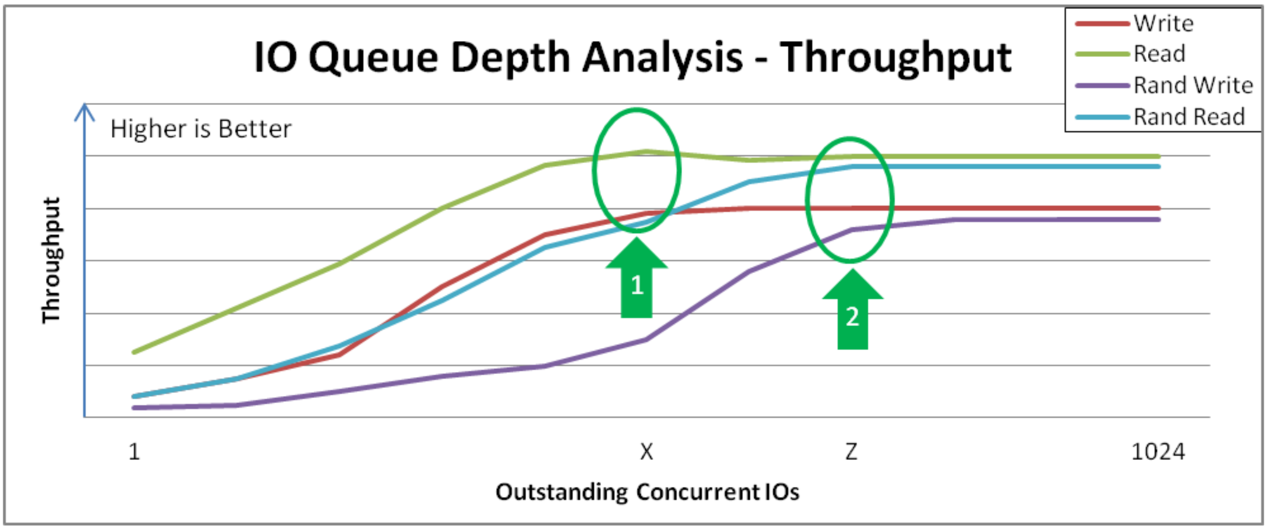
4.4.5. Analysis of VDO performance at different I/O depths

The following example analyses VDO throughput and latency recorded at different I/O depth values.

Watch the behavior across the range and the points of inflection where increased I/O depth provides diminishing throughput gains. Sequential access and random access probably peak at different values, but the peaks might be different for all types of storage configurations.

Example 4.1. I/O depth analysis

Figure 4.1. VDO throughput analysis

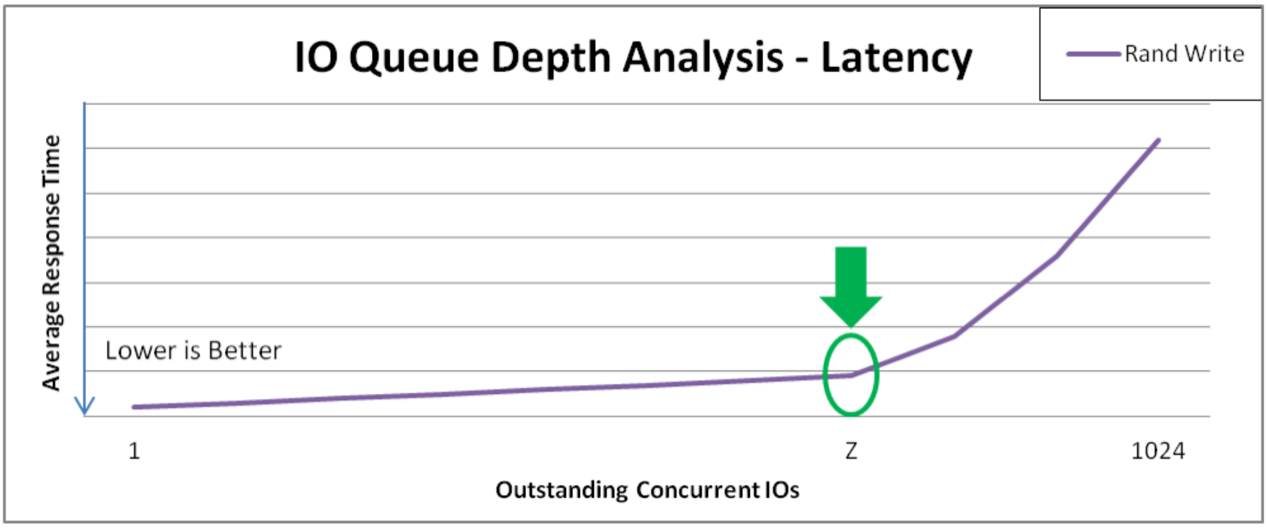


Notice the "knee" in each performance curve:

- Marker 1 identifies the peak sequential throughput at point **X**. This particular configuration does not benefit from sequential 4 KiB I/O depth larger than **X**.

- Marker 2 identifies peak random 4 KiB throughput at point **Z**. This particular configuration does not benefit from random 4 KiB I/O depth larger than **Z**.

Beyond the I/O depth at points **X** and **Z**, there are diminishing bandwidth gains, and average request latency increases 1:1 for each additional I/O request.

> The following image shows an example of the random write latency after the "knee" of the curve in the previous graph. You should test at these points for maximum throughput that incurs the least response time penalty.
>
> **Figure 4.2. VDO latency analysis**
>
> 
>

Optimal I/O depth

Point **Z** marks the optimal I/O depth. The test plan collects additional data with I/O depth equal to **Z**.

4.5. TESTING THE EFFECTS OF I/O REQUEST SIZE ON VDO PERFORMANCE

Using these tests, you can identify the block size that produces the best performance of VDO at the optimal I/O depth.

The tests perform four-corner testing at a fixed I/O depth, with varied block sizes over the range of 8 KiB to 1 MiB.

Prerequisites

- You have determined the optimal I/O depth value. For details, see Section 4.4, “Testing the effects of I/O depth on VDO performance”.
  In the following tests, replace *optimal-depth* with the optimal I/O depth value.

4.5.1. Testing the effect of I/O request size on sequential writes in VDO

This test determines how sequential write operations perform on a VDO volume at different I/O request sizes.

Procedure

1. Create a new VDO volume.
   For details, see Section 4.2, “Creating a VDO volume for performance testing” .
2. Prefill any areas that the test might access by performing a write **fio** job on the test volume:

   ```
   # fio --rw=write \
   ```

```
    --bs=8M \
    --name=vdo \
    --filename=/dev/mapper/vdo-test \
    --ioengine=libaio \
    --thread \
    --direct=1 \
    --scramble_buffers=1
```

3. Record the reported throughput and latency for the sequential write test:

```
# for iosize in 4 8 16 32 64 128 256 512 1024; do
  fio --rw=write \
      --bs=${iosize}k \
      --name=vdo \
      --filename=/dev/mapper/vdo-test \
      --ioengine=libaio \
      --numjobs=1 \
      --thread \
      --norandommap \
      --runtime=300 \
      --direct=1 \
      --iodepth=optimal-depth \
      --scramble_buffers=1 \
      --offset=0 \
      --size=100g
  done
```

4. Remove the VDO test volume.
   For details, see Section 4.3, “Cleaning up the VDO performance testing volume” .

4.5.2. Testing the effect of I/O request size on random writes in VDO

This test determines how random write operations perform on a VDO volume at different I/O request sizes.

IMPORTANT

You must recreate the VDO volume between each I/O request size test run.

