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# WebNFS Client Specification

## Status of this Memo

This memo provides information for the Internet community. This memo does not specify an Internet standard of any kind. Distribution of this memo is unlimited.

## Abstract

This document describes a lightweight binding mechanism that allows NFS clients to obtain service from WebNFS-enabled servers with a minimum of protocol overhead. In removing this overhead, WebNFS clients see benefits in faster response to requests, easy transit of packet filter firewalls and TCP-based proxies, and better server scalability.

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## 1. Introduction

The NFS protocol provides access to shared filesystems across networks. It is designed to be machine, operating system, network architecture, and transport protocol independent. The protocol currently exists in two versions: version 2 [RFC1094] and version 3 [RFC1813], both built on Sun RPC [RFC1831] at its associated eXternal Data Representation (XDR) [RFC1832] and Binding Protocol [RFC1833].

WebNFS provides additional semantics that can be applied to NFS version 2 and 3 to eliminate the overhead of PORTMAP and MOUNT protocols, make the protocol easier to use where firewall transit is required, and reduce the number of LOOKUP requests required to identify a particular file on the server. WebNFS server requirements are described in RFC 2055.

## 2. TCP vs UDP

The NFS protocol is most well known for its use of UDP which performs acceptably on local area networks. However, on wide area networks with error prone, high-latency connections and bandwidth contention, TCP is well respected for its congestion control and superior error handling. A growing number of NFS implementations now support the NFS protocol over TCP connections.

Use of NFS version 3 is particularly well matched to the use of TCP as a transport protocol. Version 3 removes the arbitrary 8k transfer size limit of version 2, allowing the READ or WRITE of very large streams of data over a TCP connection. Note that NFS version 2 is also supported on TCP connections, though the benefits of TCP data streaming will not be as great.

A WebNFS client must first attempt to connect to its server with a TCP connection. If the server refuses the connection, the client should attempt to use UDP.

## 3. Well-known Port

While Internet protocols are generally identified by registered port number assignments, RPC based protocols register a 32 bit program number and a dynamically assigned port with the portmap service which is registered on the well-known port 111. Since the NFS protocol is RPC-based, NFS servers register their port assignment with the portmap service.

NFS servers are constrained by a requirement to re-register at the same port after a server crash and recovery so that clients can recover simply by retransmitting an RPC request until a response is received. This is simpler than the alternative of having the client repeatedly check with the portmap service for a new port assignment. NFS servers typically achieve this port invariance by registering a constant port assignment, 2049, for both UDP and TCP.

To avoid the overhead of contacting the server’s portmap service, and to facilitate transit through packet filtering firewalls, WebNFS clients optimistically assume that WebNFS servers register on port 2049. Most NFS servers use this port assignment already, so this client optimism is well justified. Refer to section 8 for further details on port binding.

## 4. NFS Version 3

NFS version 3 corrects deficiencies in version 2 of the protocol as well as providing a number of features suitable to WebNFS clients accessing servers over high-latency, low-bandwidth connections.

### 4.1 Transfer Size

NFS version 2 limited the amount of data in a single request or reply to 8 kilobytes. This limit was based on what was then considered a reasonable upper bound on the amount of data that could be transmitted in a UDP datagram across an Ethernet. The 8k transfer size limitation affects READ, WRITE, and READDIR requests. When using version 2, a WebNFS client must not transmit any request that exceeds the 8k transfer size. Additionally, the client must be able to adjust its requests to suit servers that limit transfer sizes to values smaller than 8k.

NFS version 3 removes the 8k limit, allowing the client and server to negotiate whatever limit they choose. Larger transfer sizes are preferred since they require fewer READ or WRITE requests to transfer a given amount of data and utilize a TCP stream more efficiently.

While the client can use the FSINFO procedure to request the server’s maximum and preferred transfer sizes, in the interests of keeping the number of NFS requests to a minimum, WebNFS clients should optimistically choose a transfer size and make corrections if necessary based on the server’s response.

For instance, given that the file attributes returned with the filehandle from a LOOKUP request indicate that the file has a size of 50k, the client might transmit a READ request for 50k. If the server returns only 32k, then the client can assume that the server’s maximum transfer size is 32k and issue another read request for the remaining data. The server will indicate positively when the end of file is reached.

A similar strategy can be used when writing to a file on the server, though the client should be more conservative in choosing write request sizes so as to avoid transmitting large amounts of data that the server cannot handle.

