Using IKAROS to provide Scalable I/O bandwidth

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Abstract—We present IKAROS as a utility that permit us to form scalable storage platforms. IKAROS enable us to create ad-hoc nearby storage formations and use a huge number of I/O nodes in order to increase the available bandwidth. We measure the performance and scalability of IKAROS versus the IBM’s General Parallel File System (GPFS) under a variety of conditions. The measurements are based on benchmark programs that allow us to vary block sizes and to measure aggregate throughput rates.

Keywords—parallel file system; resilient storage formations; GPFS; I/O bandwidth;

I. INTRODUCTION

International collaborative scientific experiments are generating datasets which are increasing exponentially in both complexity and volume, making their analysis, archival, and sharing one of the grand challenges of the 21st century. These experiments, in their majority, adopt several computing models consisting of different Tiers (each Tier is made up of several computing centres and provides a specific set of services) and for the different steps of data processing (simulation, filtering, calibration, reconstruction and analysis) several software packages are utilized. The computing requirements are extremely demanding and, usually, spans from serial to multi-parallel or GPU-optimized jobs. The collaborative nature of these experiments demands very frequent WAN data transfers and data sharing among individuals and groups. Typically, such a computing model utilizes several different computing infrastructures like: Grids, Clouds, HPCs, Data Centers and Local computing Clusters.

Within the above described ecosystem, large-scale scientific computations tent to stretch the limits of computational power and parallel computing is generally recognized as the only viable solution to high performance computing problems. I/O has become a bottleneck in application performance as processor speed skyrockets, leaving storage hardware and software struggling to keep up. Parallel file systems have been developed in order to allow applications to make optimum use of available processor parallelism. I/O access patterns are generally divided into the following subgroups:

1. Compulsory
2. Checkpoint/restart
3. Regular snapshots of the computation's progress.
4. Out-of-core read/writes for problems which do not fit

the memory.
5. Continuous output of data for visualization and other post-processing.

In the applications with which we are most familiar, writes will need to be performed more often than reads, with categories 2 and 4 dominant.

Currently, on the one hand we have a typical HPC facility which uses a small portion of the available nodes for storage purposes (I/O nodes: acting as storage servers) and each storage server provides a huge number of hard disk through a RAID system. On the other hand traditional globally shared file systems have limitations when used with large-scale systems, because [1]:

1. Bandwidth does not scale economically to large-scale systems,
2. I/O traffic on the high speed network can impact on and be influenced by other unrelated jobs,
3. I/O traffic on the storage server can impact on and be influenced by other unrelated jobs.

Exascale systems will require I/O bandwidth proportional to their computational capacity and it seems that current file systems and HPC architectures will not able to fulfill this requirement. To avoid those limitations, one approach is to configure multiple instances of smaller capacity, higher bandwidth storage closer to the compute nodes (nearby storage) [1]. The multiple instances can provide exascale size bandwidth and capacity in aggregate and can avoid much of the impact on other jobs. This approach does not provide the same file system semantics as a globally shared file system. In particular, it does not provide file cache coherency or distributed locking, but there are many use cases where those semantics are not required. Other globally shared file system semantics are required, such as a consistent file name space, and must be provided by a nearby storage infrastructure. In cases where the usage of application data is constrained, a globally shared file system provides more functionality than the application requirements while at the same time limits the bandwidth which the application can use. Nearby storage as described above reverses that, providing more bandwidth but not providing globally shared file system behavior [1].
The paper is organized as follows: at section 2 we provide the structure and function of GPFS, while at section 3 we analyze more the potential problems and bottlenecks. At section 4 we mention the IKAROS approach and finally at sections 5 and 6 we describe the measurements method and the results.