Procedure

Perform the following series steps separately for the I/O request sizes of **4k**, **8k**, **16k**, **32k**, **64k**, **128k**, **256k**, **512k**, and **1024k**:

1. Create a new VDO volume.
   For details, see Section 4.2, “Creating a VDO volume for performance testing” .

2. Prefill any areas that the test might access by performing a write **fio** job on the test volume:

```
# fio --rw=write \
    --bs=8M \
    --name=vdo \
    --filename=/dev/mapper/vdo-test \
    --ioengine=libaio \
      --thread \
      --direct=1 \
      --scramble_buffers=1
```

3. Record the reported throughput and latency for the random write test:

```
# fio --rw=randwrite \
      --bs=request-size \
      --name=vdo \
      --filename=/dev/mapper/vdo-test \
      --ioengine=libaio \
      --numjobs=1 \
      --thread \
      --norandommap \
      --runtime=300 \
      --direct=1 \
      --iodepth=optimal-depth \
      --scramble_buffers=1 \
      --offset=0 \
      --size=100g
  done
```

4. Remove the VDO test volume.
   For details, see Section 4.3, “Cleaning up the VDO performance testing volume” .

4.5.3. Testing the effect of I/O request size on sequential read in VDO

This test determines how sequential read operations perform on a VDO volume at different I/O request sizes.

Procedure

1. Create a new VDO volume.
   For details, see Section 4.2, “Creating a VDO volume for performance testing” .

2. Prefill any areas that the test might access by performing a write **fio** job on the test volume:

```
# fio --rw=write \
      --bs=8M \
      --name=vdo \
      --filename=/dev/mapper/vdo-test \
      --ioengine=libaio \
      --thread \
      --direct=1 \
      --scramble_buffers=1
```

3. Record the reported throughput and latency for the sequential read test:

```
# for iosize in 4 8 16 32 64 128 256 512 1024; do
  fio --rw=read \
      --bs=${iosize}k \
      --name=vdo \
      --filename=/dev/mapper/vdo-test \
      --ioengine=libaio \
    --numjobs=1 \
    --thread \
    --norandommap \
    --runtime=300 \
    --direct=1 \
    --iodepth=optimal-depth \
    --scramble_buffers=1 \
    --offset=0 \
    --size=100g
  done
```

4. Remove the VDO test volume.
   For details, see Section 4.3, “Cleaning up the VDO performance testing volume” .

4.5.4. Testing the effect of I/O request size on random read in VDO

This test determines how random read operations perform on a VDO volume at different I/O request sizes.

Procedure

1. Create a new VDO volume.
   For details, see Section 4.2, “Creating a VDO volume for performance testing” .

2. Prefill any areas that the test might access by performing a write **fio** job on the test volume:

```
# fio --rw=write \
    --bs=8M \
    --name=vdo \
    --filename=/dev/mapper/vdo-test \
    --ioengine=libaio \
    --thread \
    --direct=1 \
    --scramble_buffers=1
```

3. Record the reported throughput and latency for the random read test:

```
# for iosize in 4 8 16 32 64 128 256 512 1024; do
  fio --rw=read \
    --bs=${iosize}k \
    --name=vdo \
    --filename=/dev/mapper/vdo-test \
    --ioengine=libaio \
    --numjobs=1 \
    --thread \
    --norandommap \
    --runtime=300 \
    --direct=1 \
    --iodepth=optimal-depth \
    --scramble_buffers=1 \
    --offset=0 \
    --size=100g
  done
```

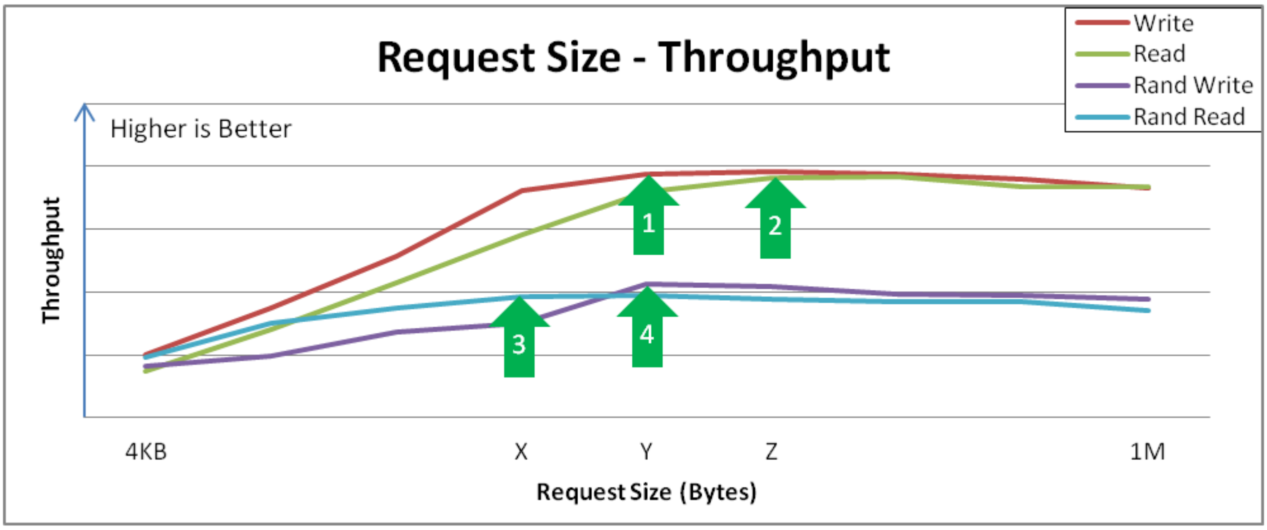
4. Remove the VDO test volume.
   For details, see Section 4.3, “Cleaning up the VDO performance testing volume” .

4.5.5. Analysis of VDO performance at different I/O request sizes

The following example analyses VDO throughput and latency recorded at different I/O request sizes.

Example 4.2. I/O request size analysis

Figure 4.3. Request size versus throughput analysis and key inflection points



Analyzing the example results:

- Sequential writes reach a peak throughput at request size **Y**.
  This curve demonstrates how applications that are configurable or naturally dominated by certain request sizes might perceive performance. Larger request sizes often provide more throughput because 4 KiB I/O operations might benefit from merging.

- Sequential reads reach a similar peak throughput at point **Z**.
  After these peaks, the overall latency before the I/O operation completes increases with no additional throughput. You should tune the device to not accept I/O operations larger than this size.

- Random reads achieve peak throughput at point **X**.
  Certain devices might achieve near-sequential throughput rates at large request size random accesses, but others suffer more penalty when varying from purely sequential access.

- Random writes achieve peak throughput at point **Y**.
  Random writes involve the most interaction of a deduplication device, and VDO achieves high performance especially when request sizes or I/O depths are large.

4.6. TESTING THE EFFECTS OF MIXED I/O LOADS ON VDO PERFORMANCE

This test determines how your VDO configuration behaves with mixed read and write I/O loads, and analyzes the effects of mixed reads and writes at the optimal random queue depth and request sizes from 4 KB to 1 MB.

This procedure performs four-corner testing at fixed I/O depth, varied block size over the 8 KB to 256 KB range, and set read percentage at 10% increments, beginning with 0%.

Prerequisites

- You have determined the optimal I/O depth value. For details, see Section 4.4, "Testing the effects of I/O depth on VDO performance".
  In the following procedure, replace *optimal-depth* with the optimal I/O depth value.

Procedure

1. Create a new VDO volume.
   For details, see Section 4.2, "Creating a VDO volume for performance testing" .

2. Prefill any areas that the test might access by performing a write **fio** job on the test volume:

```
# fio --rw=write \
     --bs=8M \
     --name=vdo \
     --filename=/dev/mapper/vdo-test \
     --ioengine=libaio \
     --thread \
     --direct=1 \
     --scramble_buffers=1
```

3. Record the reported throughput and latency for the read and write input stimulus:

```
# for readmix in 0 10 20 30 40 50 60 70 80 90 100; do
   for iosize in 4 8 16 32 64 128 256 512 1024; do
     fio --rw=rw \
       --rwmixread=$readmix \
       --bs=${iosize}k \
       --name=vdo \
       --filename=/dev/mapper/vdo-test \
       --ioengine=libaio \
       --numjobs=1 \
       --thread \
       --norandommap \
       --runtime=300 \
       --direct=0 \
       --iodepth=optimal-depth \
       --scramble_buffers=1 \
       --offset=0 \
       --size=100g
   done
  done
```

