

Enhancing performance and reliability of Network File System

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Abstract—Network File System is a widely used distributed file system that allows the user to access and manipulate storage on remote computers, as if they were a part of the local machine. Network File System is notoriously slow in its default configuration and if more clients connects to the NFS environment, it merely accentuates the delay. When configured to deliver faster speeds, the system suffers from higher risk of data corruption and loss.

This study proposes a number of modifications to the Network File System, enabling it to provide elevated system performance, while containing the risk of data loss and corruption. Further, the proposed system behaves better in congested networks by consuming less bandwidth, ensuring decent speeds, even during periods of heavy network traffic.

Index Terms—UNIX, NFS, Performance, Data loss, Data corruption

The aforestated configuration diminishes the possibilities of interactive computing, and an Operating System requiring access to data on NFS share, often ends up freezing the computer, resulting in loss of human productivity. Moreover, this bottlenecks the computer CPU, wasting valuable computing resources.

This paper proposes a number of changes to the Network File System protocol which increases the performance of Network File System while reducing the risk of data corruption and loss. The proposed system also ensures decent speeds in congested network as it consumes less bandwidth than the original NFS implementation and protects the ability of the NFS server to continue providing access to files during period of peak load.

I. INTRODUCTION

Network File System is a distributed File System protocol primarily used by the UNIX family of Operating Systems. It allows users to mount, access and manipulate disk partitions or directories on a remote computer, as if the said partition or directory was a part of the local machine. Network File System was developed as an open standard by SUN Microsystems in 1984.

NFS is widely used in Local Area Networks to conveniently share data, and provides users the ability to access their files across the network. Occasionally, a directory access protocol such as LDAP is combined with NFS, allowing the users to login to their user accounts from any computer on the network.

The main drawback of NFS is the slow read and write speeds it offers with the default setup. The current performance enhancing parameters in its configuration files, either leave the performance rates unaffected or increases the probability of data corruption and loss. Thus the users are forced to run the system with the default, slow configuration.

II. BACKGROUND WORK

Past studies have proposed new Network File System protocols for transmitting data over Wide Area Networks. Some other research have dealt with improving the performance of NFS over wireless links.

A.Muthitacharoen Et al. has proposed a Low Bandwidth Network File System, which can be used over Wide Area Networks such as the Internet. Though it minimizes the bandwidth usage of the protocol, it is meant for '90s era internet. To use it in current scenario would require extensive modification to the protocol and it is not compatible with SUN's NFS.

R.Dube Et al. has proposed several changes to the network stack to increase the performance of NFS over wireless links. The paper does not suggest changes to the NFS protocol, instead it tries to optimize the wireless network stack.

In our literature review, we are yet to come across a research, which squarely deals with enhancing the performance and reducing data corruption rates of the widely adopted

Network File System protocol, originally implemented by SUN Microsystems.

III. RESEARCH METHODOLOGY

All the benchmarks for this research study have been done using NFS v4.2. The NFS environment encompassing the client and server, was emulated using virtual machines, with the Oracle VirtualBox hypervisor. Virtual Machines (VMs) provide a convenient method of simulating target hardware and networking infrastructure. The VirtualBox hypervisor was run on RedHat Enterprise Linux 7.2, with the hardware being a powerful Xeon workstation (HP-Z640) to ensure the VMs were not bottlenecked during benchmarks. The VMs were equipped with an AMD PCnet-FAST III 100 Mbps network adapter which was bridged to the network, so that each VM represented a real machine on the network. Network Address Translation (NAT) was not used as it consumes CPU resources, which could in turn affect benchmarks. The NFS server and client VMs were set up to run Debian 9.3 (Stable) as their OS. Debian is a heavily tested distribution that ships with highly stable packages. Debian was chosen so as to minimize the chance of bugs affecting the benchmarks.

The benchmarking tools used include Bonnie ++, Phoronix Test Suite/iozone, Phoronix Test Suite/dbench, Stand-alone Dbench and the "dd" utility. dd was used to benchmark NFS performance per client and to cancel out the effects of client side read/write caches. Dbench is a powerful benchmarking tool designed to test the performance of NFS and SMB systems. It is capable of emulating upto 512 clients. All the benchmarks were done with Dbench tool emulating 6 clients. Higher number of clients not used to avoid choking the server. Benchmarking was often done through proper combination of all these tools. When eliminating client side cache effect was required, dd was run with "conv=fdatasync bs=1K" options to flush data from cache after write of each Kilobyte. Each test was run three times, and the average of the results obtained were taken as the final result.