II. STRUCTURE AND FUNCTION OF GPFS

The GPFS architecture was designed to achieve high bandwidth for concurrent access to a single file (or, of course, to separate files), especially for sequential access patterns. GPFS is implemented as a number of separate software subsystems or services. Each service may be distributed across multiple nodes. Many of the services necessary for GPFS are provided by a persistent GPFS daemon called mmfsd. Among the more important services provided by mmfsd are: (1) file system access for nodes which wish to mount GPFS; (2) a metanode service which retains file ownership and permissions information for a particular file; (3) a stripe group manager service which manages and maintains information about the various disks that make up the file system; (4) a token manager server which synchronizes concurrent access to files and ensures consistency among caches; (5) finally a configuration manager which ensures that a stripe group manager and token manager server are operational and that a quorum exists [7].

Each of the nodes dedicated to running parallel applications has an mmfsd daemon present to mount the file system and perform access. It is responsible for actually performing the reads and writes performed on that node. The Virtual Shared Disk (VSD) layer of GPFS permits a node to locally issue a write that physically occurs on a disk attached to remote node. The VSD layer therefore consists of VSD clients on the application nodes and VSD servers on the disk-attached I/O nodes. GPFS is a “client-side cache” design. The cache is kept in a dedicated and pinned area of each application node’s memory called the pagepool and is typically around 50 Mbytes per node. This cache is managed with both read-ahead (prefetch) techniques and write-behind techniques. The read-ahead algorithms are able to discover sequential access and constant-stride access. GPFS is multi-threaded. As soon as an application’s write buffer has been copied into the pagepool, the write is completed from an application thread’s point of view. GPFS schedules a worker thread to see the write through to completion by issuing calls to the VSD layer for communication to the I/O node. The amount of concurrency available for write-behind and read-ahead activities is determined by the system administrator when the file system is installed [7].

Consistency is maintained by the token manager server of the mmfsd daemon. The item being accessed (for example, a file) is termed a lock object. The per-object lock information is termed a token. On every write access, the mmfsd determines if the application holds a lock that permits the right to modify the file. If this is the first write for this node and for this file, a write token must be acquired. The mmfsd negotiates with the node that holds the token in order to get the requested token. It first contacts the token manager server for a list of nodes that have the token, then it negociates with the tokens in that list to acquire the token. This technique is employed for scalability reasons: distributing the task to the mmfsd reduces serialization at the token manager server. Moreover, in anticipation of sequential access the token manager may extend the range of bytes locked beyond what was actually requested. GPFS enforces strict POSIX atomicity semantics. That is, if two separate nodes write to the same file, and if the writes are overlapping, the overlapped region must be either entirely from node A or entirely from node B.

III. POTENTIAL PROBLEMS AND BOTTLENECKS

The data path presented at the previous section also describes the potential bottlenecks. For instance, if an application is doing a write and the pagepool is full, the write must block until some information from the pagepool can be committed. Adjusting the size of the various buffers in the data path to permit efficient performance will depend on the type and number of VSD servers in a given GPFS file system, the type and number of disk drives and the connections to these drives, and of course on the application access patterns. In general, it is best to have a balanced configuration in which in all VSD servers have similar numbers of disk drives and similar types of disk drives. The application should make large writes and reads where possible to amortize the system call cost: one write call with a one megabyte buffer is much more efficient than one million calls with a one byte buffer simply because of the CPU limitations on the application node. The GPFS block size should be compatible with the RAID array when RAIDs are employed [7].

Another potential bottleneck arises from the fact that data is copied twice within the client: once between the application’s buffer and the pagepool, and again between the pagepool and IP buffer pool. For writes, this has the advantage that the application can continue as soon as the data is copied into the pagepool. But copying the data twice can use enough memory bandwidth to limit the usefulness of having more than one processor per node write to a file concurrently. However, for all but very small jobs (i.e., those with few processes) this is of little consequence, since the throughput will be limited by the number of servers rather than by the number of clients [7].