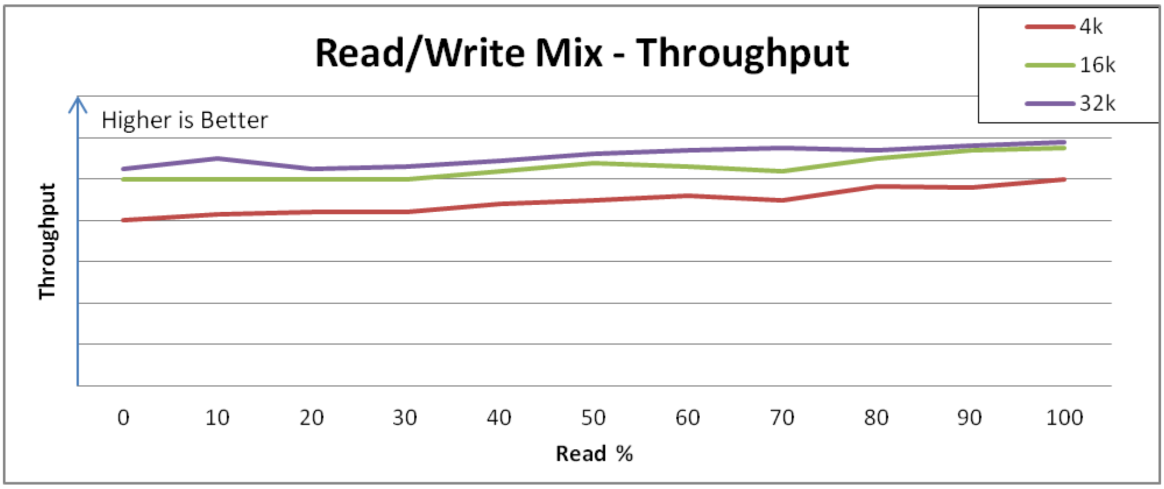
4. Remove the VDO test volume.
   For details, see Section 4.3, "Cleaning up the VDO performance testing volume".

5. Graph the test results.

   Example 4.3. Mixed I/O loads analysis

   The following image shows an example of how VDO might respond to mixed I/O loads:

Figure 4.4. Performance is consistent across varying read and write mixes



Aggregate performance and aggregate latency are relatively consistent across the range of mixing reads and writes, trending from the lower maximum write throughput to the higher maximum read throughput.

This behavior might vary with different storage, but the important observation is that the performance is consistent under varying loads or that you can understand performance expectation for applications that demonstrate specific read and write mixes.

NOTE

If your system does not show a similar response consistency, it might be a sign of a sub-optimal configuration. Contact your Red Hat Sales Engineer if this occurs.

4.7. TESTING THE EFFECTS OF APPLICATION ENVIRONMENTS ON VDO PERFORMANCE

These tests determine how your VDO configuration behaves when deployed in a mixed, real application environment. If you know more details about the expected environment, test them as well.

Prerequisites

- Consider limiting the permissible queue depth on your configuration.
- If possible, tune the application to issue requests with the block sizes that are the most beneficial to VDO performance.

Procedure

1. Create a new VDO volume.
   For details, see Section 4.2, “Creating a VDO volume for performance testing” .
2. Prefill any areas that the test might access by performing a write **fio** job on the test volume:

```
# fio --rw=write \
    --bs=8M \
    --name=vdo \
     --filename=/dev/mapper/vdo-test \
     --ioengine=libaio \
     --thread \
     --direct=1 \
     --scramble_buffers=1
```

3. Record the reported throughput and latency for the read and write input stimulus:

```
# for readmix in 20 50 80; do
   for iosize in 4 8 16 32 64 128 256 512 1024; do
     fio --rw=rw \
         --rwmixread=$readmix \
         --bsrange=4k-256k \
         --name=vdo \
         --filename=/dev/mapper/vdo-name \
         --ioengine=libaio \
         --numjobs=1 \
         --thread \
         --norandommap \
         --runtime=300 \
         --direct=0 \
         --iodepth=$iosize \
         --scramble_buffers=1 \
         --offset=0 \
         --size=100g
   done
 done
```

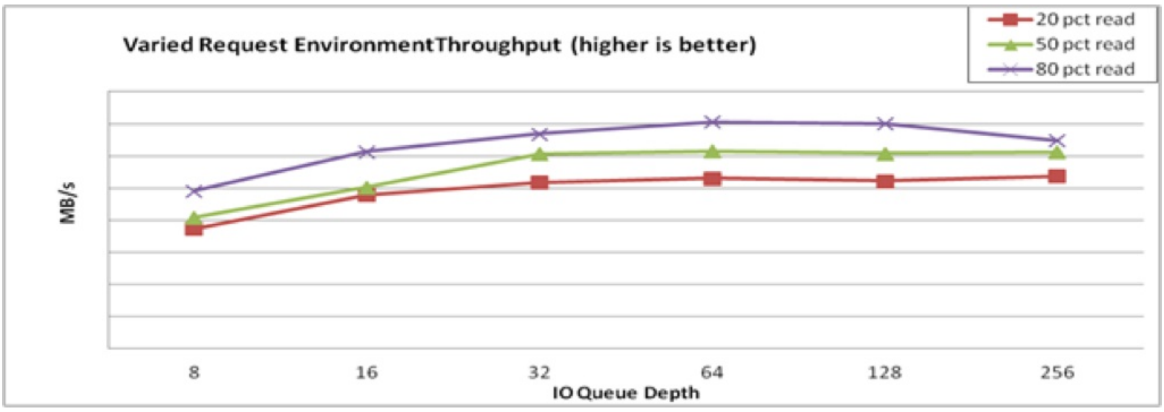
4. Remove the VDO test volume.
   For details, see Section 4.3, “Cleaning up the VDO performance testing volume” .

5. Graph the test results.

Example 4.4. Application environment analysis

The following image shows an example of how VDO might respond to mixed I/O loads:

Figure 4.5. Mixed environment performance



4.8. OPTIONS USED FOR TESTING VDO PERFORMANCE WITH FIO

The VDO tests use the **fio** utility to synthetically generate data with repeatable characteristics. The following **fio** options are necessary to simulate real world workloads in the tests:

Table 4.1. Used **fio** options

Argument	Description	Value used in the tests
--size	The quantity of data that **fio** sends to the target per job. See also the **--numjobs** option.	100 GiB
--bs	The block size of each read-and-write request produced by **fio**. Red Hat recommends a 4 KiB block size to match 4 KiB default of VDO.	4k
--numjobs	The number of jobs that **fio** creates for the benchmark. Each job sends the amount of data specified by the **--size** option. The first job sends data to the device at the offset specified by the **--offset** option. Subsequent jobs overwrite the same region of the disk unless you provide the **--offset_increment** option, which offsets each job from where the previous job began by that value. To achieve peak performance on flash disks (SSD), Red Hat recommends at least two jobs. One job is typically enough to saturate rotational disk (HDD) throughput.	1 for HDD, 2 for SSD
--thread	Instructs **fio** jobs to run in threads rather than to fork, which might provide better performance by limiting context switching.	*none*
--ioengine	The I/O engine that **fio** uses for the benchmark. Red Hat testing uses the asynchronous unbuffered engine called **libaio** to test workloads where one or more processes are making simultaneous random requests. The **libaio** engine enables a single thread to make multiple requests asynchronously before it retrieves any data. This limits the number of context switches that a synchronous engine would require if it provided the requests by many threads.	**libaio**
--direct	The option enables requests submitted to the device to bypass the kernel page cache. You must use the **libaio** engine with the**--direct** option. Otherwise, the kernel uses the sync API for all I/O requests.	1 (**libaio**)

Argument	Description	Value used in the tests
--iodepth	The number of I/O buffers in flight at any time. A high value usually increases performance, particularly for random reads or writes. High values ensure that the controller always has requests to batch. However, setting the value too high, (typically greater than 1K, might cause undesirable latency. Red Hat recommends a value between 128 and 512. The final value is a trade-off and depends on how your application tolerates latency.	128 at minimum
--iodepth_batch_submit	The number of I/O requests to create when the I/O depth buffer pool begins to empty. This option limits task switching from I/O operations to buffer creation during the test.	16
--iodepth_batch_complete	The number of I/O operations to complete before submitting a batch. This option limits task switching from I/O operations to buffer creation during the test.	16
--gtod_reduce	Disables time-of-day calls to calculate latency. This setting lowers throughput if enabled. Enable the option unless you require latency measurement.	1

CHAPTER 5. DISCARDING UNUSED BLOCKS

You can perform or schedule discard operations on block devices that support them.

