XGet: A Highly Scalable and Efficient File Transfer Tool for Clusters

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Abstract

As clusters rapidly grow in size, transferring files between nodes can no longer be solved by the traditional transfer utilities due to their inherent lack of scalability. In this paper, we describe a new file transfer utility called XGet, which was designed to address the scalability problem of standard tools. We compared XGet against four transfer tools: Bittorrent, Rsync, TFTP, and Udpcast and our results show that XGet's performance is superior to the these utilities in many cases.

1 Introduction

Transferring files between networked computers is a typical event for users and system administrators. A few prominent examples of tools that are widely employed to transfer files include: Rsync [21], SCP, TFTP [19] and Wget. These tools work well, but as the number of machines involved in the file transfers increase, their performance diminishes due to their lack of scalability. This is especially true in a cluster environment, where the average number of nodes continues to increase. For example, at the time this paper was written, the fastest supercomputer in the world, based on the Top500 list, is Los Alamos National Laboratory's Roadrunner. The building block node of this supercomputer is a tri-blade, and Roadrunner contains 3,060 tri-blades [10]. Each blade runs an operating system, which implies that Roadrunner runs 9180 operating systems in total. With a system of this size, transferring files from the head node to each of the slave nodes cannot be accomplished with traditional file transfer utilities in a nominal amount of time.

Most modern clusters are diskless systems, which eliminate the need for local disks and facilitates cluster management. Clusters configured in this manner designate a node to act as a head node, which serves boot images to each of the slave nodes; typically, with a utility such as TFTP. Upon startup, the slave nodes download the image (usually by means of embedded code either in the network device or the BIOS) and then uses this image to boot the system. For example, the Preboot

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Execution Environment (PXE) [1], is a standard system for booting diskless clusters that operates in this manner. Typical protocols used by embedded code for downloading boot images are unscalable and could produce undesirable results, such as extremely long boot times.

While there are multiple utilities and protocols available for transferring files, none of them were lightweight enough and/or were able to scale effectively on the cluster used as a testbed in this work. XGet was created to fulfill the need for a highly scalable and lightweight file transfer tool with the sole purpose of transferring identical file(s) to multiple nodes within a cluster. The original target usage was intended for only transferring boot images and it was appropriately named XBootfs. XBootfs was used for booting by being included in a minimal boot image and then used to download a larger one; this image was then decompressed, the kernel executed with kexec, and a traditional boot process proceeded.

At the time, XBootfs lacked some basic features such as support for multiple files, retries, and load balancing. In this work, we extended XBootfs' capabilities by adding features suggested by the authors of the Perceus project [9]. In this way, XBootfs evolved into a more general tool that can be used for transferring any type of file between nodes in a Local Area Network (LAN). Additional uses include transferring large data sets or transferring entire operating systems in order to create multiple clones. To reflect this change, we renamed XBootfs to XGet to signify the generality of the new design.

2 Design

XGet is designed to be relatively easy to use and small so it can fit in a boot image where resources are limited. Since the target environment is a cluster, we are able to keep the implementation rather simple by withholding features that are not pertinent to this environment. For example, there is no support for congestion control as our experience shows us this is not necessary in LANs and will create excessive overhead for little or no gain. The prime reasons for supporting congestion control are to ensure scalability and reliability in a volatile environment, such as the Internet. Typical clusters interconnects exhibit high performance characteristics such as low latency and high bandwidth. Due to these properties and given a typical scientific or technical application workload, cluster interconnects do not usually suffer from network congestion. Network traffic can be more easily controlled in a LAN at the protocol and network hardware levels, which eliminates the need for explicit control at the application level. Scalability, however, is an issue of great concern to us as it is not addressed by many of the common tools.

XGet maintains its scalability by creating a peer-to-peer network between nodes in a LAN. The peer-to-peer network created is not a pure peer-to-peer network as some services, such as routing, are centralized at the master server. As clients connect to the master server and request files, the master provides routing information notifying them of which server to download from. The network created in this manner resembles a tree, built by the master server in order to provide optimal structure and balance. By building a balanced dynamic tree, XGet has the ability to scale to thousands of nodes while maintaining good performance. The actual heuristics used when building the tree are described in the next section. Figure 1 shows a visualization of a tree constructed after transferring one file from a single head node to ninety-one slave nodes in a cluster.

