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Network File System (NFS) Upper-Layer Binding To RPC-Over-RDMA Version 2
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Abstract

This document specifies Upper-Layer Bindings of Network File System (NFS) protocol versions to RPC-over-RDMA version 2.

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[1.](#) Introduction

The RPC-over-RDMA version 2 transport may employ direct data placement to convey data payloads associated with RPC transactions [[RPCRDMA2](#)]. RPC client and server implementations using RPC-over-RDMA version 2 must agree which XDR data items and RPC procedures are eligible to use direct data placement (DDP) to enable successful interoperation.

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An Upper-Layer Binding specifies this agreement for one or more versions of one RPC program. Other operational details, such as RPC binding assignments, pairing Write chunks with result data items, and reply size estimation, are also specified by this Binding.

This document contains material required of Upper-Layer Bindings, as specified in [[RPCRDMA2](#)], for the following NFS protocol versions:

- o NFS version 2 [[RFC1094](#)]
- o NFS version 3 [[RFC1813](#)]
- o NFS version 4.0 [[RFC7530](#)]
- o NFS version 4.1 [[RFC5661](#)]
- o NFS version 4.2 [[RFC7862](#)]

The current document also provides Upper-Layer Bindings for auxiliary protocols used with NFS versions 2 and 3 (see [Section 5](#)).

This document assumes the reader is already familiar with concepts and terminology defined in [[RPCRDMA2](#)] and the documents it references.

[2.](#) Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [BCP 14](#) [[RFC2119](#)] [[RFC8174](#)] when, and only when, they appear in all capitals, as shown here.

[3.](#) Reply Size Estimation

During the construction of each RPC Call message, a Requester is responsible for allocating appropriate resources for receiving the corresponding Reply message. If the Requester expects that the RPC Reply message could be larger than its inline threshold, it MAY provide Write chunks wherein the Responder can place results and Reply chunks wherein the Responder can place the reply's Payload stream.

[4.](#) Upper-Layer Binding for NFS Versions 2 and 3

The Upper-Layer Binding specification in this section applies to NFS version 2 [[RFC1094](#)] and NFS version 3 [[RFC1813](#)]. For brevity, in this document, a "Legacy NFS client" refers to an NFS client using

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version 2 or version 3 of the NFS RPC program (100003) to communicate with an NFS server. Likewise, a "Legacy NFS server" is an NFS server communicating with clients using NFS version 2 or NFS version 3.

The following XDR data items in NFS versions 2 and 3 are DDP-eligible:

- o The opaque file data argument in the NFS WRITE procedure
- o The pathname argument in the NFS SYMLINK procedure
- o The opaque file data result in the NFS READ procedure
- o The pathname result in the NFS READLINK procedure

All other argument or result data items in NFS versions 2 and 3 are not DDP-eligible.

A transport error does not indicate whether the server has processed the arguments of the RPC Call, or whether the server has accessed or modified client memory associated with that RPC.

4.1. Reply Size Estimation

A Legacy NFS client determines the maximum reply size for each operation using the criteria outlined in [Section 3](#).

4.2. RPC Binding Considerations

Legacy NFS servers traditionally listen for clients on UDP and TCP port 2049. Additionally, they register these ports with a local portmapper service [[RFC1833](#)].

A Legacy NFS server supporting RPC-over-RDMA version 2 on such a network and registering itself with the RPC portmapper MAY choose an arbitrary port, or MAY use the alternative well-known port number for its RPC-over-RDMA service (see [Section 9](#)). The chosen port MAY be registered with the RPC portmapper using the netids assigned in [[RPCRDMA2](#)].

4.3. Transport Considerations

Legacy NFS client implementations often rely on a transport-layer keep-alive mechanism to detect when a legacy server has become unresponsive. When an NFS server is no longer responsive, client-side keep-alive terminates the connection, which in turn triggers reconnection and RPC retransmission.

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4.3.1. Keep-Alive

Some RDMA transports (such as the Reliable Connected QP type on InfiniBand) have no keep-alive mechanism. Without a disconnect or new RPC traffic, such connections can remain alive long after an NFS server has become unresponsive or unreachable. Once an NFS client has consumed all available RPC-over-RDMA version 2 credits on that transport connection, it awaits a reply indefinitely before sending another RPC request.

Legacy NFS clients SHOULD reserve one RPC-over-RDMA version 2 credit to use for periodic server or connection health assessment. Either peer can use this credit to drive an RPC request on an otherwise idle connection, triggering either an affirmative server response or a connection termination.