5.1. BLOCK DISCARD OPERATIONS

Block discard operations discard blocks that are no longer in use by a mounted file system. They are useful on:

- Solid-state drives (SSDs)
- Thinly-provisioned storage

Requirements

The block device underlying the file system must support physical discard operations.

Physical discard operations are supported if the value in the **/sys/block/*device*/queue/discard_max_bytes** file is not zero.

5.2. TYPES OF BLOCK DISCARD OPERATIONS

You can run discard operations using different methods:

Batch discard

Are run explicitly by the user. They discard all unused blocks in the selected file systems.

Online discard

Are specified at mount time. They run in real time without user intervention. Online discard operations discard only the blocks that are transitioning from used to free.

Periodic discard

Are batch operations that are run regularly by a **systemd** service.

All types are supported by the XFS and ext4 file systems and by VDO.

Recommendations

Red Hat recommends that you use batch or periodic discard.

Use online discard only if:

- the system’s workload is such that batch discard is not feasible, or
- online discard operations are necessary to maintain performance.

5.3. PERFORMING BATCH BLOCK DISCARD

This procedure performs a batch block discard operation to discard unused blocks on a mounted file system.

Prerequisites

- The file system is mounted.
- The block device underlying the file system supports physical discard operations.

Procedure

- Use the **fstrim** utility:
    - To perform discard only on a selected file system, use:

      ```
      # fstrim mount-point
      ```

    - To perform discard on all mounted file systems, use:

      ```
      # fstrim --all
      ```

If you execute the **fstrim** command on:

- a device that does not support discard operations, or
- a logical device (LVM or MD) composed of multiple devices, where any one of the device does not support discard operations,

the following message displays:

```
# fstrim /mnt/non_discard

fstrim: /mnt/non_discard: the discard operation is not supported
```

Additional resources

- The **fstrim(8)** man page

5.4. ENABLING ONLINE BLOCK DISCARD

This procedure enables online block discard operations that automatically discard unused blocks on all supported file systems.

Procedure

- Enable online discard at mount time:
    - When mounting a file system manually, add the **-o discard** mount option:

      ```
      # mount -o discard device mount-point
      ```

    - When mounting a file system persistently, add the **discard** option to the mount entry in the **/etc/fstab** file.

Additional resources

- The **mount(8)** man page
- The **fstab(5)** man page

5.5. ENABLING ONLINE BLOCK DISCARD USING RHEL SYSTEM ROLES

This section describes how to enable online block discard using the **storage** role.

Prerequisites

- An Ansible playbook including the **storage** role exists.

For information on how to apply such a playbook, see Applying a role.

5.5.1. Example Ansible playbook to enable online block discard

This section provides an example Ansible playbook. This playbook applies the **storage** role to mount an XFS file system with online block discard enabled.

```
---
- hosts: all
  vars:
    storage_volumes:
      - name: barefs
        type: disk
        disks:
          - sdb
        fs_type: xfs
        mount_point: /mnt/data
        mount_options: discard
  roles:
    - rhel-system-roles.storage
```

5.5.2. Additional resources

- Managing file systems.

5.6. ENABLING PERIODIC BLOCK DISCARD

This procedure enables a **systemd** timer that regularly discards unused blocks on all supported file systems.

Procedure

- Enable and start the **systemd** timer:

  ```
  # systemctl enable --now fstrim.timer
  ```

CHAPTER 6. OVERVIEW OF PERSISTENT NAMING ATTRIBUTES

As a system administrator, you need to refer to storage volumes using persistent naming attributes to build storage setups that are reliable over multiple system boots.

6.1. DISADVANTAGES OF NON-PERSISTENT NAMING ATTRIBUTES

Red Hat Enterprise Linux provides a number of ways to identify storage devices. It is important to use the correct option to identify each device when used in order to avoid inadvertently accessing the wrong device, particularly when installing to or reformatting drives.

Traditionally, non-persistent names in the form of **/dev/sd*(major number)(minor number)*** are used on Linux to refer to storage devices. The major and minor number range and associated **sd** names are allocated for each device when it is detected. This means that the association between the major and minor number range and associated **sd** names can change if the order of device detection changes.

Such a change in the ordering might occur in the following situations:

- The parallelization of the system boot process detects storage devices in a different order with each system boot.

- A disk fails to power up or respond to the SCSI controller. This results in it not being detected by the normal device probe. The disk is not accessible to the system and subsequent devices will have their major and minor number range, including the associated **sd** names shifted down. For example, if a disk normally referred to as **sdb** is not detected, a disk that is normally referred to as **sdc** would instead appear as **sdb**.

- A SCSI controller (host bus adapter, or HBA) fails to initialize, causing all disks connected to that HBA to not be detected. Any disks connected to subsequently probed HBAs are assigned different major and minor number ranges, and different associated **sd** names.

- The order of driver initialization changes if different types of HBAs are present in the system. This causes the disks connected to those HBAs to be detected in a different order. This might also occur if HBAs are moved to different PCI slots on the system.

- Disks connected to the system with Fibre Channel, iSCSI, or FCoE adapters might be inaccessible at the time the storage devices are probed, due to a storage array or intervening switch being powered off, for example. This might occur when a system reboots after a power failure, if the storage array takes longer to come online than the system take to boot. Although some Fibre Channel drivers support a mechanism to specify a persistent SCSI target ID to WWPN mapping, this does not cause the major and minor number ranges, and the associated **sd** names to be reserved; it only provides consistent SCSI target ID numbers.

These reasons make it undesirable to use the major and minor number range or the associated **sd** names when referring to devices, such as in the **/etc/fstab** file. There is the possibility that the wrong device will be mounted and data corruption might result.

Occasionally, however, it is still necessary to refer to the **sd** names even when another mechanism is used, such as when errors are reported by a device. This is because the Linux kernel uses **sd** names (and also SCSI host/channel/target/LUN tuples) in kernel messages regarding the device.

6.2. FILE SYSTEM AND DEVICE IDENTIFIERS

This sections explains the difference between persistent attributes identifying file systems and block devices.

File system identifiers

File system identifiers are tied to a particular file system created on a block device. The identifier is also stored as part of the file system. If you copy the file system to a different device, it still carries the same file system identifier. On the other hand, if you rewrite the device, such as by formatting it with the **mkfs** utility, the device loses the attribute.

File system identifiers include:

- Unique identifier (UUID)
- Label

Device identifiers

Device identifiers are tied to a block device: for example, a disk or a partition. If you rewrite the device, such as by formatting it with the **mkfs** utility, the device keeps the attribute, because it is not stored in the file system.

Device identifiers include:

- World Wide Identifier (WWID)
- Partition UUID
- Serial number

Recommendations

- Some file systems, such as logical volumes, span multiple devices. Red Hat recommends accessing these file systems using file system identifiers rather than device identifiers.

6.3. DEVICE NAMES MANAGED BY THE UDEV MECHANISM IN /DEV/DISK/

This section lists different kinds of persistent naming attributes that the **udev** service provides in the **/dev/disk/** directory.

The **udev** mechanism is used for all types of devices in Linux, not just for storage devices. In the case of storage devices, Red Hat Enterprise Linux contains **udev** rules that create symbolic links in the **/dev/disk/** directory. This enables you to refer to storage devices by:

- Their content
- A unique identifier
- Their serial number.

Although **udev** naming attributes are persistent, in that they do not change on their own across system reboots, some are also configurable.

6.3.1. File system identifiers

The UUID attribute in /dev/disk/by-uuid/

Entries in this directory provide a symbolic name that refers to the storage device by a **unique identifier** (UUID) in the content (that is, the data) stored on the device. For example:

```
/dev/disk/by-uuid/3e6be9de-8139-11d1-9106-a43f08d823a6
```

You can use the UUID to refer to the device in the **/etc/fstab** file using the following syntax:

```
UUID=3e6be9de-8139-11d1-9106-a43f08d823a6
```

You can configure the UUID attribute when creating a file system, and you can also change it later on.