3 Implementation

XGet is built on top of the 9P protocol [20, 17], which has the ability to create a file system in user space. 9P was created for, and is used by, the Plan 9 operating system [20]. We used libraries from the Npfs project [8] to implement the 9P protocol in user space. Currently, these libraries use TCP for the underlying communication protocol, however, additional protocol support will be available in the near future.

3.1 The 9P Protocol

XGet uses the single threaded versions of the libraries from the Npfs project. These libraries are designed around an event driven architecture and are thus able to handle events from multiple sources asynchronously, without the need for multi-threading. Each 9P file operation consists of one or more events, which are handled by the event queue. 9P files are similar to remote procedure calls due to the fact that 9P files are not directly tied to local files, but instead to user defined functions. These functions initiate specific actions depending upon

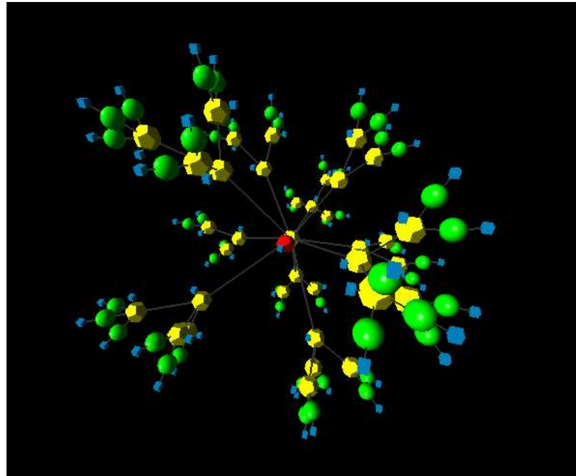

Figure 1: A visualization of the n-ary tree created by XGet. The red dodecahedron is the master server; the yellow dodecahedrons are the clients, which have been assigned as workers; the green spheres are clients, which are not workers; and the blue cubes represent a single file. Note that the tree depicted is limited to four levels and is evenly balanced. This visualization was created with Ubigraph [12].

the file accessed and the file operation requested. XGet's implementation takes advantage of the 9P file interface by sending and receiving messages with read and write operations from and to 9P files. These messages could contain binary data from the file(s) being transferred, or ASCII control messages informing the client or server of an event. This design greatly simplifies XGet's implementation while maintaining all the functionality of alternative protocols. It is possible for the file system created by 9P to behave traditionally (provided that the operating system used contains a driver that supports 9P), however, that is not the intended usage of XGet and is thus beyond the scope of this paper.

9P is a relatively simple protocol as it only contains seventeen different packet types [20, 17]. These packets incur minimal header overhead, with the largest header size consisting of twenty-three bytes [17]. In contrast to other protocols, 9P contains far more messages and header overhead than is necessary for merely transferring files. For instance, TFTP only contains five different packet types [19] to accomplish the same task as XGet. 9P was chosen over other protocols for its flexibility and ease of use. If a new feature is added to XGet in the future, the entire protocol does not need to be redesigned or an additional packet type does not need to be added. A new feature can be accommodated in XGet by simply creating a new file or a new message in an existing file.

3.2 XGet

XGet creates a peer-to-peer network out of a master server and one or more clients. This network is created by the interaction between the master and the clients through 9P file operations. When a client starts, it connects to the master server and performs the steps necessary to set up the file transfer(s). The first step taken is to retrieve routing information from the master to determine where the file is to be downloaded from. The client could be routed to download directly from the master or from a secondary server. After the client has finished setting up the file, it advertises to the master that it is available to become a secondary server for this file. The master then determines whether or not this client meets specific requirements and if it does, it accepts the client as a "worker" (also known as a secondary server). The master adds this worker to its worker list, which contains information about each secondary server, and is searched when a client requests routing information from the master. Redirecting clients to secondary servers and creating workers out of clients creates a dynamic n-ary tree. This tree is how XGet maintains its scalable properties even if run on thousands of nodes.