IV. WORKING AND TYPICAL PERFORMANCE OF NFS

Remote Procedure Call (RPC) in External Data Representation (XDR) format. RPC allows the NFS client to execute instructions on the server. XDR is a data representation standard that provides a uniform data format, comprehensible by a variety of computers. This is one of the factors that provides NFS with cross platform compatibility. The working of NFS protocol has been shown in Fig. 1. NFS by default runs in what is called server side synchronous mode. In this mode, when the NFS client receives a write operation, it connects to the server, requests a write and eventually transfers the data. Once the transfer is complete, the server syncs the data to its disks. On completion of the sync operation, the server then returns an acknowledgment message back to the client. The issue arises with the prolonged waiting period the client endures for the required acknowledgement. This considerably slows down the system. Furthermore, clients are often configured to work in client side synchronous mode, wherein the client is forced to

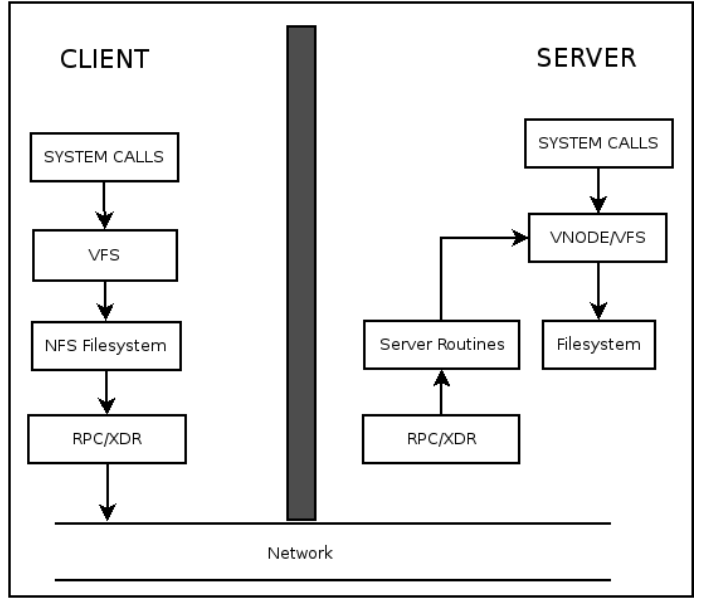


Fig. 1. VFS-NFS handover.

write the data to the server as soon as it receives the request. This often causes the system to crawl.

The performance of an NFS system with client and server side synchronous mode turned on was benchmarked with client side options in /etc/fstab set as [rw, sync, hard, intr 0 0] and the server side options in /etc/exports set as [rw, no-root-squash, subtree-check]. The benchmarks were conducted using dbench utility part of Phoronix Test Suite. This resulted in a performance of 0.94 MB/s. The speeds obtained are thus clearly sub-optimal. The performance graph obtained from the benchmark has been shown in Fig. 2.

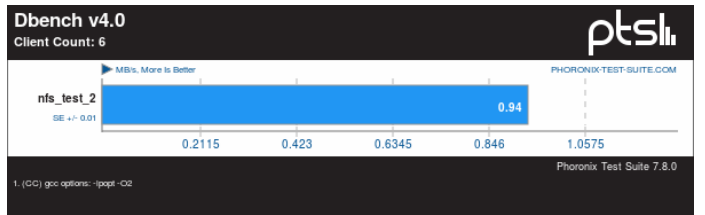


Fig. 2. Performance with client and server sync.

V. PARAMETERS AFFECTING PERFORMANCE

NFS configuration at the client end are in /etc/fstab file, while at the server end, the configuration are in /etc/exports file. The commonly used options are listed in TABLE I and TABLE II. Various combinations of these options were benchmarked. It was observed that most of the options did not improve the performance of the NFS environment. Server performance remained at 0.94 MB/s.