IV. IKAROS APPROACH

IKAROS is as a utility that enable us to create scalable storage formations, on-demand. IKAROS unifies remote and local access in the overall data flow, by permitting direct access to each I/O node. In this way we can handle the overall data flow at the network layer. IKAROS enable us to create ad-hoc nearby storage formations and use a huge number of I/O nodes.
in order to increase the available bandwidth [3, 4]. IKAROS permit us to create more user-driven computing facilities with application users and owners playing a decisive role in governance and focusing on placing computer science and the harvesting of ‘big data’ at the center of scientific discovery. This approach enable us to virtually connect, at the users level, the several different computing facilities (Grids, Clouds, HPCs, Data Centers, Local computing Clusters and personal storage devices), being utilized, on-demand based on the needs, by using well know standards and protocols, like HTTP. Additionally, this approach enables users to experience and utilize, seamlessly, techniques like parallel data transfers and striping servers outside the Grid, without using complicated tools like GridFTP and without focusing to IT issues. Local cluster or even Data Center administrators, most of the times, are not willing to install and maintain tools like globus/GridFTP [5] if the infrastructure is not participating in a Grid related project.

More specific, IKAROS allows data in a file to be striped across multiple disk volumes on multiple heterogeneous nodes and provides the utility for the storage system to access and transfer a data file in parts and in parallel mode, without a specific order, according to clients requests. IKAROS defines three types of nodes: The Client node, the Meta-data node and the I/O node. The node types are peers with the ability to act in any mode (i.e. any node can act at the same time, as a Client, meta-data node or I/O node), driven by user requests [3].

The IKAROS metadata management service (iMDS) holds a key role in the IKAROS architecture. The iMDS permit us to handle the metadata sub-systems differently based on the needs. We may respond to a client/application request with three different ways. The client may find the answer: 1) within his own “cache”, 2) locally at a nearby iMDS utility or 3) at an external infrastructure/utility. This approach, focusing on flexibility, can scale both up and down and so can provide more cost effective infrastructures for both large scale and smaller size systems, unlike the competition. We are able to use existing cloud infrastructures (acting as the external MDS utility), such as Facebook and Gmail, in order to dynamical manage, share and publish metadata. In this way we do not have to build our own utilities for searching, sharing and publishing, additionally we are enabling users to dynamically use the infrastructure, by creating on demand storage formations [6].

At the local level the IKAROS architecture, described in detail at [3], permit us to deal with the limitations that a traditional globally shared file system can not overcome when used with large-scale systems because:

1. bandwidth does not scale economically to large-scale systems,
2. I/O traffic on the high speed network can impact on and be influenced by other unrelated jobs,
3. I/O traffic on the storage server can impact on and be influenced by other unrelated jobs.

In this paper we provide a use case where IKAROS is dealing with the third problem (3): the I/O traffic on the storage servers.

V. EXPERIMENTS

The experiments shown here have been chosen because they show the effects of varying the I/O characteristics of application programs. We measured how aggregate throughput varied depending on the number and configuration of client processes and the size of individual transfers. We also show how GPFS and IKAROS performance scales with system size and throughput of parallel tasks creating and writing a single large file, and of reading an existing file. To measure the throughput of writes, the benchmark performs a barrier, then each task records a “wall clock” starting time, process 0 creates the file and all other processes wait at a barrier before opening it, then all processes write their data according to the chosen application characteristics (in the tests shown here, always independently of each other, filling the file without gaps and without overlap); finally, all processes close the file and record their ending time. The throughput is calculated as the total number of bytes written in the total elapsed wall clock time (the latest end time minus the earliest start time). This approach is very conservative, but its advantages are that it includes the overhead of the opening and closing and any required seeks, etc., and measures true aggregate throughput rather than, for example, an average of perprocess throughput rates. We run on the measurements at the Cytera HPC system and all the nodes being used were on exclusive mode (only used by our process). The Cytera machine consists by 100 nodes (96 Compute nodes) each with 12 CPU cores, 48 GBs of RAM and 15K rpm local HDD. The nodes are connected over a QDR (40Gb/s) infiniband. The GPFS file system is implemented by 4 storage servers. It is supported by 360 TBs raw disk in 18 Raid6 arrays each with 10 (7200 rpm SATA). The GPFS metadata is provided by 4 Raid10 arrays (one associated at each server). For implementing IKAROS we are using the computing nodes and the local hard disks provide be them (one 15K rpm HDD per node).