To avoid performance problems, the master builds the tree according to three heuristics: the number of levels in the tree should be limited, the number of connections per worker should be evenly distributed, and clients using more than one worker (i.e., when download-

ing more than one file) should not be assigned workers that have the same tree levels as other workers assigned to the client. If the tree was built without guidance, it would be possible for it to become highly unbalanced. Performance issues would ensue if the number of tree edges became too large and a node closer to the master exhibited a performance or stability issue. To avoid this problem, the master monitors the tree level of each client and only creates workers out out of clients with a tree level below the maximum permitted. Currently, we limit the number of levels in the tree to four (the master is located at level zero). When the master chooses a worker for a client, it checks to see how many clients the worker is currently serving in addition to the level. If it does not exceed the maximum level limit and has the least number of connections compared to every other worker serving the same file, it is assigned to a client. The last heuristic conflicts with the other two, so it is given the lowest priority. This heuristic encourages the master to assign to a client a worker with a tree level different than the levels of the other workers assigned to the client. This prevents large variations in the file transfer completion times between clients. It is not always possible to achieve this, so it is attempted as a best effort.

When XGet is started as the master server, it creates a 9P file system and a file named `log`. It then continues to populate its 9P file system by scanning the local files to be served. For each file discovered, a 9P directory, with the same name as the local file, is created in the virtual file system exported by the master server. Each 9P directory contains four files: `redir`, `avail`, `data`, and `checksum`. When a client reads or writes to any of these virtual files, specific actions, which are bound to each file, are initiated. The 9P files created in the virtual file system are key components and warrant additional explanation.

Clients write to the `log` file on the master to relay noteworthy information to the user. The master displays the messages written to the `log` file on the user's console. This centralizes the log information at the master and therefore eliminates the need to collect individual log files at each slave node. A client receives routing information from the master server by reading from the `redir` file. Once the master receives the read request, it initiates the procedure described above to route the client to the appropriate server. The `checksum` file is always accessed from the master server and returns the local file's checksum when read by a client. The checksum is used to verify that the file downloaded by the client is correct. The `avail` file is written to by a client and informs the master server that this client is now available to serve the file. The last file, `data`, when read, returns the data contained by the local file on the server it is being downloaded from. This file is not necessarily opened from the master server; where it is accessed from is determined by the result of reading the `redir` file described above. Table 1 summarizes the behavior of each of the five 9P files previously described. Figure 2 shows a worker and a client downloading File1. The worker is downloading directly from the master, while the client is downloading from the worker. The worker and the client are shown performing file operations on the four 9P files in the File1 directory (the File1 directory represents the local file named File1). Arrows directed towards a 9P file indicate that the client is writing to the file. Conversely, arrows directed towards the client or worker indicate the client or worker is reading the file. The only difference between a client downloading from the master versus a client downloading from a worker, is the client accesses the file named `data` from the worker it was assigned to, instead of directly from the master.

Once a client starts, it mounts the file system on the master server and traverses its contents. The client determines which 9P directories represent files served by the master and retrieves the necessary information by reading from the master's `redir` and `crc` files. The client then adds the file to its own 9P file system and writes to the master's `avail` file to advertise its availability to serve. After the client completes these steps, it schedules the file transfer. By performing the initialization in this way, it is possible for the client to become a secondary server before it actually begins downloading the file. This is the intended behavior and clients scheduled to a secondary server in this situation will still receive the file correctly. After the clients begin transferring files, they continue downloading until either an error occurs, or they complete the transfers. If a client encounters an error during the transfer, it will attempt to retry the download up to twenty times by default. The retry is always attempted directly from the master rather than trying to find another worker. Once a client finishes downloading all of the files it intended, it will continue to serve until one of the following occurs: either there are no clients connected to it or two times the time taken to download the files has passed since the

Table 1: **9P Files Used by XGet**

9P File Name	*Description*
`log`	Displays debugging information to the user
`redir`	Returns routing information
`checksum`	Returns the checksum of the local file
`avail`	Informs the master server of a client's ability to serve
`data`	Returns the data belonging to the local file