One significant characteristic observed was that the client side UDP option reduced the speeds to 0.77 MB/s. The end of experiments resulted in the observation that, only the client

TABLE I
NFS OPTIONS-CLIENT SIDE

SlNo.	Option	Description
1	rw	Read/Write
2	syn	Sync file system with the server
3	hard	NFS requests are retried indefinitely
4	intr	Provided for backward compatibility
5	nfsvers	Specifies the nfs versions
6	rsize	Maximum number of bytes when reading data
7	wsize	Maximum number of bytes when writing data
8	udp	Specifies the connection to UDP
9	async	Asynchronous write

TABLE II
NFS OPTIONS-SERVER SIDE

SlNo.	Option	Description
1	rw	Read/Write
2	no-root-squash	Turn off root squashing
3	subtree-check	Specified directory/its subrectory for access
4	async	Synchronous write
5	sync	Asynchronous write

and server side asynchronous mode provided a considerable elevation in performance.

VI. PERFORMANCE WITH SERVER SIDE ASYNC

In server side synchronous mode, the server waits till the data has been written to its disk before returning the acknowledgment message to the client. Server side asynchronous mode changes the behaviour of NFS server such that it returns the acknowledgment message as soon as the client completes the transfer of data to server's buffer. This has tremendous impact on the performance of the system.

An NFS system with server side asynchronous mode was benchmarked with the client side options in /etc/fstab set as [rw, sync, hard, intr 0 0] and server side options in /etc/exports set as [rw, no-root-squash, no-subtree-check, async]. The test conducted using dbench resulted in 28.72 MB/s, a huge boost in performance, compared with side synchronous mode, which returned 0.94 MB/s in dbench. The performance graph obtained has been shown in Fig 3. Benchmarks were also



Fig. 3. Performance with client side sync and server side async.

conducted with dd utility, with a block size of 1KB, file size of 2GB and fdatsync option turned on. The aim was to measure the worst case performance of server side asynchronous mode. The benchmark resulted in 7.1 MB/s which was still significantly higher than results recorded with server side synchronous mode with caching.

The higher performance comes from the fact that the clients no longer have to wait till the server syncs the data with its disks. Clients can transfer data to the server's buffer and get on with other tasks such as writing additional files. This also means that more number of clients can access the server in unit time. Still, with the current protocol, it is not advisable to leave server side async turned on due to the possibility of data loss and corruption.

A. Reliability concerns with Server side ASYNC

An advantage of enabling server side asynchronous mode is that, more clients can access the server in unit time. A side effect is that it can cause a write queue to form on the client side. That is, writing a file to the server gives no guarantee that it has been written to permanent storage. In the event of a server crash, the data written immediately before can be lost. Frustrating part is when the data loss affects most of the clients which has written to the server shortly before the crash, and not just a single computer.

If a server crash occurs, a client has no means of protecting itself from the data loss. A client has no NFS cache that is permanent in nature. Even if the client has the lost file in its primary memory, there is a high chance of losing it. This is because, if prior to crash the server was serving a critical configuration file, the application dependant on the file can crash as well. If the application is part of the Operating System, it can bring down the whole system. The latter is often the case with environments where home directory is served by an NFS share. Thus, with the current system, server side asynchronous mode is rather a risky option to leave turned on.

B. Fixing server side ASYNC behaviour

Once NFS handovers the write request to the NFS client, it transfers the received data to the server rather than writing it to the local storage. In case of data loss, the file cannot be recovered, as the only copy of the file was in the server's memory. The solution is to create a buffer in the client's local storage such that, a copy of all the data written to the server will be kept with the client.

The buffer is a predefined storage area in the client's secondary memory. It acts like a ring buffer with a flexible memory size. The oldest files are deleted once the buffer reaches a predefined size. The NFS client will maintain a plaintext file in the buffer containing, names of each file in the buffer, its path and hash generated from each file. During an NFS write operation, the client stores a copy of the file in the buffer area and updates the metadata file with the information regarding the new file. The hash is calculated whenever a file is written to the buffer. To minimize the CPU overhead for hash calculation, a lightweight hashing algorithm such as QUARK or PHOTON is implemented. The following figure shows the working and structure of the buffer.

In case of a server crash, the server creates a list of corrupted or lost files. During the first boot after the crash, the server requests the metadata file from each client that connects to it. Once the server receives the metadata, it calculates the hash

