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Support for Data Reduction Attributes in nfsv4 Version 2
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Abstract

This document proposes extending NFSv4 operations to add new named attributes to be used in the protocol to provide information about the data reduction properties of files. The new data reduction attributes are proposed to allow the client application to communicate to the NFSv4 server data reduction attributes associated with files and directories using new metadata, communicated to the Block Storage data reduction engines. Corresponding new named attributes are proposed to allow clients and client applications to query the server for data reduction attributes support and allow to get and set data reduction attributes on files and directories. Such data reduction metadata is used as hints to the file server about what type of data reduction to apply. The proposed data reduction attributes include achievable ratios for compression and deduplication plus whether each data reduction technique applies to a file or directory.

Status of This Memo

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1. Introduction

Many NFS servers use expensive solid state media, e.g., NVMe SSDs, complemented by data reduction processing of files to reduce their size on the Block Storage via compression and deduplication, thereby optimizing media usage. This draft considers scenarios in which data reduction processing is performed in Block Storage for NFS servers, i.e., compression and deduplication processing occurs in the background or inline as a consequence of NFS files being written to the Block Storage. In these scenarios, the data reduction engines in Block Storage have limited information about how reducible (compressible and/or deduplicate-able) the data written to NFS is.

There is additional strong interest to improve data reduction when using NVMe accessed media and exposing such data attributes to the Block Storage as files or directory attributes over NFS is one means of providing this critical information to Block Storage data reduction engines.

There is an expired draft for use of NVMe (over fabric) in accessing a pNFS SCSI Layout [3] which could will be extended to communicate data reduction attributes to NVMe storage. The shortcoming of the current pNFS SCSI NVMe layout is that it has no information related to data reduction attributes. This document discusses potential use of NFSv4 named attributes as currently standardized in [2], for communicating additional data reduction metadata; a future version of this document will propose updates to the NFSv4 protocol to support this functionality.

The purpose of this draft is to define new name attributes that will allow applications to send richer metadata information to the NFS server in order to optimize Block Storage data reduction engine operations and improve data reduction for data stored by NFS servers.

Applications can handle files with different compression and deduplication characteristics and send this information to the data reduction engines. Current applications have defined data reduction characteristics and there are clear definitions for the typical compression and deduplication ratios of some types of data independent of the application that generated the data. For example electronic data analysis (EDA) has no single de facto standard file extension but generates application files with common compression and deduplication characteristics. Knowing that a file is compressed improves the latency and/or throughput of the NFS server by not attempting to further compress the files. An additional example is that NFS backup of files that are already stored on the Block Storage is likely to result in a very high deduplication ratio.

1.1 Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [1].

In this document, these words will appear with that interpretation only when in ALL CAPS. Lower case uses of these words are not to be interpreted as carrying RFC-2119 significance. We will refer to the block devices used by the NFS servers as "Block Storage".

2. Use Cases

Applications can use named attributes to store metadata together with the files and directories. Metadata regarding data reduction attributes may be available from applications that use different types of files. This metadata may not be directly useful to the file system but is relevant to the compression and deduplication engines used by the Block Storage to improve data reduction. Use of data reduction metadata is not expected to significantly impact I/O latency or throughput (IOPS).

```
                         File Domain | Block Domain
                                     |
          +-------------+            |          +-----------------+
          | NFS Server  |------------|--------->|Reduction Engine |
          +------+------+            |          +--------+--------+
                 ^                   |                   |
                 |                   |                   |
                 |                   |                   v
          +------+------+            |          +--------+--------+
          | NFS Client  |            |          | Block storage   |
          +------+------+            |          +-----------------+
                 ^                   |
                 |                   |
                 |                   |
          +------+------+            |
          | Application |            |
```

```
       +-------------+             |
```

Figure 1: Data Reduction Domains for NFSv4

Figure 1 shows the NFSv4 server configuration, data flow and functionality domains with the data reduction engine in the Block domain and located above the Block Storage. This figure represents NFSv4 without parallel NFS (pNFS) support. In this structure the NFS server can communicate named attributes as metadata directly to the Reduction Engine via an extension to the interface to Block Storage.

In general applications using block devices rely on SCSI protocols to access the data. Although SCSI protocols have a rich API, most communication between hosts and Block Storage, e.g., storage arrays, is in terms of blocks, not files. In contrast, applications use large files to read and write data to and from NFS servers. In general, NFS servers use NFS file systems that are stored on SCSI (or NVMe) devices provisioned from Block Storage, e.g., external storage arrays, as Block Storage but file metadata, e.g., file type and file size, is not transferred to the block array in a explicit manner.