The Label attribute in /dev/disk/by-label/

Entries in this directory provide a symbolic name that refers to the storage device by a **label** in the content (that is, the data) stored on the device.

For example:

```
/dev/disk/by-label/Boot
```

You can use the label to refer to the device in the **/etc/fstab** file using the following syntax:

```
LABEL=Boot
```

You can configure the Label attribute when creating a file system, and you can also change it later on.

6.3.2. Device identifiers

The WWID attribute in /dev/disk/by-id/

The World Wide Identifier (WWID) is a persistent, **system-independent identifier** that the SCSI Standard requires from all SCSI devices. The WWID identifier is guaranteed to be unique for every storage device, and independent of the path that is used to access the device. The identifier is a property of the device but is not stored in the content (that is, the data) on the devices.

This identifier can be obtained by issuing a SCSI Inquiry to retrieve the Device Identification Vital Product Data (page **0x83**) or Unit Serial Number (page **0x80**).

Red Hat Enterprise Linux automatically maintains the proper mapping from the WWID-based device name to a current **/dev/sd** name on that system. Applications can use the **/dev/disk/by-id/** name to reference the data on the disk, even if the path to the device changes, and even when accessing the device from different systems.

Example 6.1. WWID mappings

WWID symlink	Non-persistent device	Note
/dev/disk/by-id/scsi-3600508b400105e210000900000490000	**/dev/sda**	A device with a page **0x83** identifier
/dev/disk/by-id/scsi-SSEAGATE_ST373453LW_3HW1RHM6	**/dev/sdb**	A device with a page **0x80** identifier

WWID symlink	Non-persistent device	Note
/dev/disk/by-id/ata-SAMSUNG_MZNLN256HMHQ-000L7_S2WDNX0J336519-part3	**/dev/sdc3**	A disk partition

In addition to these persistent names provided by the system, you can also use **udev** rules to implement persistent names of your own, mapped to the WWID of the storage.

The Partition UUID attribute in /dev/disk/by-partuuid

The Partition UUID (PARTUUID) attribute identifies partitions as defined by GPT partition table.

Example 6.2. Partition UUID mappings

PARTUUID symlink	Non-persistent device
/dev/disk/by-partuuid/4cd1448a-01	**/dev/sda1**
/dev/disk/by-partuuid/4cd1448a-02	**/dev/sda2**
/dev/disk/by-partuuid/4cd1448a-03	**/dev/sda3**

The Path attribute in /dev/disk/by-path/

This attribute provides a symbolic name that refers to the storage device by the **hardware path** used to access the device.

WARNING

The Path attribute is unreliable, and Red Hat does not recommend using it.

6.4. THE WORLD WIDE IDENTIFIER WITH DM MULTIPATH

This section describes the mapping between the World Wide Identifier (WWID) and non-persistent device names in a Device Mapper Multipath configuration.

If there are multiple paths from a system to a device, DM Multipath uses the WWID to detect this. DM Multipath then presents a single "pseudo-device" in the **/dev/mapper/wwid** directory, such as **/dev/mapper/3600508b400105df70000e00000ac0000**.

The command **multipath -l** shows the mapping to the non-persistent identifiers:

- ***Host*:*Channel*:*Target*:*LUN***
- **/dev/sd** name
- ***major*:*minor*** number

> **Example 6.3. WWID mappings in a multipath configuration**
>
> An example output of the **multipath -l** command:
>
> ```
> 3600508b400105df70000e00000ac0000 dm-2 vendor,product
> [size=20G][features=1 queue_if_no_path][hwhandler=0][rw]
> \_ round-robin 0 [prio=0][active]
>  \_ 5:0:1:1 sdc 8:32  [active][undef]
>  \_ 6:0:1:1 sdg 8:96  [active][undef]
> \_ round-robin 0 [prio=0][enabled]
>  \_ 5:0:0:1 sdb 8:16  [active][undef]
>  \_ 6:0:0:1 sdf 8:80  [active][undef]
> ```

DM Multipath automatically maintains the proper mapping of each WWID-based device name to its corresponding **/dev/sd** name on the system. These names are persistent across path changes, and they are consistent when accessing the device from different systems.

When the **user_friendly_names** feature of DM Multipath is used, the WWID is mapped to a name of the form **/dev/mapper/mpath*N***. By default, this mapping is maintained in the file **/etc/multipath/bindings**. These **mpath*N*** names are persistent as long as that file is maintained.

IMPORTANT

If you use **user_friendly_names**, then additional steps are required to obtain consistent names in a cluster.

6.5. LIMITATIONS OF THE UDEV DEVICE NAMING CONVENTION

The following are some limitations of the **udev** naming convention:

- It is possible that the device might not be accessible at the time the query is performed because the **udev** mechanism might rely on the ability to query the storage device when the **udev** rules are processed for a **udev** event. This is more likely to occur with Fibre Channel, iSCSI or FCoE storage devices when the device is not located in the server chassis.
- The kernel might send **udev** events at any time, causing the rules to be processed and possibly causing the **/dev/disk/by-*/** links to be removed if the device is not accessible.
- There might be a delay between when the **udev** event is generated and when it is processed, such as when a large number of devices are detected and the user-space **udevd** service takes some amount of time to process the rules for each one. This might cause a delay between when the kernel detects the device and when the **/dev/disk/by-*/** names are available.
- External programs such as **blkid** invoked by the rules might open the device for a brief period of time, making the device inaccessible for other uses.

6.6. LISTING PERSISTENT NAMING ATTRIBUTES

This procedure describes how to find out the persistent naming attributes of non-persistent storage devices.

Procedure

- To list the UUID and Label attributes, use the **lsblk** utility:

  ```
  $ lsblk --fs storage-device
  ```

  For example:

  Example 6.4. Viewing the UUID and Label of a file system

  ```
  $ lsblk --fs /dev/sda1

  NAME FSTYPE LABEL UUID                                 MOUNTPOINT
  sda1 xfs    Boot  afa5d5e3-9050-48c3-acc1-bb30095f3dc4 /boot
  ```

- To list the PARTUUID attribute, use the **lsblk** utility with the **--output +PARTUUID** option:

  ```
  $ lsblk --output +PARTUUID
  ```

  For example:

  Example 6.5. Viewing the PARTUUID attribute of a partition

  ```
  $ lsblk --output +PARTUUID /dev/sda1

  NAME MAJ:MIN RM  SIZE RO TYPE MOUNTPOINT PARTUUID
  sda1   8:1    0  512M  0 part /boot      4cd1448a-01
  ```

- To list the WWID attribute, examine the targets of symbolic links in the **/dev/disk/by-id/** directory. For example:

  Example 6.6. Viewing the WWID of all storage devices on the system

  ```
  $ file /dev/disk/by-id/*

  /dev/disk/by-id/ata-QEMU_HARDDISK_QM00001
  symbolic link to ../../sda
  /dev/disk/by-id/ata-QEMU_HARDDISK_QM00001-part1
  symbolic link to ../../sda1
  /dev/disk/by-id/ata-QEMU_HARDDISK_QM00001-part2
  symbolic link to ../../sda2
  /dev/disk/by-id/dm-name-rhel_rhel8-root
  symbolic link to ../../dm-0
  /dev/disk/by-id/dm-name-rhel_rhel8-swap
  symbolic link to ../../dm-1
  /dev/disk/by-id/dm-uuid-LVM-
  QIWtEHtXGobe5bewlIUDivKOz5ofkgFhP0RMFsNyySVihqEl2cWWbR7MjXJolD6g
  symbolic link to ../../dm-1
  /dev/disk/by-id/dm-uuid-LVM-
  ```

```
QIWtEHtXGobe5bewlIUDivKOz5ofkgFhXqH2M45hD2H9nAf2qfWSrlRLhzfMyOKd
symbolic link to ../../dm-0
/dev/disk/by-id/lvm-pv-uuid-atlr2Y-vuMo-ueoH-CpMG-4JuH-AhEF-wu4QQm
symbolic link to ../../sda2
```

6.7. MODIFYING PERSISTENT NAMING ATTRIBUTES

This procedure describes how to change the UUID or Label persistent naming attribute of a file system.