4.3.2. Replay Detection

Legacy NFS servers can employ request replay detection to reduce the risk of data corruption that could result when a client retransmits a request. A legacy NFS server can choose to send a cached response when a replay is detected, rather than executing the request again. Replay detection is not perfect, but it is usually adequate.

For legacy NFS servers, replay detection commonly utilizes heuristic indicators such as the IP address of the NFS client, the source port of the connection, the transaction ID of the request, and the contents of the request's RPC and upper-layer protocol headers. In short, replay detection is typically based on a connection tuple and the request's XID. A legacy NFS client is careful to re-use the same source port, if practical, when reconnecting so that legacy NFS servers are better able to detect retransmissions.

However, a legacy NFS client operating over an RDMA transport has no control over connection source ports. It is almost certain that an RPC request that is retransmitted on a new connection can never be detected as a replay if the legacy NFS server includes the connection source port in its replay detection heuristics.

Therefore a legacy NFS server using an RDMA transport should never use a legacy NFS client connection's source port as part of RPC request replay detection.

5. Upper-Layer Bindings for NFS Version 2 and 3 Auxiliary Protocols

Storage administrators typically deploy NFS versions 2 and 3 with several other protocols, sometimes referred to as "NFS auxiliary protocols." These are distinct RPC programs that define procedures

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that are not part of the NFS RPC program (100003). The Upper-Layer Bindings in this section apply to:

- o Versions 2 and 3 of the MOUNT RPC program (100005) [[RFC1813](#)]
- o Versions 1, 3, and 4 of the NLM RPC program (100021) [[RFC1813](#)]
- o Version 1 of the NSM RPC program (100024), described in Chapter 11 of [[XNFS](#)]
- o Version 1 of the NFSACL RPC program (100227), which does not have a public definition. NFSACL is treated in this document as a de facto standard, as there are several interoperating implementations.

[5.1.](#) MOUNT, NLM, and NSM Protocols

Historically, NFS/RDMA implementations have chosen to convey the MOUNT, NLM, and NSM protocols via TCP. A legacy NFS server implementation MUST provide support for these protocols via TCP to enable interoperation of these protocols when NFS/RDMA is in use.

[5.2.](#) NFSACL Protocol

Often legacy clients and servers that support the NFSACL RPC program convey NFSACL procedures on the same connection as the NFS RPC program (100003). Utilizing the same connection obviates the need for separate rpcbind queries to discover server support for this RPC program.

ACLs are typically small, but even large ACLs must be encoded and decoded to some degree. Thus no data item in this Upper-Layer Protocol is DDP-eligible.

For procedures whose replies do not include an ACL object, the size of a reply is determined directly from the NFSACL RPC program's XDR definition. Legacy client implementations should choose a maximum size for ACLs based on internal limits.

[6.](#) Upper-Layer Binding For NFS Version 4

The Upper-Layer Binding specification in this section applies to versions of the NFS RPC program defined in NFS version 4.0 [[RFC7530](#)] NFS version 4.1 [[RFC5661](#)] and NFS version 4.2 [[RFC7862](#)].

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6.1. DDP-Eligibility

Only the following XDR data items in the COMPOUND procedure of all NFS version 4 minor versions are DDP-eligible:

- o The opaque data field in the WRITE4args structure
- o The linkdata field of the NF4LNK arm in the createtype4 union
- o The opaque data field in the READ4resok structure
- o The linkdata field in the READLINK4resok structure

6.2. Reply Size Estimation

Within NFS version 4, there are certain variable-length result data items whose maximum size cannot be estimated by clients reliably because there is no protocol-specified size limit on these result arrays. These include:

- o The attrlist4 field
- o Fields containing ACLs such as fattr4_acl, fattr4_dacl, and fattr4_sacl
- o Fields in the fs_locations4 and fs_locations_info4 data structures
- o Fields which pertain to pNFS layout metadata, such as loc_body, loh_body, da_addr_body, lou_body, lrf_body, fattr_layout_types, and fs_layout_types

6.2.1. Reply Size Estimation for Minor Version 0

The NFS version 4.0 protocol itself does not impose any bound on the size of NFS calls or responses.