An NFS Server might be able to infer data reduction characteristics based on the file type, e.g., a ".mp4" file can be expected to be an MP4 file that contains MPEG-4 content [7]. This is not sufficient due to file content variability, e.g., as a large variety of codecs are used to create MPEG-4 content whose compressibility may vary by codec. To go beyond the file type, the NFS Server could read the file contents to determine compressibility, but this is problematic due to complexity, e.g., the NFS Server may need to parse a significant amount of an MP4 file to obtain the information necessary to understand its compressibility characteristics. This may be impractical if the file is not written to the NFS Server sequentially, and moreover introduces an undesirable dependency on not only the MP4 file format, but also the set of supported codecs that it supports and individual codec characteristics. It is much better to have the application provide information on compressibility, as the application that generates an MP4 file has the information on the file's contents. A mechanism is needed to pass that information to the NFS Server; this document proposes adding and using new named attributes.

So, although the attributes are stored with the files, the current NFSv4 named attributes specifications [4] indicates that named attributes are accessed by the OPENATTR operation, which accesses a hidden directory of attributes associated with a file system object and contains files whose names represent the named attributes and whose data bytes are the value of the attribute. If the NFS server extracts the data reduction named attributes and pass their contents to the Block Storage functionality, the Block Storage reduction engines could parse that content and adapt its data reduction behavior accordingly.

```
                               File Domain |    Block Domain
          +-------------+                  |      +------------------+
          |             |------------------|----->|                  |
          | pNFS Server |          +-------|----->| Reduction Engine |
          |             |          |  +----|----->|                  |
          +------+------+          |  |    |      +---------+--------+
                 ^                 |  |    |                |
                 |                 |  |    |                |
                 |                 |  |    |                v
          +------+------+  NVMe    |  |    |       +--------+--------+
          | pNFS Client |----------+  |    |       | Block storage   |
          |             |-------------+    |       +-----------------+
          +------+------+  SCSI            |
                 ^                         |
                 |                         |
                 |                         |
          +------+------+                  |
          | Application |                  |
          +-------------+                  |
```

Figure 2: Data Reduction Domains for pNFS over NVMe or SCSI

The filehandle for the named attributes is a directory object accessible by LOOKUP or READDIR and contains files whose names represent the named attributes and whose data bytes are the value of the attribute. The current situation is that data reduction done in the block domain lacks critical information that could be provided by the applications in order to improve efficiency of data compression and deduplication.

Figure 2 shows another scenario with a pNFS Server and a block pNFS Client that accesses Block storage using either NVMe or SCSI over a network. In this scenario the pNFS Client could send data reduction attributes directly to the reduction engine above the Block storage layer if the block storage protocol (NVMe or SCSI in the figure) supports doing so. The assumption is that the application has additional information related to files types and typical compression and deduplication parameters associated to different file types, e.g., see the above discussion of MPEG-4 content. The application can convey this information to the reduction engine to improve the reduction engine efficiency. If the application does not do so, then the user can also add data reduction characteristics for individual files towards improving data reduction efficiency without needing to change the storage array configuration.

For this pNFS scenario the application enables sending data reduction parameters to the Block Device using extensions to the SCSI or NVMe protocols. The pNFS Client still needs to pass the data reduction named attributes to the pNFS Server because the pNFS Client is always allowed to fall back from a pNFS write to an NFS write via the NFS Server; this fallback is similar to the previous case where the NFS Server stores the data reduction named attributes in hidden directories of attributes associated with each file and directory.

For example a video application knows whether a file consists of compressed data or uncompressed data. The application writing the data to the pNFS client can set a named attribute that will indicate that a file is uncompressed and hence it is likely to be productive for the data reduction engine to reduce the file's size. The pNFS client passes that information via a hidden named attribute that hints that the file is compressible. The pNFS server will change or add a new data reduction named attribute and will transmit the data bytes, that are the value of the named attribute, to the Block Storage as a hint that the data is uncompressed. The pNFS client will stream the video using the pNFS NVMe data protocol and the compression engine in the Block Storage will compress the data blocks as long as the uncompressed hint is set in NVMe writes from the pNFS Client. If the named attribute data bytes are changed to indicate that the data has been compressed, the compression engine does not compress the incoming blocks.

A second example is related to encrypted files that can be neither compressed nor deduplicated in the absence of file copying. For this specific example we envision a not-deduplicatable hint. In this scenario the NFS client sets the deduplication hint to advise to the data reduction engine that deduplication should be enabled for the file. Alternatively if a new file is being written that is not based on modifying an existing file the deduplication hint is set to indicate that deduplication should be disabled.

Another use case involves compressed video files and images that are written by video applications. As such files are already compressed, further attempts to compress them are likely to be pointless, and may negatively impact the performance of the NFS Server.