NOTE

Changing **udev** attributes happens in the background and might take a long time. The **udevadm settle** command waits until the change is fully registered, which ensures that your next command will be able to utilize the new attribute correctly.

In the following commands:

- Replace *new-uuid* with the UUID you want to set; for example, **1cdfbc07-1c90-4984-b5ec-f61943f5ea50**. You can generate a UUID using the **uuidgen** command.
- Replace *new-label* with a label; for example, **backup_data**.

Prerequisites

- If you are modifying the attributes of an XFS file system, unmount it first.

Procedure

- To change the UUID or Label attributes of an **XFS** file system, use the **xfs_admin** utility:

```
# xfs_admin -U new-uuid -L new-label storage-device
# udevadm settle
```

- To change the UUID or Label attributes of an **ext4**, **ext3**, or **ext2** file system, use the **tune2fs** utility:

```
# tune2fs -U new-uuid -L new-label storage-device
# udevadm settle
```

- To change the UUID or Label attributes of a swap volume, use the **swaplabel** utility:

```
# swaplabel --uuid new-uuid --label new-label swap-device
# udevadm settle
```

CHAPTER 7. USING THE WEB CONSOLE FOR MANAGING VIRTUAL DATA OPTIMIZER VOLUMES

This chapter describes the Virtual Data Optimizer (VDO) configuration using the RHEL 8 web console. After reading it, you will be able to:

- Create VDO volumes
- Format VDO volumes
- Extend VDO volumes

Prerequisites

- The RHEL 8 web console is installed and accessible.
  For details, see Installing the web console.

7.1. VDO VOLUMES IN THE WEB CONSOLE

Red Hat Enterprise Linux 8 supports Virtual Data Optimizer (VDO). VDO is a block virtualization technology that combines:

Compression

For details, see Enabling or disabling compression in VDO.

Deduplication

For details, see Enabling or disabling deduplication in VDO.

Thin provisioning

For details, see Thinly-provisioned logical volumes (thin volumes).

Using these technologies, VDO:

- Saves storage space inline
- Compresses files
- Eliminates duplications
- Enables you to allocate more virtual space than how much the physical or logical storage provides
- Enables you to extend the virtual storage by growing

VDO can be created on top of many types of storage. In the RHEL 8 web console, you can configure VDO on top of:

- LVM

  NOTE

  It is not possible to configure VDO on top of thinly-provisioned volumes.

- Physical volume

- Software RAID

For details about placement of VDO in the Storage Stack, see System Requirements.

Additional resources

- For details about VDO, see Deduplicating and compressing storage.

7.2. CREATING VDO VOLUMES IN THE WEB CONSOLE

This section helps you to create a VDO volume in the RHEL web console.

Prerequisites

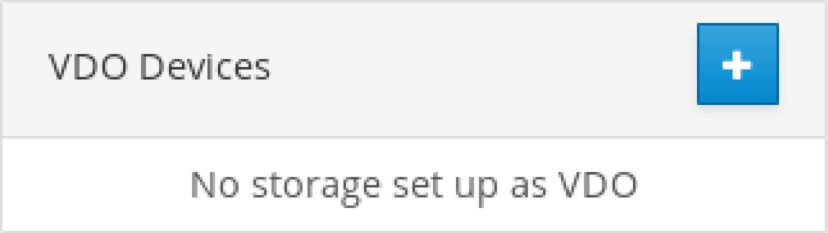
- Physical drives, LVMs, or RAID from which you want to create VDO.

Procedure

1. Log in to the RHEL 8 web console.
   For details, see Logging in to the web console .

2. Click **Storage**.

3. Click the **+** icon in the **VDO Devices** box.

   No storage set up as VDO

4. In the **Name** field, enter a name of a VDO volume without spaces.

5. Select the drive that you want to use.

6. In the **Logical Size** bar, set up the size of the VDO volume. You can extend it more than ten times, but consider for what purpose you are creating the VDO volume:

   - For active VMs or container storage, use logical size that is ten times the physical size of the volume.

   - For object storage, use logical size that is three times the physical size of the volume.

   For details, see Deploying VDO.

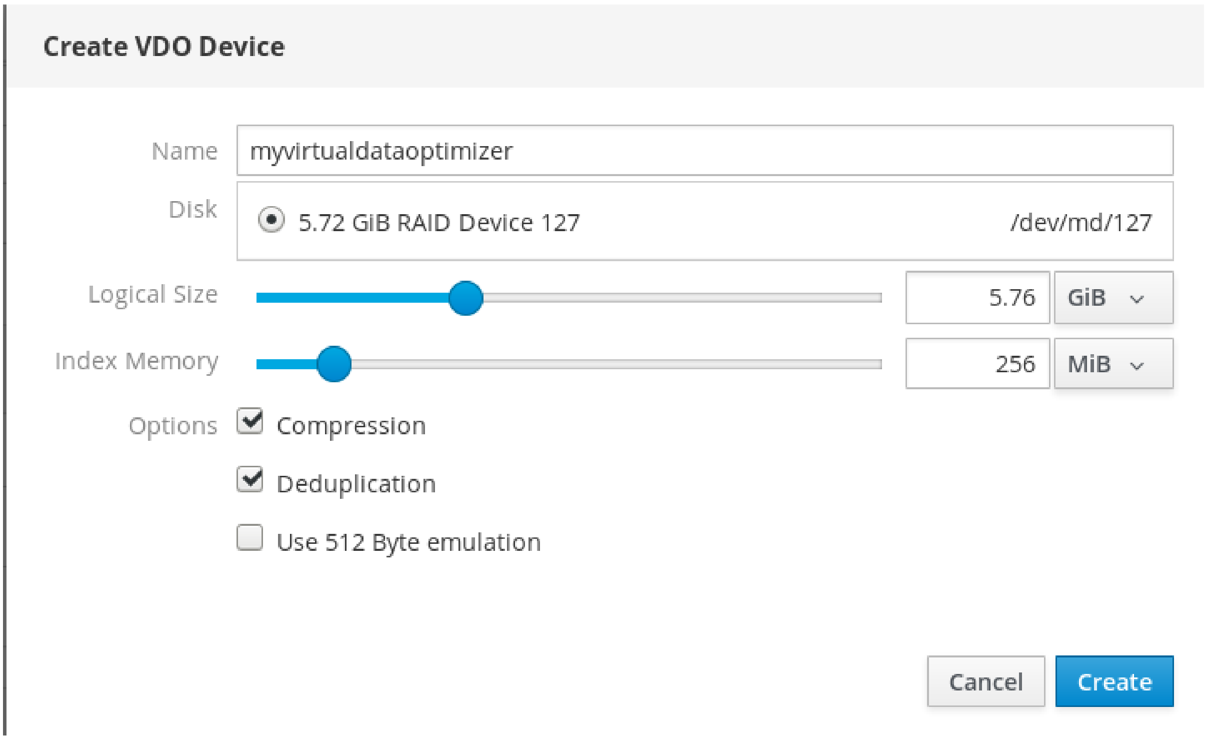
7. In the **Index Memory** bar, allocate memory for the VDO volume.
   For details about VDO system requirements, see System Requirements.

8. Select the **Compression** option. This option can efficiently reduce various file formats.
   For details, see Enabling or disabling compression in VDO.

9. Select the **Deduplication** option.
   This option reduces the consumption of storage resources by eliminating multiple copies of duplicate blocks. For details, see Enabling or disabling deduplication in VDO .

10. [Optional] If you want to use the VDO volume with applications that need a 512 bytes block size, select **Use 512 Byte emulation**. This reduces the performance of the VDO volume, but should be very rarely needed. If in doubt, leave it off.