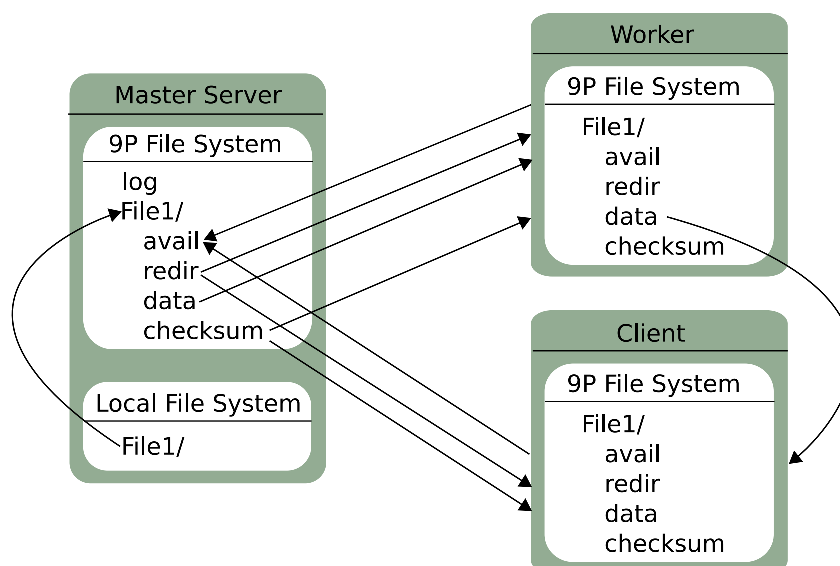

Figure 2: A diagram showing the interaction between a client, a worker, and the master XGet server. In this diagram, the master server is serving its 9P file system, which contains the `log` file and one directory named "File1". This directory represents the local file with the same name. The directory in the 9P file system on the master server contains four 9P files: `avail`, `redir`, `data`, and `checksum`. After connecting to the master server, the worker reads from the `redir` file, the `checksum` file, and writes to the `avail` file for File1. The worker in this diagram is downloading directly from the master server by reading from the master's `data` file. The client depicted here is not downloading from the master, but instead from the worker. Arrows directed towards a 9P file indicate that the client is writing to the file. Arrows directed towards the client or worker indicate that it is reading the file.

client was started. This way, the user does not need to guess how long each client needs to serve for or forcibly kill the clients after their job as servers has completed.

4 Usage

To begin transferring files with XGet, the user first needs to run XGet on the server that contains the files to be transferred (usually the head node). The command to launch the server would look similar to:

```
xget /tmp/files_to_serve
```

This example would launch XGet as a master server and informs it to serve all the files and sub directories under the directory `/tmp/files_to_serve`. Next, XGet clients need to be started on the slave nodes. An example command to launch a client is as follows:

```
xget -n master .  /tmp/xget_output
```

In this example, "master" can be the host name or IP address of the master server. The period directs the client to begin searching for files to download at the root of the file system served by the master. In this case, the client will download every file and sub directory that resides under the directory `/tmp/files_to_serve` on the master server. The last argument is the destination directory for the files downloaded. If the user wishes to download a specific file or directory, as opposed to every file and sub directory served by the master, the user can specify the file or directory on the command line. An example of this is:

```
xget -n master file/to/download
        /tmp/xget_output
```

In this case, the source is no longer a period, but a specific file or directory. This implies that the server has a file or directory named `/tmp/files_to_serve/file/to/download`.

5 Related Work

There are many file transfer utilities which are widely used and/or could be used for transferring boot images to nodes on a LAN including: Rsync, Bittorrent [2], TFTP, Udpcast[13], PCP [15], as well as others. While these tools work well in many situations, most of them do not address the exact same issues as XGet, and the ones that do have certain shortcomings.

5.1 Rsync

Rsync is a file transfer protocol designed to update files at a destination by transferring only the differences between files on low bandwidth, high latency connections [21]. Rsync includes a client/server protocol for transferring files between many nodes simultaneously. However, Rsync was not designed with scalability in mind. Even though Rsync was not designed to solve the same problem as XGet, it is commonly used for transferring files between many nodes in a LAN simultaneously.