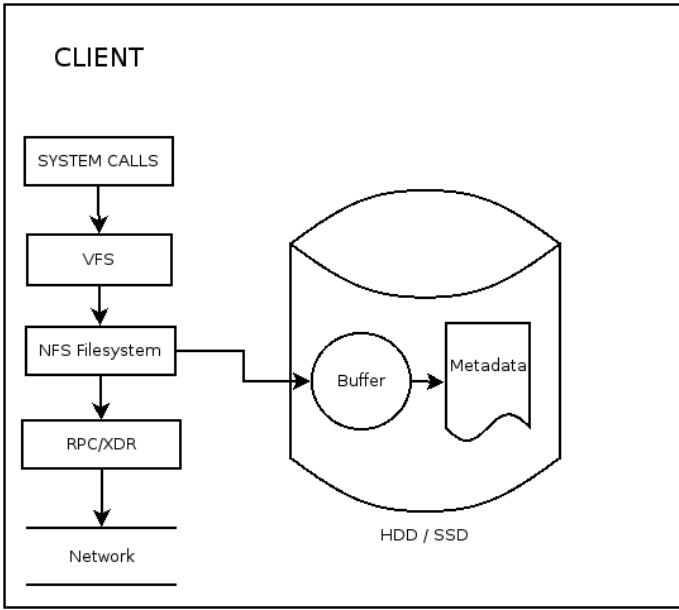


Fig. 4. Working and structure of buffer and metadata.

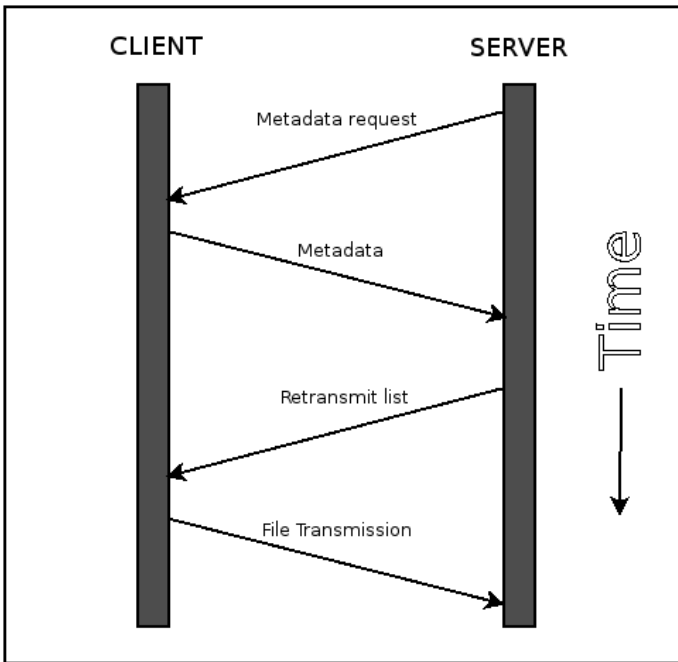


Fig. 5. Working and structure of buffer.

for the local copy of each file that is listed in the metadata. If a file is missing or if the hashes do not match, they are added to the retransmit-list, a list of files to be retransmitted from the client. Once the metadata file from a client is fully scanned, the retransmit list is sent to the client. The client in turn transmits a new copy of each file in the retransmit list. The following figure shows the error recovery process.

C. Advantages of the proposed solution

The proposed solution has several advantages, the most important one being higher security against data corruption and loss. With the current system, due to concerns pertaining to data loss, the server side asynchronous mode is turned off by default. The proposed solution once implemented, virtually eliminates the chance of data loss and makes it safe to leave the server side asynchronous mode turned on.

The solution allows the NFS environment to maintain high speeds while keeping chances of data loss negligibly low. The solution is also easy to implement as it requires changes to the NFS protocol alone, leaving the Operating System untouched.

VII. CLIENT SIDE ASYNCHRONOUS MODE

Client side asynchronous mode is another method, that can be used to improve the performance of Network File System. Client side asynchronous mode uses the client's RAM as a giant cache. Once enabled, writes to the NFS server are written to the client's RAM instead. The file gets written to the server only if one of the following conditions are met:

- Memory fills up
- An application flushes cache using sync, fsync or msync
- A file is closed with close()
- A file is locked/unlocked using fcntl
- Client shutdown

That is, when using client side asynchronous mode, writes to the server are drastically reduced. This benefits both the client doing the write and the environment as a whole. For the client, it reduces the number of instances it has to transfer data to the server. For the server, it reduces the number of writes it has to deal with in unit time. This also means that the rest of the clients have to wait less to read/write to the server.

The performance from client side asynchronous mode is not obvious from the benchmarks. Client side asynchronous mode has mixed results from the benchmarks with pts/dbench measuring a marginally low 24 MB/s down from 28 MB/s with only server side asynchronous mode turned on, while dd measured 68 MB/s, an increase of 10 MB/s compared with only server side asynchronous mode turned on. Regardless of the benchmark, client side asynchronous mode certainly improves the performance of the network.