11. Click **Create**.



Create VDO Device

Name: myvirtualdataoptimizer

Disk: ● 5.72 GiB RAID Device 127 /dev/md/127

Logical Size: 5.76 GiB

Index Memory: 256 MiB

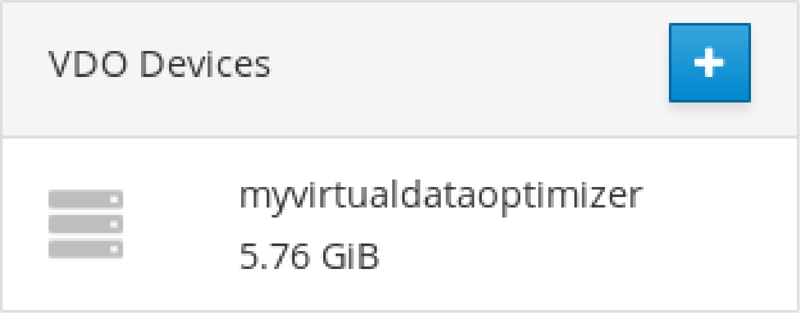
Options:

☑ Compression

☑ Deduplication

☐ Use 512 Byte emulation

If the process of creating the VDO volume succeeds, you can see the new VDO volume in the **Storage** section and format it with a file system.



VDO Devices

myvirtualdataoptimizer
5.76 GiB

7.3. FORMATTING VDO VOLUMES IN THE WEB CONSOLE

VDO volumes act as physical drives. To use them, you need to format them with a file system.

> **WARNING**
>
> Formatting VDO will erase all data on the volume.

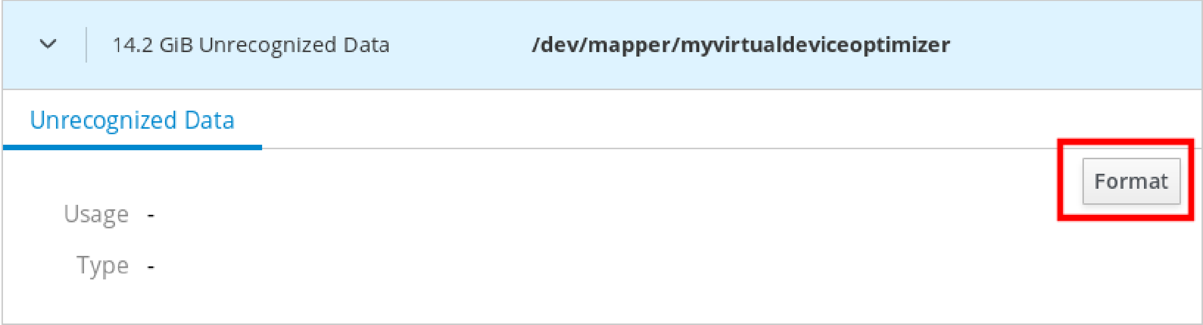
The following steps describe the procedure to format VDO volumes.

Prerequisites

- A VDO volume is created. For details, see Section 7.2, “Creating VDO volumes in the web console”.

Procedure

1. Log in to the RHEL 8 web console.
   For details, see Logging in to the web console .
2. Click **Storage**.
3. Click the VDO volume.
4. Click on the **Unrecognized Data** tab.
5. Click **Format**.



14.2 GiB Unrecognized Data /dev/mapper/myvirtualdeviceoptimizer

Unrecognized Data

Usage -

Type -

6. In the **Erase** drop down menu, select:

   Don’t overwrite existing data

   The RHEL web console rewrites only the disk header. The advantage of this option is the speed of formatting.

   Overwrite existing data with zeros

   The RHEL web console rewrites the whole disk with zeros. This option is slower because the program has to go through the whole disk. Use this option if the disk includes any data and you need to rewrite them.

7. In the **Type** drop down menu, select a filesystem:

   - The **XFS** file system supports large logical volumes, switching physical drives online without outage, and growing. Leave this file system selected if you do not have a different strong preference.
     XFS does not support shrinking volumes. Therefore, you will not be able to reduce volume formatted with XFS.

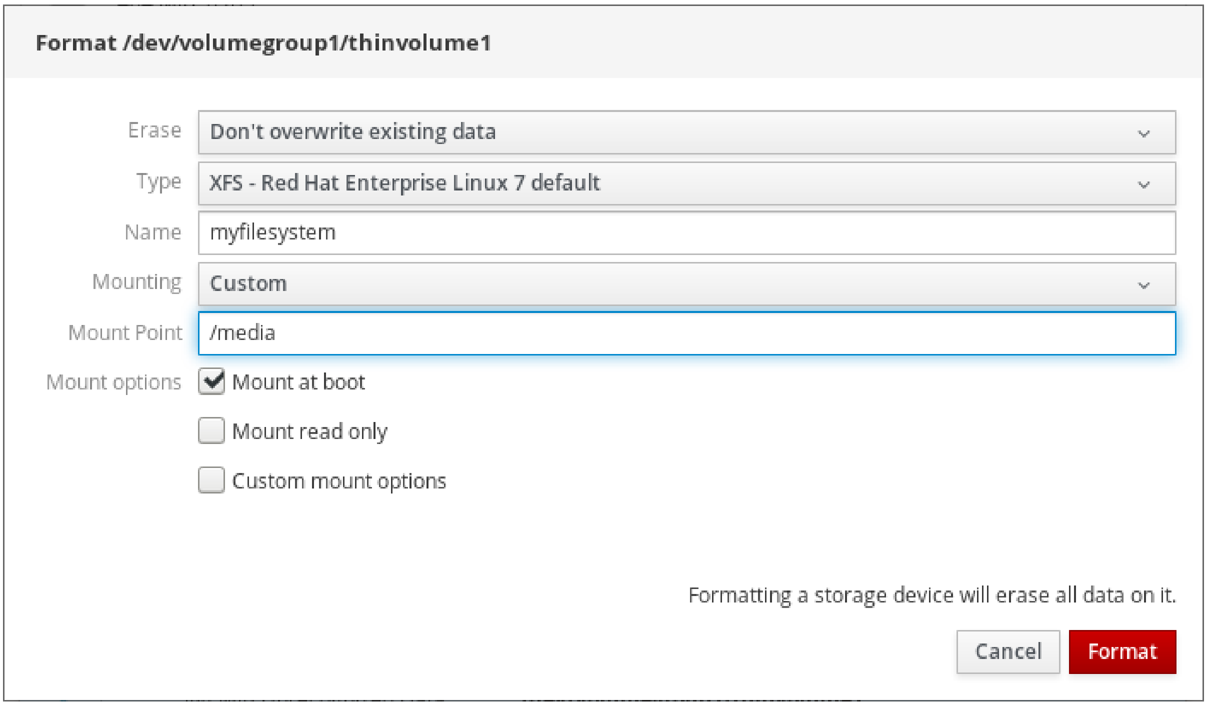
   - The **ext4** file system supports logical volumes, switching physical drives online without outage, growing, and shrinking.

   You can also select a version with the LUKS (Linux Unified Key Setup) encryption, which allows you to encrypt the volume with a passphrase.

8. In the **Name** field, enter the logical volume name.
9. In the **Mounting** drop down menu, select **Custom**.
   The **Default** option does not ensure that the file system will be mounted on the next boot.

10. In the **Mount Point** field, add the mount path.

11. Select **Mount at boot**.



Format /dev/volumegroup1/thinvolume1

Erase: Don't overwrite existing data

Type: XFS - Red Hat Enterprise Linux 7 default

Name: myfilesystem

Mounting: Custom

Mount Point: /media

Mount options: ☑ Mount at boot

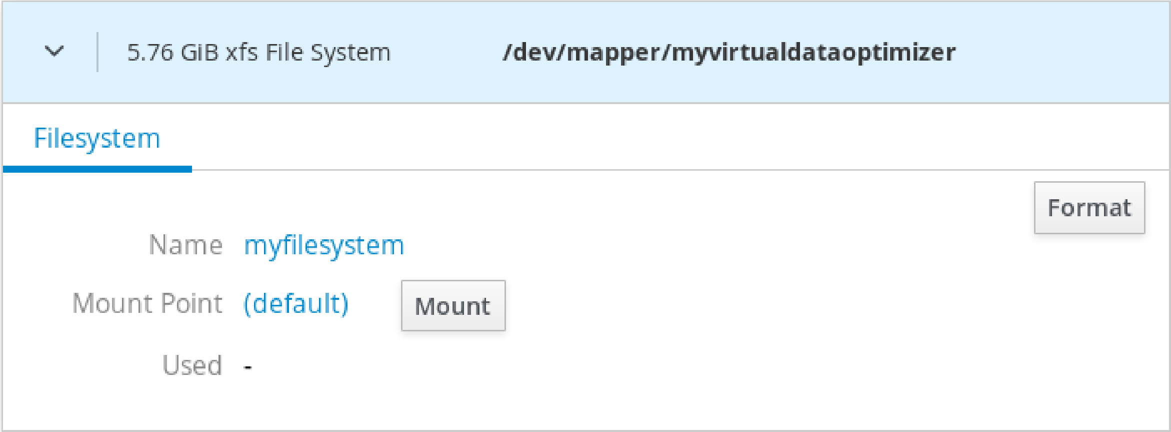
□ Mount read only

□ Custom mount options

Formatting a storage device will erase all data on it.