An additional scenario involves metadata at the start (header) of the file; an application that did not generate the file may nonetheless be able to access the metadata section in the file and set the named attributes file based on compression and deduplication found in the file header. The NFS server doesn't have visibility into metadata included in file headers and cannot send file header content to the data reduction engine as separate metadata. Only the user application can access and parse the header and add or update the attribute value when the file is written to the NFS server.

Additional examples of known data reduction attributes is implemented in benchmarks such as SPECsfs that is using predefined data reduction attributes. SPECsfs workloads [8] have DR/CR (Deduplication Ratio/Compression Ratio) characteristics that were collected from actual user data. They are as follows:

EDA	DR/CR=50%/50%
SWBUILD	DR/CR=0/80%
VDI	DR/CR=55%/70%
DB	DR/CR=0/50%
VDA	DR/CR=0/0
IT infrastucture	DR/CR=30%/50%
Oracle DW	DR/CR=15%/70%
Oracle OLTP	DR/CR=0%/65%
Exchange 2010	DR/CR=15%/35%
Geoseismic	DR/CR=3%/40%

Another scenario involves placing files with the same known data reduction characteristics in same directory, where the user or an application sets data reduction named attribute in the directory of attributes associated with the directory that are intended to apply to all files in the directory and possibly also sub-directories. In this case the NFS Server uses the data reduction named attributes of the directory to inform the data reduction engine of the data reduction characteristics of blocks in all files in that directory.

3 New Named Attributes

Named attributes, [4], are a means to associate a hidden directory of attributes with file system objects, e.g., files and directories. Named attributes are especially useful when they add information that is not, or cannot be, present in the associated object itself. User-space applications can arbitrarily create, read from, and write new attributes of a file in that directory.

As named attributes are stored in a hidden directory applications do not need to be concerned about how the attributes are stored internally on the underlying file system. All major operating systems provide various flavors of named attributes. Many user space tools allow named attributes to be included in attributes that need to be preserved when files and directories are updated, moved or copied. The filehandle for named attributes is a directory object accessible by LOOKUP or READDIR and contains files whose names represent the named attributes and whose data bytes are the value of the attribute.

The proposed data reduction attributes are opaque to the file system but can be used by the data reduction engines in the Block Storage reduction engine to increase the data reduction and server operations by viewing the named attributes as hints from the client application regarding file compression and deduplication characteristics. The Block Storage will parse these attributes and change the data reduction methods according to these hints with no need for the file system to know about the data reduction methods used.

Named attributes are intended for data needed by applications rather than by an NFS client implementation. NFS implementors are strongly encouraged to define the new data re4duction attributes as RECOMMENDED attributes. Named attributes have long been considered unsuitable for portability because they are inadequately defined and not formally documented by any standard (such as POSIX). However, evidence suggests that named attributes are widely deployed and their support in modern disk-based file systems is fairly universal. What is different in the new usecase is that the hidden metadata can be retrieved by the NFS server and understood by the data reduction engines of the Block Devices.
The data reductiom named attributes can be 0 or 100 where 0 means "don't do this" hint and 100 is a "do this, but can't predict how much reduction will actually result" hint. They can also take on a percentage value, e.g., from the SPECsfs data shown above.
Any regular file or directory may have a set of named attributes, consisting of a hidden file whose names represent the named attributes and whose data bytes are the value of the associated attribute value [4].

As currently specified, the NFS client or server SHOULD interpret the contents of the named attribute files. This document proposed to add special named attributes that will be specifically used for data reduction. The data reduction named attributes can be provided by extended attributes supported by most modern file systems and can be retrieved from the local file systems on the client and added to the NFS new named attributes when files are exported from local file system extended attributes of the files to the named attributes in NFS.

4 File System Support

In Linux, ext3, ext4, JFS, XFS, Btrfs, among other file systems support extended attributes. The getfattr and setfattr utilities can be used to retrieve and set xattrs. The names of the extended attributes must be prefixed by the name of the category and a dot; hence these categories are generally qualified as name spaces. In the NTFS file system, extended attributes are one of several supported "file streams" [5].

Named attributes can be retrieved and set through system calls, [6], or shell commands and generally supported by user-space tools that preserve other file attributes. For example, the "rsync" remote copy program will correctly preserve extended attributes between Linux/ext4 and OSX/hfs by stripping off the Linux-specific "user." prefix.

5 Namespaces

Operating systems may define multiple "namespaces" in which named attributes can be set. Namespaces are more than organizational classes; the operating system may enforce different data reduction policies and allow different reduction characteristics depending on the namespace. The namespace for these attributes may be accessed by using the OPENATTR operation. The OPENATTR operation returns a filehandle for a virtual "named attribute directory", and further perusal and modification of the namespace may be done using operations that work on more typical directories.