## 4.2 Fast Writes

NFS version 2 requires the server to write client data to stable storage before responding to the client. This avoids the possibility of the the server crashing and losing the client's data after a positive response. While this requirement protects the client from data loss, it requires that the server direct client write requests directly to the disk, or to buffer client data in expensive non-volatile memory (NVRAM). Either way, the effect is poor write performance, either through inefficient synchronous writes to the disk or through the limited buffering available in NVRAM.

NFS version 3 provides clients with the option of having the server buffer a series of WRITE requests in unstable storage. A subsequent COMMIT request from the client will have the server flush the data to stable storage and have the client verify that the server lost none of the data. Since fast writes benefit both the client and the server, WebNFS clients should use WRITE/COMMIT when writing to the server.

## 4.3 READDIRPLUS

The NFS version 2 READDIR procedure is also supported in version 3. READDIR returns the names of the entries in a directory along with their fileids. Browser programs that display directory contents as a list will usually display more than just the filename; a different icon may be displayed if the entry is a directory or a file. Similarly, the browser may display the file size, and date of last modification.

Since this additional information is not returned by READDIR, version 2 clients must issue a series of LOOKUP requests, one per directory member, to retrieve the attribute data. Clearly this is an expensive operation where the directory is large (perhaps several hundred entries) and the network latency is high.

The version 3 READDIRPLUS request allows the client to retrieve not only the names of the directory entries, but also their file attributes and filehandles in a single call. WebNFS clients that require attribute information for directory entries should use READDIRPLUS in preference to READDIR.

## 5. Public Filehandle

NFS filehandles are normally created by the server and used to identify uniquely a particular file or directory on the server. The client does not normally create filehandles or have any knowledge of the contents of a filehandle.

The public filehandle is an an exception. It is an NFS filehandle with a reserved value and special semantics that allow an initial filehandle to be obtained. A WebNFS client can use the public filehandle as an initial filehandle rather than using the MOUNT protocol. Since NFS version 2 and version 3 have different filehandle formats, the public filehandle is defined differently for each.

The public filehandle is a zero filehandle. For NFS version 2 this is a filehandle with 32 zero octets. A version 3 public filehandle has zero length.

### 5.1 NFS Version 2 Public Filehandle

A version 2 filehandle is defined in RFC 1094 as an opaque value occupying 32 octets. A version 2 public filehandle has a zero in each octet, i.e. all zeros.

```
 1                                                             32
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

### 5.2 NFS Version 3 Public Filehandle

A version 3 filehandle is defined in RFC 1813 as a variable length opaque value occupying up to 64 octets. The length of the filehandle is indicated by an integer value contained in a 4 octet value which describes the number of valid octets that follow. A version 3 public filehandle has a length of zero.

```
+-+-+-+-+
|   0   |
+-+-+-+-+
```

## 6. Multi-component Lookup

Normally the NFS LOOKUP request (version 2 or 3) takes a directory filehandle along with the name of a directory member, and returns the filehandle of the directory member. If a client needs to evaluate a pathname that contains a sequence of components, then beginning with the directory filehandle of the first component it must issue a series of LOOKUP requests one component at a time. For instance, evaluation of the Unix path "a/b/c" will generate separate LOOKUP requests for each component of the pathname "a", "b", and "c".

A LOOKUP request that uses the public filehandle can provide a pathname containing multiple components. The server is expected to evaluate the entire pathname and return a filehandle for the final component. Both canonical (slash-separated) and server native pathnames are supported.

For example, rather than evaluate the path "a/b/c" as:

```
     LOOKUP  FH=0x0  "a"  --->
                          <---  FH=0x1
     LOOKUP  FH=0x1  "b"  --->
                          <---  FH=0x2
     LOOKUP  FH=0x2  "c"  --->
                          <---  FH=0x3
```

Relative to the public filehandle these three LOOKUP requests can be replaced by a single multi-component lookup:

```
     LOOKUP  FH=0x0  "a/b/c"  --->
                              <---  FH=0x3
```

Multi-component lookup is supported only for LOOKUP requests relative to the public filehandle.

### 6.1 Canonical Path vs. Native Path

If the pathname in a multi-component LOOKUP request begins with an ASCII character, then it must be a canonical path. A canonical path is a hierarchically-related, slash-separated sequence of components, <directory>/<directory>/.../<name>. Occurrences of the "/" character within a component must be escaped using the escape code %2f. Non-ascii characters within components must also be escaped using the "%" character to introduce a two digit hexadecimal code. Occurrences of the "%" character that do not introduce an encoded character must themselves be encoded with %25.

If the first character of the path is a slash, then the canonical path will be evaluated relative to the server's root directory. If the first character is not a slash, then the path will be evaluated relative to the directory with which the public filehandle is associated.

Not all WebNFS servers can support arbitrary use of absolute paths. Clearly, the server cannot return a filehandle if the path identifies a file or directory that is not exported by the server. In addition, some servers will not return a filehandle if the path names a file or directory in an exported filesystem different from the one that is associated with the public filehandle.

If the first character of the path is 0x80 (non-ascii) then the following character is the first in a native path. A native path conforms to the normal pathname syntax of the server. For example:

```
     Lookup for Canonical Path:

             LOOKUP FH=0x0 "/a/b/c"

     Lookup for Native Path:

             LOOKUP FH=0x0  0x80 "a:b:c"
```

## 6.2 Symbolic Links

On Unix servers, components within a pathname may be symbolic links. The server will evaluate these symbolic links as a part of the normal pathname evaluation process. If the final component is a symbolic link, the server will return its filehandle, rather than evaluate it.

If the attributes returned with a filehandle indicate that it refers to a symbolic link, then it is the client's responsibility to deal with the link by fetching the contents of the link using the READLINK procedure. What follows is determined by the contents of the link.

Evaluation of symbolic links by the client is defined only if the symbolic link is retrieved via the multi-component lookup of a canonical path.

### 6.2.1 Absolute Link

If the first character of the link text is a slash "/", then the following path can be assumed to be absolute. The entire path must be evaluated by the server relative to the public filehandle:

```
     LOOKUP  FH=0x0  "a/b"  --->
                            <---  FH=0x1 (symbolic link)
     READLINK FH=0x1        --->
                            <---  "/x/y"
     LOOKUP  FH=0x0  "/x/y"
                            <---  FH=0x2
```

So in this case the client just passes the link text back to the server for evaluation.

### 6.2.2 Relative Link

If the first character of the link text is not a slash, then the following path can be assumed to be relative to the location of the symbolic link. To evaluate this correctly, the client must substitute the link text in place of the final pathname component that named the link and issue a another LOOKUP relative to the public filehandle.

```
     LOOKUP  FH=0x0  "a/b"  --->
                            <---  FH=0x1 (symbolic link)
     READLINK FH=0x1        --->
                            <---  "x/y"
     LOOKUP  FH=0x0  "a/x/y"
                            <---  FH=0x2
```

By substituting the link text in the link path and having the server evaluate the new path, the server effectively gets to evaluate the link relative to the link's location.

The client may also "clean up" the resulting pathname by removing redundant components as described in Section 4. of RFC 1808.

## 6.3 Filesystem Spanning Pathnames

NFS LOOKUP requests normally do not cross from one filesystem to another on the server.  For instance if the server has the following export and mounts:

```
/export           (exported)

/export/bigdata   (mountpoint)
```

then an NFS LOOKUP for "bigdata" using the filehandle for "/export" will return a "no file" error because the LOOKUP request did not cross the mountpoint on the server.  There is a practical reason for this limitation: if the server permitted the mountpoint crossing to occur, then a Unix client might receive ambiguous fileid information inconsistent with it’s view of a single remote mount for "/export". It is expected that the client resolve this by mirroring the additional server mount, e.g.

```
Client                            Server

/mnt         <--- mounted on --- /export

/mnt/bigdata <--- mounted on --- /export/bigdata
```

However, this semantic changes if the client issues the filesystem spanning LOOKUP relative to the public filehandle. If the following filesystems are exported:

```
/export           (exported public)