Some of the data items enumerated in [Section 6.2](#) (in particular, the items related to ACLs and fs_locations) make it difficult to predict the maximum size of NFS version 4.0 replies that interrogate variable-length fattr4 attributes. Client implementations might rely upon internal architectural limits to constrain the reply size, but such limits are not always guaranteed to be reliable.

When an NFS version 4.0 client expects an especially sizeable fattr4 result, it can provide a Reply chunk to enable that server to return that result via explicit RDMA. An NFS version 4.0 client can use short Reply chunk retry when an NFS COMPOUND containing a GETATTR operation encounters a transport error.

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6.2.2. Reply Size Estimation for Minor Version 1 and Newer

In NFS version 4.1 and newer minor versions, the `csa_fore_chan_attrs` argument of the `CREATE_SESSION` operation contains a `ca_maxresponsesize` field. The value in this field can be taken as the absolute maximum size of replies generated by an NFS version 4.1 server.

A client can use this value in cases where it is not possible to estimate a reply size upper bound precisely. In practice, objects such as ACLs, named attributes, layout bodies, and security labels are much smaller than this maximum.

6.3. RPC Binding Considerations

NFS version 4 servers are required to listen on TCP port 2049, and they are not required to register with a `rpcbind` service [[RFC7530](#)].

Therefore, an NFS version 4 server supporting RPC-over-RDMA version 2 MUST use the alternative well-known port number for its RPC-over-RDMA service (see [Section 9](#) Clients SHOULD connect to this well-known port without consulting the RPC portmapper (as for NFS version 4 on TCP transports).

6.4. NFS COMPOUND Requests

6.4.1. Multiple DDP-eligible Data Items

An NFS version 4 COMPOUND procedure can contain more than one operation that carries a DDP-eligible data item. An NFS version 4 client provides XDR Position values in each Read chunk to disambiguate which chunk is associated with which argument data item. However, NFS version 4 server and client implementations must agree in advance on how to pair Write chunks with returned result data items.

In the following lists, a "READ operation" refers to any NFS version 4 operation that has a DDP-eligible result data item. An NFS version 4 client applies the mechanism specified in Section 4.3.2 of [[RPCRDMA2](#)] is applied to this class of operations as follows:

- o If an NFS version 4 client wishes all DDP-eligible items in an NFS reply to be conveyed inline, it leaves the Write list empty.

An NFS version 4 server applies that mechanism as follows:

- o The first chunk in the Write list MUST be used by the first READ operation in an NFS version 4 COMPOUND procedure. The next Write chunk is used by the next READ operation, and so on.
- o If an NFS version 4 client has provided a matching non-empty Write chunk, then the corresponding READ operation MUST return its DDP-eligible data item using that chunk.
- o If an NFS version 4 client has provided an empty matching Write chunk, then the corresponding READ operation MUST return all of its result data items inline.
- o If a READ operation returns a union arm which does not contain a DDP-eligible result, and the NFS version 4 client has provided a matching non-empty Write chunk, an NFS version 4 server MUST return an empty Write chunk in that Write list position.
- o If there are more READ operations than Write chunks, then remaining NFS Read operations in an NFS version 4 COMPOUND that have no matching Write chunk MUST return their results inline.

6.4.2. Chunk List Complexity

The RPC-over-RDMA version 2 protocol does not place any limit on the number of chunks or segments that may appear in Read or Write lists. However, for various reasons, NFS version 4 server implementations often have practical limits on the number of chunks or segments they can process in a single RPC transaction conveyed via RPC-over-RDMA version 2.

These implementation limits are especially important when Kerberos integrity or privacy is in use [[RFC7861](#)]. GSS services increase the size of credential material in RPC headers, potentially requiring the use of a Long message, which increases the complexity of chunk lists independent of the particular NFS version 4 COMPOUND being conveyed.

In the absence of explicit knowledge of the server's limits, NFS version 4 clients SHOULD follow the prescriptions listed below when constructing RPC-over-RDMA version 2 messages. NFS version 4 servers MUST accept and process all such requests.

- o The Read list can contain either a Position-Zero Read chunk, one Read chunk with a non-zero Position, or both.
- o The Write list can contain no more than one Write chunk.
- o Any chunk can contain up to sixteen RDMA segments.

NFS version 4 clients wishing to send more complex chunk lists can provide configuration interfaces to bound the complexity of NFS version 4 COMPOUNDS, limit the number of elements in scatter-gather operations, and avoid other sources of chunk overruns at the receiving peer.