5.2 Bittorrent

The Bittorrent protocol was created for the purpose of transferring multi-media files over the Internet. Due to its scalable properties, it is also being used for transferring files over LANs. Bittorrent and XGet are quite similar; they both create a peer-to-peer network and generate an ad-hoc tree. Bittorrent usually requires at least three items in order to transfer files: a torrent file, the tracker, and the client. To use Bittorrent, one needs to first create a metainfo file (or .torrent file) that includes: the tracker's URL, file size, suggested file name, and other data about the file(s) being shared [16]. Next, a tracker needs to be started before any of the clients can begin transferring data. The tracker is a lightweight server that provides routing information to each of the clients in the network. After the tracker is running, a client with a completed version of the file(s) being served needs to start. This client then "seeds" the file(s) for the other clients. Once other clients have started, they connect to the tracker, which redirects them to the appropriate client to download from. The main differences between Bittorrent and XGet are: XGet does not require clients to load small files informing them of the files being transferred, and Bittorrent clients receive portions of files from many clients, rather than being assigned to a single secondary server as in XGet.

5.3 TFTP

TFTP is an extremely simple protocol built on top of UDP, which was first published in 1980 [19]. It is client/server based and supports a single file transfer per session. It is normally found in embedded software such as Ethernet card firmware where the code must remain small. For example, TFTP is used by PXE, which

is commonly used to boot diskless clusters. TFTP does not scale as it was never intended to be used for transferring files to many machines simultaneously. Extensions to the protocol have added the ability for TFTP to work over Multicast, which does make it more scalable.

5.4 Udpcast

Udpcast is a file transfer tool that uses Multicast. As with TFTP and Rsync, it employs a client/server architecture. Udpcast's target usage is similar to XGet's as it is lightweight and can easily be included into a minimal boot image. While Udpcast can be used to transfer boot images, it does not support transferring multiple files simultaneously, so it would most likely not be used for transferring multiple data sets.

5.5 PCP

The PCP file transfer utility creates an n-ary tree to transfer files between nodes, just as XGet. The problem with this program is that it relies on a separate daemon running on each node for authentication. For this reason, PCP would not be a likely candidate for inclusion in a minimal boot image and was not considered in our performance analysis.

6 Performance Analysis and Comparison

We compared XGet against four file transfer utilities, which are widely used and/or could be used for transferring boot images to nodes on a LAN. The utilities selected were: Rsync, Bittorrent, TFTP, and Udpcast. All of our tests were performed on a ninety-two node Linux cluster with XCPU [18] as the process management system and Myrinet as the network interconnect. Two types of experiments were chosen to represent the intended usage of XGet: transferring a single file of increasing size (Experiment 1) and transferring multiple files of a fixed size (Experiment 2). Both experiments were run ten times in order to ensure accurate results.

Experiment 1 represents the transferring of boot or OS images. This experiment consisted of ten individual tests. During each test, a single file of a specific size was transferred from the head node to each of the slave nodes. The file sizes used ranged from 10MB to 100MB and increased in increments of 10MB. This range of file sizes was chosen since it represents typical boot image sizes.

Experiment 2 represents the transferring of data sets. Data set file sizes are different for each application. We used a file size of 100MB to represent a data set since it is large enough to demonstrate the performance of each tool in this mode of use. For this experiment, eight tests were performed and during each test, one or more files were transferred from the head node to each slave node. The number of files transferred ranged from one to eight and increased in increments of one.

For every utility tested, each test followed a strict order of events. First the files to transfer were generated. Then, the corresponding daemon was executed on the head node. To ensure that old files from previous tests did not interfere with the results, the old downloaded files were deleted on each client. Before the tests began, the start time was recorded and one client was executed on each of the ninety-one slave nodes with XCPU. For all of the tests except for Bittorrent, the time when a test finished was taken to be the time when the last client exited. The issues related to Bittorrent and an explanation of how we calculated the time taken for a test to complete, are described in the Testing Considerations for Bittorrent section below. The total run-time for a test was therefore taken to be the time when the test finished subtracted by the start time.