A. Enhancing client side ASYNC

The behaviour of client side asynchronous mode can be further enhanced to optimize the performance of an NFS environment. This can be done by modifying the server such that it keeps two variables, max-count and current-count. max-count is the maximum number of clients which can write to the NFS server at a time, while current-count is the number of clients which are currently writing to the server. max-count is a user configurable value and can be optimized as per the size of the network.

The client side asynchronous behaviour is modified such that, the clients try to write to the server as soon as a threshold is reached. The threshold is user configurable and

can be optimized as per the configuration of the system. The server initially sets the value of current-count to 0. The server increments the value by one whenever a new client connects. When the client tries to connect to the server, the server checks if the current-count is less than max-count. The server allows the client to connect only if $\text{max_count} - \text{current_count} \geq 1$. In case the server has reached its client limit, it denies the connection. The client waits for a random time rand-wait-time before trying to connect again. rand-wait-time is also user configurable and needs to be optimized per the size of the network.

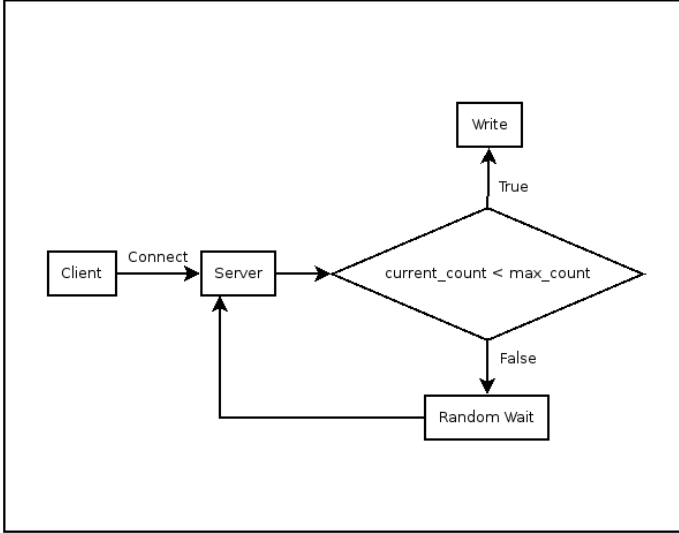


Fig. 6. Error recovery.

B. Advantages of proposed solution

The proposed solution provides a number of considerable advantages over the current system. First and foremost, it guards the data against corruption. With the current system, a particular file can remain in the memory for too long, while the proposed system forces the NFS client to flush its caches when a limit is reached. That is, a file won't remain in the cache for long, making sure it gets written to the server and to the proposed buffer, reducing the risk of data corruption.

The current client side asynchronous mode tries to fill up the RAM before trying to transfer the contents to the buffer. This can negatively affect the performance of both the applications running on the client and the network. If a particularly heavy application needs to be loaded, the client is forced to flush the caches, thus initiating the NFS write. The client will need to wait for the write to complete before the application can be properly loaded. This introduces unnecessary latency to the system. The proposed system also makes sure that the server's capacity is not wasted. The system makes sure a healthy number of clients get to write to the server throughout its running time.

Regardless of the number of active clients, the number of clients doing write to the server will remain a constant. This can improve the overall performance of the environment by

ensuring that the server can provide decent read/write speeds regardless of the state of the environment. Thus the proposed system can provide a swift and mature NFS behaviour.

VIII. OVERALL PERFORMANCE

TABLE III
NFS OPTIONS-SERVER SIDE

SINo.	Client	Server	Performance
1	sync	sync	sample
2	sync	async	sample
3	async	sync	sample
4	async	sync	sample

IX. CONCLUSION

Network File System, though introduced in 1984, is still a widely deployed distributed file system. This study introduces a couple of methods which can enhance the reliability and performance of the Network File System.

The study proposes a pseudo ring buffer on the client's secondary storage and proposes changes to the behaviour of NFS client and server to drastically reduce the rate of data corruption and loss, when using server side asynchronous mode. The paper also proposes changes in behaviour of the NFS client and server when using client side asynchronous mode with an aim to reduce data loss and improve overall performance of the system.

Once implemented, the changes suggested in this paper can enhance the performance of the NFS protocol while bringing down the risk of data corruption and loss.

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