12. Click **Format**.
Formatting can take several minutes depending on the used formatting options and the volume size.

After a successful finish, you can see the details of the formatted VDO volume on the **Filesystem** tab.



5.76 GiB xfs File System /dev/mapper/myvirtualdataoptimizer

Name: myfilesystem

Mount Point: (default)

Used: -

13. To use the VDO volume, click **Mount**.

At this point, the system uses the mounted and formatted VDO volume.

7.4. EXTENDING VDO VOLUMES IN THE WEB CONSOLE

This section describes extending VDO volumes in the RHEL 8 web console.

Prerequisites

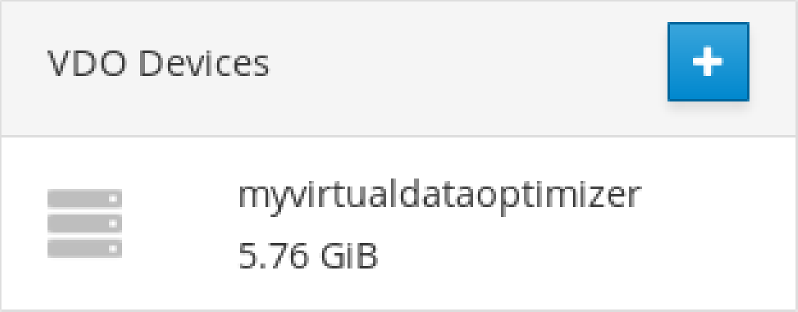
- The VDO volume created.

Procedure

1. Log in to the RHEL 8 web console.
   For details, see Logging in to the web console .

2. Click **Storage**.

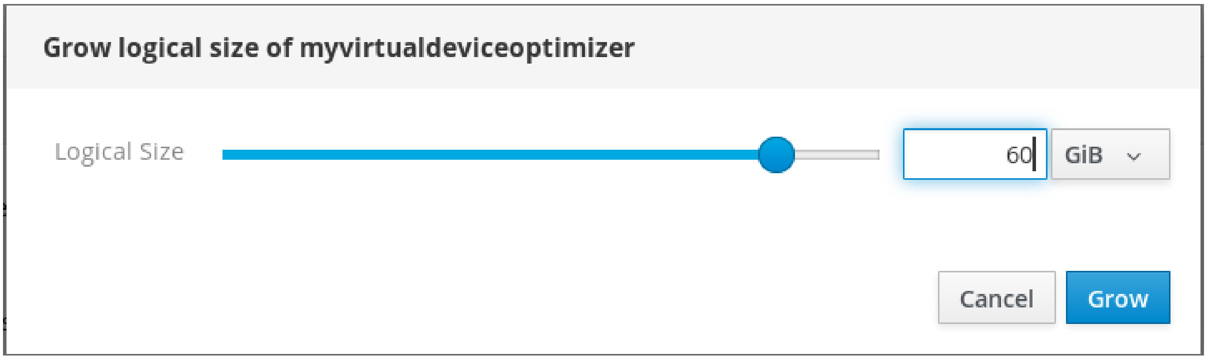
3. Click your VDO volume in the **VDO Devices** box.



myvirtualdataoptimizer
5.76 GiB

4. In the VDO volume details, click the **Grow** button.

5. In the **Grow logical size of VDO** dialog box, extend the logical size of the VDO volume.

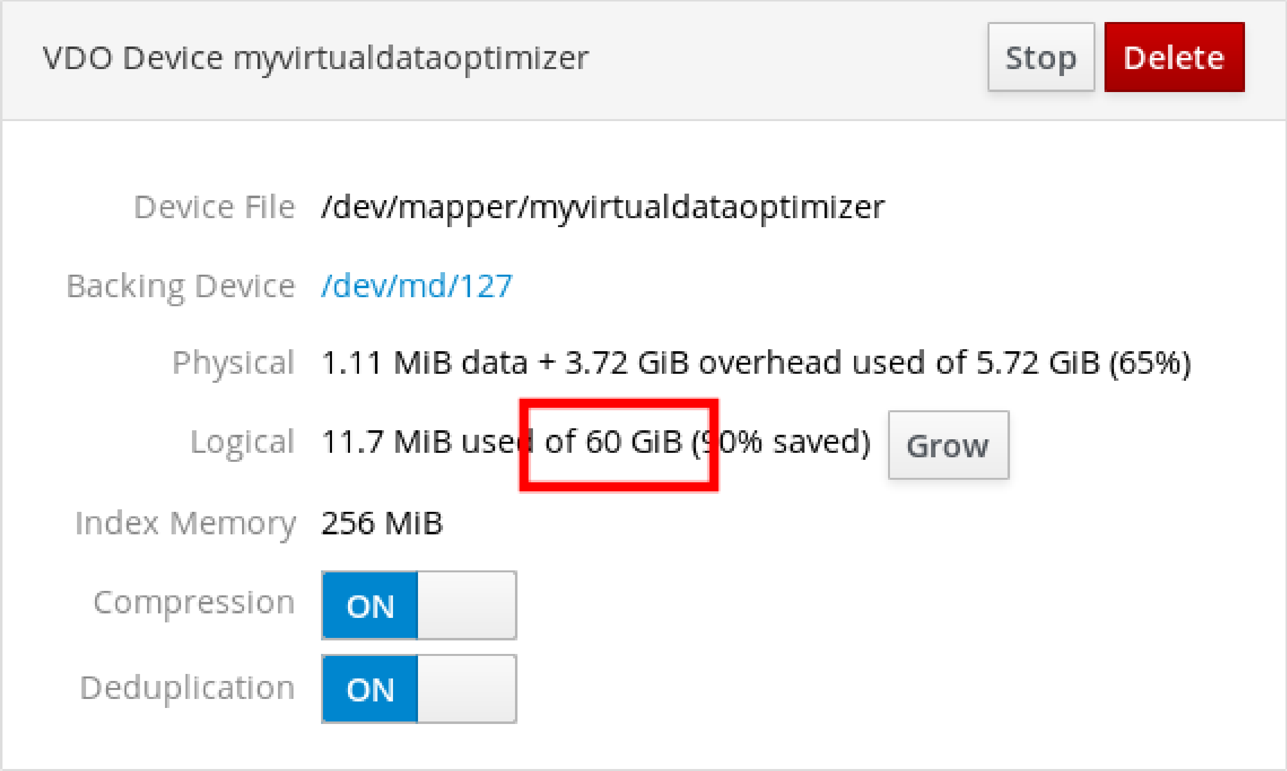

Grow logical size of myvirtualdeviceoptimizer

Logical Size: 60 GiB

   Original size of the logical volume from the screenshot was 6 GB. As you can see, the RHEL web console enables you to grow the volume to more than ten times the size and it works correctly because of the compression and deduplication.

6. Click **Grow**.

If the process of growing VDO succeeds, you can see the new size in the VDO volume details.



VDO Device myvirtualdataoptimizer

Device File /dev/mapper/myvirtualdataoptimizer

Backing Device /dev/md/127

Physical 1.11 MiB data + 3.72 GiB overhead used of 5.72 GiB (65%)

Logical 11.7 MiB used of 60 GiB (90% saved)

Index Memory 256 MiB

Compression ON

Deduplication ON