6.1 Testing Considerations for Bittorrent

The official Bittorrent distribution, which is available on the Bittorrent website [2], contains a tracker and a client written in Python. A Python program would most likely not be included in a minimal boot image as it depends on an entire Python installation in order to run. Another client was necessary for our testing in order to compare a client which could be used in the same situations as XGet. Although Bittorrent is extremely popular and there are many clients available, we could not find a client ideally suited for a cluster environment. Every client we found features an interface of some kind and thus requires interaction in order to exit the client after it completes the transfer and finishes serving to other clients. Regardless of this shortcoming, we found two clients with the potential of being used to transfer boot images: Enhanced Ctorrent [3] and Transmission [11]. Transmission proved to be much slower than Enhanced Ctorrent. Enhanced Ctorrent, however, was not entirely

stable and would sometimes crash without finishing the files transfers. Despite Enhanced Ctorrent's stability issues, we chose it instead of Transmission since it demonstrates the potential of using the Bittorrent protocol in a LAN. The last issue we encountered was the tracker from the official Bittorrent distribution for Linux would not work with any other client besides the official one. So instead, we used Opentracker [4].

We tested the performance of Bittorrent by first executing the tracker on the head node, a client on the head node to seed, and then one client on each of the ninety-one slave nodes. Since the clients would not exit once they completed transferring or serving, we used an option in Enhanced Ctorrent to write the current time to a file when the client finished downloading. After a period of time elapsed, we collected the files containing the time stamps and took the largest time as the time when the test finished. The problem with this method is its reliance on the accuracy of the clocks on the head node and the other ninety-one nodes. To mitigate this issue, we synced all of the clocks with the *ntpdate* program before the tests were run.

6.2 Testing Considerations for TFTP

The TFTP server and client selected were from the tftp-hpa [6] project. This server and client does not support the Multicast extension to TFTP. Atftp [14] does support Multicast, but demonstrated to be extremely unstable in our test cluster.

TFTP was never intended to transfer multiple files simultaneously, so we did not perform the multiple file test for this protocol.

6.3 Testing Considerations for Udpcast

Udpcast does not support transferring more than one file simultaneously, so we did not perform the multiple file test.

6.4 Results

Figure 3 shows the average results of Experiment 1. Figure 4 shows the same results as Figure 3, but for XGet and Bittorrent only. Figure 3 clearly illustrates that TFTP is not a scalable file transfer solution. Using TFTP for booting ninety-one nodes would take over two minutes and thirty seconds for only a 20MB boot image. Bittorrent and XGet produced very similar results, however, Bittorrent's results were slightly superior to XGet's as the file size increased. When transferring an 100MB file, on average, Bittorrent finished the transfer to all clients in around eleven seconds, while XGet took fifteen seconds. For smaller file sizes, XGet's and Bittorrent's results were extremely close. Transferring a 20MB file took XGet eight and a half seconds where as Bittorrent required around nine and a half seconds to complete. These results clearly demonstrate that Bittorrent and XGet perform well for transferring one file of sizes 10MB to 100MB. Figure 5 shows the results of Experiment 2. Figure 6 shows the same results as Figure 5, but for XGet and Bittorrent only. Rsync does not perform well in this test when compared to XGet and Bittorrent. Rsync's performance dramatically decreased as the number of files transferred increased. Bittorrent performed better than XGet for transferring six or more files simultaneously. For example, transferring eight 100MB files took Bittorrent around forty-three seconds, while XGet required sixty-six and half seconds to complete the test. XGet, however, did perform slightly better than Bittorrent for transferring four or less files. For example, when transferring two 100MB files, XGet took about nineteen seconds where as Bittorrent required twenty seconds to complete.

We have found that XGet's performance deficiencies can be attributed to XGet's implementation, not the 9P protocol itself. Performance can be further enhanced by improving the algorithms employed by XGet directly. This will be addressed in future work.

7 Future Work

Performance improvements to XGet are needed as shown in the results section. This can be accomplished by optimizing the algorithms used by XGet's implementation. In addition to implementation improvements, boot time can be reduced by integrating XGet with gPXE.

gPXE is an advanced replacement for the PXE firmware, which supports multiple network transfer protocols including protocols based on TCP such as HTTP and iSCSI [7]; traditional PXE supports only the TFTP [1] protocol. By writing a plug-in for gPXE, we can provide the ability to boot a host with XGet directly.