/export/bigdata   (exported mountpoint)
```

then an NFS LOOKUP for "bigdata" relative to the public filehandle will cross the mountpoint - just as if the client had issued a MOUNT request - but only if the new filesystem is exported, and only if the server supports Export Spanning Pathnames described in Section 6.3 of RFC 2055 [RFC2055].

## 7. Contacting the Server

WebNFS clients should be optimistic in assuming that the server supports WebNFS, but should be capable of fallback to conventional methods for server access if the server does not support WebNFS.

The client should start with the assumption that the server supports:

- NFS version 3.

- NFS TCP connections.

- Public Filehandles.

If these assumptions are not met, the client should fall back gracefully with a minimum number of messages. The following steps are recommended:

1. Attempt to create a TCP connection to the server’s port 2049.

   If the connection fails then assume that a request sent over UDP will work. Use UDP port 2049.

   Do not use the PORTMAP protocol to determine the server’s port unless the server does not respond to port 2049 for both TCP and UDP.

2. Assume WebNFS and V3 are supported.
   Send an NFS version 3 LOOKUP with the public filehandle for the requested pathname.

   If the server returns an RPC PROG_MISMATCH error then assume that NFS version 3 is not supported. Retry the LOOKUP with an NFS version 2 public filehandle.

   Note: The first call may not necessarily be a LOOKUP if the operation is directed at the public filehandle itself, e.g. a READDIR or READDIRPLUS of the directory that is associated with the public filehandle.

   If the server returns an NFS3ERR_STALE, NFS3ERR_INVAL, or NFS3ERR_BADHANDLE error, then assume that the server does not support WebNFS since it does not recognize the public filehandle. The client must use the server’s portmap service to locate and use the MOUNT protocol to obtain an initial filehandle for the requested path.

WebNFS clients can benefit by caching information about the server: whether the server supports TCP connections (if TCP is supported then the client should cache the TCP connection as well), which protocol the server supports and whether the server supports public filehandles. If the server does not support public filehandles, the client may choose to cache the port assignment of the MOUNT service as well as previously used pathnames and their filehandles.

## 8. Mount Protocol

If the server returns an error to the client that indicates no support for public filehandles, the client must use the MOUNT protocol to convert the given pathname to a filehandle.  Version 1 of the MOUNT protocol is described in Appendix A of RFC 1094 and version 3 in Appendix I of RFC 1813. Version 2 of the MOUNT protocol is identical to version 1 except for the addition of a procedure MOUNTPROC_PATHCONF which returns POSIX pathconf information from the server.

At this point the client must already have some indication as to which version of the NFS protocol is supported on the server.  Since the filehandle format differs between NFS versions 2 and 3, the client must select the appropriate version of the MOUNT protocol. MOUNT versions 1 and 2 return only NFS version 2 filehandles, whereas MOUNT version 3 returns NFS version 3 filehandles.

Unlike the NFS service, the MOUNT service is not registered on a well-known port.  The client must use the PORTMAP service to locate the server’s MOUNT port before it can transmit a MOUNTPROC_MNT request to retrieve the filehandle corresponding to the requested path.

```
    Client                                       Server
    ------                                       ------

    -------------- MOUNT port ? -------------->  Portmapper
    <-------------- Port=984 ------------------

    ------- Filehandle for /export/foo ?  ---->  Mountd @ port 984
    <--------- Filehandle=0xf82455ce0..  ------
```

NFS servers commonly use a client’s successful MOUNTPROC_MNT request request as an indication that the client has "mounted" the filesystem and may maintain this information in a file that lists the filesystems that clients currently have mounted.  This information is removed from the file when the client transmits an MOUNTPROC_UMNT request.  Upon receiving a successful reply to a MOUNTPROC_MNT request, a WebNFS client should send a MOUNTPROC_UMNT request to prevent an accumulation of "mounted" records on the server.

Note that the additional overhead of the PORTMAP and MOUNT protocols will have an effect on the client’s binding time to the server and the dynamic port assignment of the MOUNT protocol may preclude easy firewall or proxy server transit.

The client may regain some performance improvement by utilizing a pathname prefix cache. For instance, if the client already has a filehandle for the pathname "a/b" then there is a good chance that the filehandle for "a/b/c" can be recovered by by a lookup of "c" relative to the filehandle for "a/b", eliminating the need to have the MOUNT protocol translate the pathname. However, there are risks in doing this. Since the LOOKUP response provides no indication of filesystem mountpoint crossing on the server, the relative LOOKUP may fail, since NFS requests do not normally cross mountpoints on the server. The MOUNT service can be relied upon to evaluate the pathname correctly - including the crossing of mountpoints where necessary.

## 9. Exploiting Concurrency

NFS servers are known for their high capacity and their responsiveness to clients transmitting multiple concurrent requests. For best performance, a WebNFS client should take advantage of server concurrency. The RPC protocol on which the NFS protocol is based, provides transport-independent support for this concurrency via a unique transaction ID (XID) in every NFS request.

There is no need for a client to open multiple TCP connections to transmit concurrent requests. The RPC record marking protocol allows the client to transmit and receive a stream of NFS requests and replies over a single connection.

### 9.1 Read-ahead

To keep the number of READ requests to a minimum, a  WebNFS client should use the maximum transfer size that it and the server can support. The client can often optimize utilization of the link bandwidth by transmitting concurrent READ requests. The optimum number of READ requests needs to be determined dynamically taking into account the available bandwidth, link latency, and I/O bandwidth of the client and server, e.g. the following series of READ requests show a client using a single read-ahead to transfer a 128k file from the server with 32k READ requests:

```
     READ XID=77 offset=0   for 32k  -->
     READ XID=78 offset=32k for 32k  -->
                               <-- Data for XID 77
     READ XID=79 offset=64k for 32k  -->
                               <-- Data for XID 78
     READ XID=80 offset=96k for 32k  -->
                               <-- Data for XID 79
                               <-- Data for XID 80
```

The client must be able to handle the return of data out of order. For instance, in the above example the data for XID 78 may be received before the data for XID 77.

The client should be careful not to use read-ahead beyond the capacity of the server, network, or client, to handle the data. This might be determined by a heuristic that measures throughput as the download proceeds.

## 9.2 Concurrent File Download

A client may combine read-ahead with concurrent download of multiple files.  A practical example is that of Web pages that contain multiple images, or a Java Applet that imports multiple class files from the server.

Omitting read-ahead for clarity, the download of multiple files, "file1", "file2", and "file3" might look something like this:

```
     LOOKUP XID=77 0x0 "file1"         -->
     LOOKUP XID=78 0x0 "file2"         -->
     LOOKUP XID=79 0x0 "file3"         -->
                                       <-- FH=0x01 for XID 77
     READ XID=80 0x01 offset=0 for 32k -->
                                       <-- FH=0x02 for XID 78
     READ XID=81 0x02 offset=0 for 32k -->
                                       <-- FH=0x03 for XID 79
     READ XID=82 0x03 offset=0 for 32k -->
                                       <-- Data for XID 80
                                       <-- Data for XID 81
                                       <-- Data for XID 82
```

Note that the replies may be received in a different order from the order in which the requests were transmitted. This is not a problem, since RPC uses the XID to match requests with replies.  A benefit of the request/reply multiplexing provided by the RPC protocol is that the download of a large file that requires many READ requests will not delay the concurrent download of smaller files.

Again, the client must be careful not to drown the server with download requests.

## 10.0 Timeout and Retransmission

A WebNFS client should follow the example of conventional NFS clients and handle server or network outages gracefully.  If a reply is not received within a given timeout, the client should retransmit the request with its original XID (described in Section 8 of RFC 1831).

The XID can be used by the server to detect duplicate requests and avoid unnecessary work.

While it would seem that retransmission over a TCP connection is unnecessary (since TCP is responsible for detecting and retransmitting lost data), at the RPC layer retransmission is still required for recovery from a lost TCP connection, perhaps due to a server crash or, because of resource limitations, the server has closed the connection.  When the TCP connection is lost, the client must re-establish the connection and retransmit pending requests.

The client should set the request timeout according to the following guidelines:

- A timeout that is too small may result in the wasteful transmission of duplicate requests. The server may be just slow to respond, either because it is heavily loaded, or because the link latency is high.

- A timeout that is too large may harm throughput if the request is lost and the connection is idle waiting for the retransmission to occur.

- The optimum timeout may vary with the server’s responsiveness over time, and with the congestion and latency of the network.

- The optimum timeout will vary with the type of NFS request.  For instance, the response to a LOOKUP request will be received more quickly than the response to a READ request.

- The timeout should be increased according to an exponential backoff until a limit is reached. For instance, if the timeout is 1 second, the first retransmitted request should have a timeout of two seconds, the second retransmission 4 seconds, and so on until the timeout reaches a limit, say 30 seconds. This avoids flooding the network with retransmission requests when the server is down, or overloaded.

As a general rule of thumb, the client should start with a long timeout until the server’s responsiveness is determined.  The timeout can then be set to a value that reflects the server’s responsiveness to previous requests.

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## 12. Security Considerations

Since the WebNFS server features are based on NFS protocol versions 2 and 3, the RPC based security considerations described in RFC 1094, RFC 1831, and RFC 1832 apply here also.

Clients and servers may separately negotiate secure connection schemes for authentication, data integrity, and privacy.

## 13. Acknowledgements

This specification was extensively reviewed by the NFS group at SunSoft and brainstormed by Michael Eisler.

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