If an NFS version 4 server receives an RPC request via RPC-over-RDMA version 2 that it cannot process due to chunk list complexity limits, it SHOULD return one of the following responses to the client:

- o A problem is detected by the transport layer while parsing the transport header in an RPC Call message. The server responds with an RDMA2_ERROR message with the err field set to ERR_CHUNK.
- o A problem is detected during XDR decoding of the RPC Call message while the RPC layer reassembles the call's XDR stream. The server responds with an RPC reply with its "reply_stat" field set to MSG_ACCEPTED and its "accept_stat" field set to GARBAGE_ARGS.

After receiving one of these errors, an NFS version 4 client SHOULD NOT retransmit the failing request, as the result would be the same error. It SHOULD immediately terminate the RPC transaction associated with the XID in the reply.

6.4.3. NFS Version 4 COMPOUND Example

The following example shows a Write list with three Write chunks, A, B, and C. The NFS version 4 server consumes the provided Write chunks by writing the results of the designated operations in the compound request (READ and READLINK) back to each chunk.

Write list:

A --> B --> C

NFS version 4 COMPOUND request:

PUTFH	LOOKUP	READ	PUTFH	LOOKUP	READLINK	PUTFH	LOOKUP	READ
		v			v			v
		A			B			C

If the NFS version 4 client does not want to have the READLINK result returned via RDMA, it provides an empty Write chunk for buffer B to indicate that the READLINK result must be returned inline.

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6.5. NFS Callback Requests

The NFS version 4 family of protocols support server-initiated callbacks to notify NFS version 4 clients of events such as recalled delegations.

6.5.1. NFS Version 4.0 Callback

NFS version 4.0 implementations typically employ a separate TCP connection to handle callback operations, even when the forward channel uses an RPC-over-RDMA version 2 transport.

No operation in the NFS version 4.0 callback RPC program conveys a data payload of significant size. Therefore, no XDR data items in this RPC program is DDP-eligible.

A CB_RECALL reply is small and fixed in size. The CB_GETATTR reply contains a variable-length fattr4 data item. See [Section 6.2.1](#) for a discussion of reply size prediction for this data item.

An NFS version 4.0 client advertises netids and ad hoc port addresses for contacting its NFS version 4.0 callback service using the SETCLIENTID operation.

6.5.2. NFS Version 4.1 Callback

In NFS version 4.1 and newer minor versions, callback operations may appear on the same connection as is used for NFS version 4 forward channel client requests. NFS version 4 clients and servers MUST use the approach described in [[RFC8167](#)] to convey backchannel operations on an RPC-over-RDMA version 2 transport.

The `csa_back_chan_attrs` argument of the CREATE_SESSION operation contains a `ca_maxresponsesize` field. The value in this field is the absolute maximum size of backchannel replies generated by a replying NFS version 4 client.

There are no DDP-eligible data items in callback procedures defined in NFS version 4.1 or NFS version 4.2. However, some callback operations, such as messages that convey device ID information, can be sizeable. A sender can use Message Continuation or a Long message in this situation.

When an NFS version 4.1 client can support Long Calls in its backchannel, it reports a backchannel `ca_maxrequestsize` that is larger than the connection's inline thresholds. Otherwise, an NFS version 4 server MUST use only Short messages to convey backchannel operations.

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6.6. Session-Related Considerations

The presence of an NFS version 4 session (as defined in [\[RFC5661\]](#)) does not effect the operation of RPC-over-RDMA version 2. None of the operations introduced to support NFS sessions (e.g., the SEQUENCE operation) contain DDP-eligible data items. There is no need to match the number of session slots with the number of available RPC-over-RDMA version 2 credits.

However, there are a few new cases where an RPC transaction can fail. For example, a Requester might receive, in response to an RPC request, an RDMA2_ERROR message with a rdma_err value of ERR_CHUNK. These situations are not different from existing RPC errors, which an NFS session implementation can already handle for other transport types. Moreover, there might be no SEQUENCE result available to the Requester to distinguish whether failure occurred before or after the Responder executed the requested operations.

When a transport error occurs (e.g., an RDMA2_ERROR type message is received), the Requester proceeds, as usual, to match the incoming XID value to a waiting RPC Call. The Requester terminates the RPC transaction and reports the result status to the RPC consumer. The Requester's session implementation then determines the session ID and slot for the failed request and performs slot recovery to make that slot usable again. Otherwise, that slot could be rendered permanently unavailable.