The 9P implementation used currently uses TCP as its underlying protocol. We plan to remove this limi-

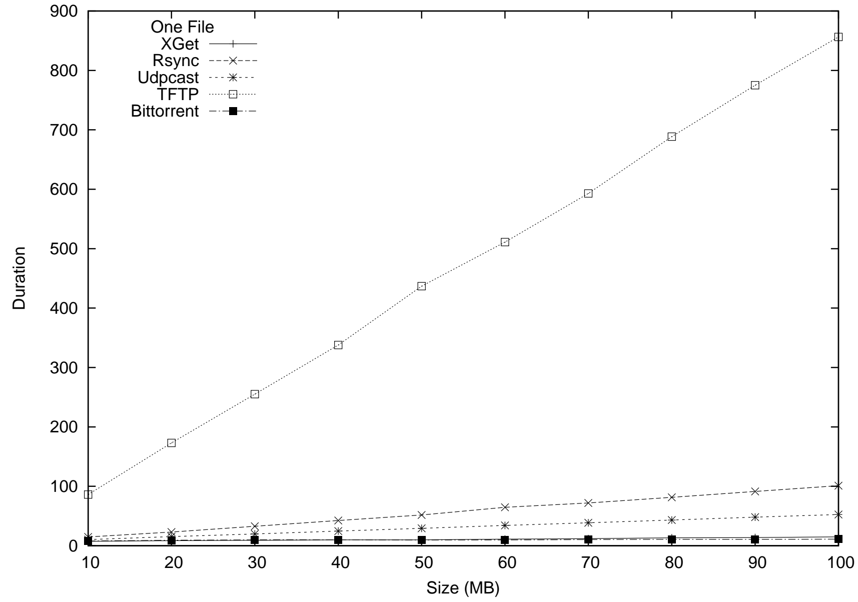

Figure 3: The average results of Experiment 1 for Rsync, Bittorrent, TFTP, Udpcast, and XGet.

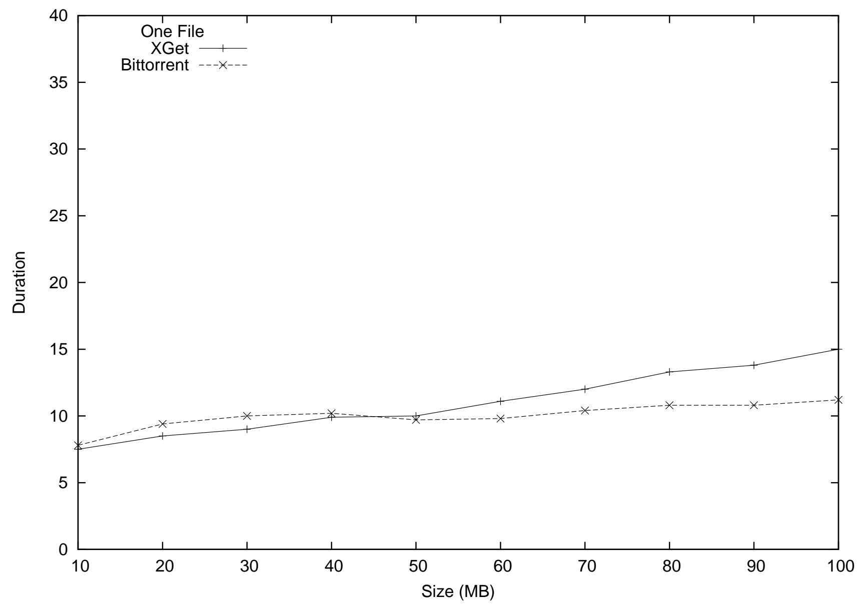

Figure 4: The average results of Experiment 1 for Bittorrent and XGet.