The results, for the GPFS, indicate the peak performance the file system is capable of delivering rather than what a user would see in the presence of other jobs competing for the same resources. The I/O performance seen in real applications will depend on complex interactions between the system and the application’s run time behavior. Competition with other applications for I/O resources, wild access patterns, and some randomness in the file system can cause performance to be lowered. On the other hand, IKAROS framework enable us to create concurrent client requests that will not compete each other for I/O bandwidth.
VI. EXPERIMENTAL RESULTS

For a given GPFS file system, the most important factors affecting performance (aside from the access pattern) are the number of parallel processes participating in the transfers, and the size of the individual transfers. Fig. 1 shows that performance is highest when the ratio of client processes to server nodes is near to 5:1. (though the nodes running our experiments have 12 processors per node, we ran only one client task per node). This ratio is slightly better but close to the 4:1 ratio measured at Lawrence Livermore National Laboratory at 2000 [7] by using 38 servers and 152 clients.

At Fig. 1 we wrote a 80 GB file, split into separate files, one file for each client process. As mentioned at [7] when the client:server ratio is too low the servers are starved for data; when it is too high the receiving buffers fill up faster than they can be drained, eventually causing packets to be dropped and retries initiated, reducing performance.

As we mentioned at the previous section the Cytera machine uses 180 hard disks distributed at the 4 storage servers in 18 Raid6 arrays. This Raid 6 configuration in principles can provide us a throughput close to 4200 MB/s which is way higher than the measured GPFS peak performance at Cytera, which is around 1600 MB/s.

At Fig 2 we show the performance of writing a 80 GB file (in total) from one computing node to 1,2,4 and 8 computing nodes by using the IKAROS framework. For all the data transfers we used only hard disks located at the compute nodes (one per node). In this scenario we actually have 1 client writing the file to 1-8 storage servers.

Fig 2 shows that if the data file is located at a single disk, which is the case most of the times (the compute nodes used by the applications are equipped with a single disk), the best split ratio is 1:4. At the following measurements (Fig 3) we show that if we maintain this ratio (4 dedicated HDDs serving each client for writing/splitting the file) we can fully utilize the available I/O and network bandwidth.

At Fig. 3 we use up to 16 concurrent clients because the measurements at Fig 1 clearly shows that the GPFS performance, for the current system, is seriously impacted after this limit. Each time we measure the performance of GPFS versus IKAROS on 4:4, 4:2 and 4:1 write ratios (HDDs:client). In this way we are able to create a virtual cluster of dedicated (4:1) or semi-dedicated (4:2, 4:4) storage facility for each client, where the I/O traffic can not be impacted by other client requests. At Fig. 3 we clearly show that IKAROS can outperform GPFS by using 4:2 and 4:1 ratios and that this approach can easily scale with only barrier the network bandwidth.

CONCLUSION

IKAROS permit us to create scalable storage formations, concluding to more user-driven computing facilities with application users and owners playing a decisive role in governance and focusing on placing computer science and the harvesting of ‘big data’ at the center of scientific discovery. This approach enable users and applications to be able to fully utilize the available resources, based on the needs. Here we have to highlight that IKAROS is not acting as a scheduling or a load balancing utility, these algorithms/procedures should be
decided at the application level (based to each applications needs). IKAROS provides the framework to implement the applications demands on the fly something that it can not be found to other systems like the GFPS. IKAROS approach is extremely useful because there are use cases where applications does not need all the features and the complexity that a traditional file systems provides. Additionally, it seems that Exascale systems will require to fully utilize the available I/O bandwidth something that IKAROS is able to provide on demand.

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