When an NFS session is not present (for example, when NFS version 4.0 is in use), a transport error does not indicate whether the server has processed the arguments of the RPC Call, or whether the server has accessed or modified client memory associated with that RPC.

6.7. Transport Considerations

6.7.1. Congestion Avoidance

[Section 3.1 of \[RFC7530\]](#) states:

Where an NFS version 4 implementation supports operation over the IP network protocol, the supported transport layer between NFS and IP MUST be an IETF standardized transport protocol that is specified to avoid network congestion; such transports include TCP and the Stream Control Transmission Protocol (SCTP).

[Section 2.9.1 of \[RFC5661\]](#) further states:

Even if NFS version 4.1 is used over a non-IP network protocol, it is RECOMMENDED that the transport support congestion control.

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It is permissible for a connectionless transport to be used under NFS version 4.1; however, reliable and in-order delivery of data combined with congestion control by the connectionless transport is REQUIRED. As a consequence, UDP by itself MUST NOT be used as an NFS version 4.1 transport.

RPC-over-RDMA version 2 utilizes only RDMA Reliable Connected QP type connections [[RPCRDMA2](#)]. RDMA Reliable Connected QPs are reliable, connection-oriented transports that guarantee in-order delivery, meeting all the above requirements.

6.7.2. Retransmission and Keep-alive

NFS version 4 client implementations often rely on a transport-layer keep-alive mechanism to detect when an NFS version 4 server has become unresponsive. When an NFS server is no longer responsive, client-side keep-alive terminates the connection, which in turn triggers reconnection and RPC retransmission.

Some RDMA transports (such as the Reliable Connected QP type on InfiniBand) have no keep-alive mechanism. Without a disconnect or new RPC traffic, such connections can remain alive long after an NFS server has become unresponsive. Once an NFS client has consumed all available RPC-over-RDMA version 2 credits on that transport connection, it indefinitely awaits a reply before sending another RPC request.

NFS version 4 clients SHOULD reserve one RPC-over-RDMA version 2 credit to use for periodic server or connection health assessment. Either peer can use this credit to drive an RPC request on an otherwise idle connection, triggering either a quick affirmative server response or immediate connection termination.

In addition to network partition and request loss scenarios, RPC-over-RDMA version 2 transport connections can be terminated when a Transport header is malformed, Reply messages exceed receive resources, or when too many RPC-over-RDMA messages are sent at once. In such cases:

- o If a transport error occurs (e.g., an RDMA2_ERROR type message is received) before the disconnect or instead of a disconnect, the Requester MUST respond to that error as prescribed by the specification of the RPC transport. Then the NFS version 4 rules for handling retransmission apply.
- o If there is a transport disconnect and the Responder has provided no other response for a request, then only the NFS version 4 rules for handling retransmission apply.

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7. Extending NFS Upper-Layer Bindings

RPC programs such as NFS are required to have an Upper-Layer Binding specification to interoperate on RPC-over-RDMA version 2 transports [[RPCRDMA2](#)]. Via standards action, the Upper-Layer Binding specified in this document can be extended to cover versions of the NFS version 4 protocol specified after NFS version 4 minor version 2, or to cover separately published extensions to an existing NFS version 4 minor version, as described in [[RFC8178](#)].

8. Security Considerations

RPC-over-RDMA version 2 supports all RPC security models, including RPCSEC_GSS security and transport-level security [[RFC7861](#)]. The choice of what Direct Data Placement mechanism to convey RPC argument and results does not affect this since it changes only the method of data transfer. Because the current document defines only the binding of the NFS protocols atop [[RPCRDMA2](#)], all relevant security considerations are, therefore, described at that layer.

9. IANA Considerations

The use of direct data placement in NFS introduces a need for an additional port number assignment for networks that share traditional UDP and TCP port spaces with RDMA services. The iWARP protocol is such an example [[RFC5040](#)] [[RFC5041](#)].

For this purpose, the current document specifies a set of transport protocol port number assignments. IANA has assigned the following ports for NFS/RDMA in the IANA port registry, according to the guidelines described in [[RFC6335](#)].

```
nfsrdma 20049/tcp Network File System (NFS) over RDMA
nfsrdma 20049/udp Network File System (NFS) over RDMA
nfsrdma 20049/sctp Network File System (NFS) over RDMA
```

The current document should be added as a reference for the nfsrdma port assignments. The current document does not alter these assignments.

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