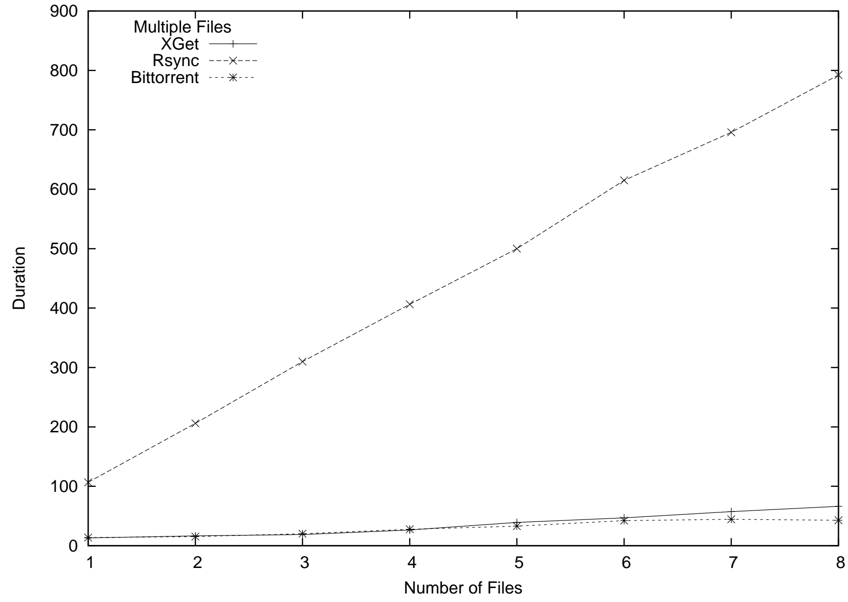

Figure 5: The average results of Experiment 2 for Rsync, Bittorrent, TFTP, Udpcast, and XGet.

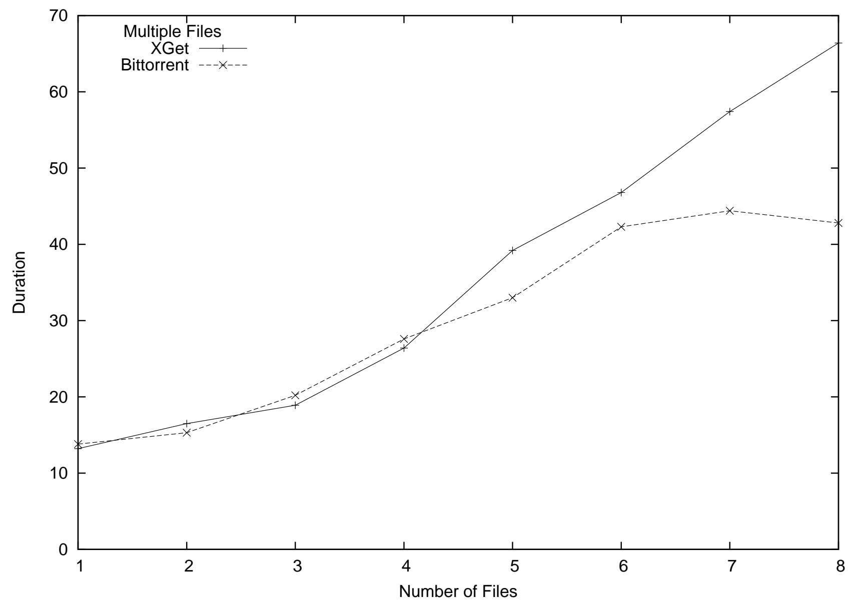

Figure 6: The average results of Experiment 2 for Bittorrent and XGet.

tation by adding support for additional protocols and transfer mechanisms such as UDP and RDMA [5].

8 Conclusion

XGet is a highly scalable file transfer tool, built on top of the 9P protocol, which can be used for transferring files within a LAN. It maintains its scalability by transforming clients into workers to create a dynamic n-ary tree. It is designed to be a lightweight solution, which can be easily used for transferring boot images to nodes within a cluster.

When compared to other file transfer utilities, XGet performed very well and was only surpassed by Bittorrent in some cases. While Bittorrent performed well in all cases, it is extremely complicated to set up and was never designed for this type of environment. To illustrate this point, every client for Linux we found would not terminate after a defined period of time and features a user interface. Another issue with Bittorrent is the Torrent files; they are cumbersome since they must be transferred to the clients before the actual file transfers begin. For these reasons, XGet is the most realistic solution out of all tools tested.

9 Acknowledgments

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