6 Data Reduction Named Attributes

RFC5661 defines named attributes as opaque byte streams that are associated with a directory or file and referred to by a string name

[4]. Named attributes are intended to be used by client applications as a method to associate application-specific data with a regular file or directory. We will use these named attributes directories to add New Data Reduction attributes similar in concept and use to other named attributes, but there are subtle differences.

Named attributes are accessed by NFSv4 OPENATTR operation, which accesses a hidden directory of attributes associated with a file system object. Named attributes are accessible to the application layer using GETATTR and OPENATTR and can be modified by users. File systems typically define individual named attributes using named attributes GETATTR and SETATTR operations. Named attributes generally have size limits ranging from a few bytes to several kilobytes; the maximum supported size is not universally defined and is usually restricted by the file system.

There are no clear indications on how named attributes are mapped to any existing recommended or optional file attributes defined in RFC 5661 [2]; as a result, most NFS client implementations ignore application-specified named attributes. This results in data loss if one copies, over the NFS protocol, a file with data reduction related named attributes from one file system to another that also supports named attributes. Although different data reduction engines achieve different levels of reduction these attributes are used by the reduction engines to increase the reduction to different levels for different algorithms.

While it should be possible to write guidance about how a client can use the named attributes mechanism to act as carving out some namespace and specifying locking primitives to enforce atomicity constraints on individual get/set operations, this is problematic for data reduction attributes that are specific to specific applications and file types and not defined by the user. As such there will be mechanisms that will detect the data reduction attributes from the application or from local file system xattrs [6].

The different implementations of the protocol would have to address these attributes based on additional guidance such as reserving some portion of named attribute namespace for xattr-like [6] functionality.

7 Protocol Enhancements

This section proposes enhancements to the NFSv4 protocol operations to allow data reduction named attributes to be queried and modified by clients. A new attribute is added to bitmap4 data type to allow data reduction named attributes support to be queried. This follows the guidelines specified in [2] with respect to minor versioning. We propose to add 2 bits that will be passed to the reduction engine and used to activate/deactivate the compression and/or the deduplication operations. For example READDIR may be used to get a list of such named attributes, and LOOKUP and OPEN may select a particular attribute. Creation of a new named attribute may be the result of an OPEN specifying file creation. Once an OPEN is done, named attributes may be examined and changed by normal READ and WRITE operations using the filehandles and stateid returned by OPEN.

The protocol detailes will be provided in the next version of the draft. It is RECOMMENDED that servers support arbitrary named attributes. A client should not depend on the ability to store any named attributes in the server's file system.

8. IANA Considerations

All IANA considerations are covered in [4].

9. Security Considerations

The additions to the NFS protocol for supporting data reduction named attributes do not alter the security considerations of the NFSv4.1 protocol [4]. Data reduction hints may enable attacks on Block Storage resources that support the NFS Server. Hinting at more data reduction than is possible may cause excessive data reduction processing, and hinting at less data reduction than is possible, including hinting not to perform any data reduction, may result in consumption of more potentially expensive storage capacity. A future version of this draft will discuss what to do about these possible resource attacks.

10. References

10.1. Normative References

[1] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

[2] Shepler, S., Ed., Eisler, M., Ed., and D. Noveck, Ed., "Network File System (NFS) Version 4 Minor Version 1 External Data Representation Standard (XDR) Description", RFC 5662, January 2010.

[4] Shepler, S., Ed., Eisler, M., Ed., and D. Noveck, Ed., "Network File System (NFS) Version 4 Minor Version 1 Protocol", RFC 5661, January 2010.

10.2 Informative References

[3] C. Hellwig, "Using the Parallel NFS (pNFS) SCSI Layout with NVMe", June 2017, https://tools.ietf.org/html/draft-hellwig-nfsv4-scsi-layout- ... nvme-00

[5] http://www.freedesktop.org/wiki/CommonExtendedAttributes, "Guidelines for extended attributes".

[6] M. Naik, M. Eshel, "File System Extended Attributes in NFSv4" https://datatracker.ietf.org/doc/rfc8276/

[7] ISO/IEC 14496-14 "Information technology - Coding of audio-visual objects - Part 14: MP4 file format"

[8] SPEC SFS 2014 SP2 User's Guide, http://spec.org/sfs2014/docs/usersguide.pdf

Acknowledgments

This draft has attempted to capture the latest industry trends of adding data reduction attributes needed to increase efficiency of newest flash NVMe technology for file servers. New protocols were proposed specific for NVMe media and we were inspired by new drafts proposed by the editor of this draft.

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