Study on Flash-Based Storage System

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Abstract:

The characters of low latency, high concurrency, high efficiency, and small size bring flash memory widespread concerns. In order to prevent the operating system from optimization, the direct replacement of flash-based solid-state drives for hard disk drives has hidden these properties from the operating system. In this paper, I will make some comparison and analysis about the storage systems built on the raw flash, including flash accelerating cards, flash arrays, and flash-based clusters. Besides, three aspects of challenges and design issues are concluded from the comparison of these flash based storage systems. Firstly, I pointed out a report about I/O stack redesign issues, which are come from system software refinement and interfaces. Secondly, I will introduce several reliability approaches from the system level. Finally, presented the energy efficiency and the size of the flash based storage. In the end, I summarized the research work and pointed out the possible research directions.

Key words: energy efficient, I/O stack; storage system; reliability; flash memory;

During the recent 30 years, the gap of I/O processing performance between the computer system and CPU rapidly expanding , and with the rapid development of multi-core technology, this gap will grow. At the same time, the appearance of social networking, mobile networking and Internet of things led to the high requirement in high-performance computing and processing capabilities. Therefore, the I/O the ability of computer systems is becoming an urgent problem in computer science development.

Traditional disk storage systems have made many efforts to solve this problem. These disk systems with RAID technology achieve parallel access technology in multiple disks , and the I/O requests are distributed to multiple disk devices. Internally, the disk system read and write data through technologies like distribution of data, I/O Scheduling and other means to reduce seek time, in order to improve the throughput of the disk.

Although the traditional disk storage system effectively enhance the bandwidth, but access latency is hard to reduce. So, it still can not meet the requirements of high latency applications. Meanwhile, in order to meet the great need of parallel access performance in multiple disk devices, storage systems are often deployed far more disks

than the actual the number of disk capacity needs, and the system scale is expanded. It not only enhances the complexity of the system on the one hand , but also increases energy consumption.

In recent years, with the increase in the capacity and decline in the price of flash memory chips, now the flash memory chips gradually come to personal computers as well as the deployment of large-scale data devices from mobile devices . The features like low latency , low energy consumption, small size, light weight , seismic and others make the flash memory gain great concern by computer scientists.

1. Flash Memory Storage System Status

Flash memory device is mainly composed of two parts: flash media, the flash controller, as shown in Fig 1. Flash memory storage system operation use page as read and write unit, block as delete unit. Internal devices are organized in a multi-channel flash particle package, the package can be connected to a plurality of particles on each channel, a shared transport channel between the multi particulates package, but the instruction can be executed independently. Besides, each particle inside the package contains two or more Flash particles, and each can be independently selected to execute instructions. Interior of the particle can be divided into a plurality of flash memory chips, each flash chip containing a buffer register, for temporarily storing read and write data through

multiple levels of instruction parallel execution. Flash memory devices take advantage of the access performance of the media and the flash controller is responsible for address mapping, garbage collection and wear leveling. In fact, Because of the limited number of erase cycles, flash controller device wear leveling algorithm to balance the internal flash memory blocks, while garbage collection algorithms try to select a higher efficiency of the block erase recovery to control the write amplification. In order to improve the overall life of the equipment, controller not only need to maintain efficient data address mapping queries, but also need to balance equipment internal wear and write amplification control.

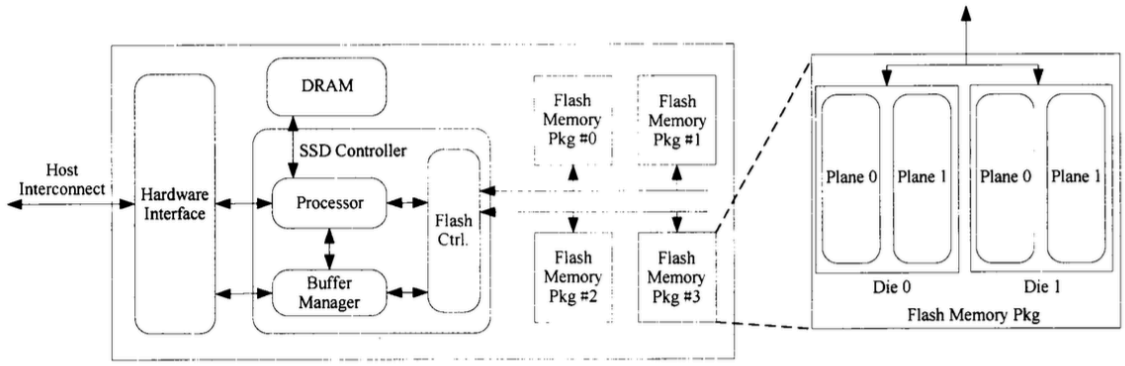

Fig. 1 An illustration of SSD archtecture[1].

Flash memory mainly exists in two forms: SSD (solid state drive, SSD) and bare flash. SSD can handle SATA command inside the apparatus by Flash Translation Layer (FTI). Its external interfaces have no difference with the traditional disk . SSD and traditional disk have a very small difference in the external use, so that you can simply replace traditional disk by the SSD disk. That is also the reason why solid-state disk become the

main form of the current flash memory storage systems , including personal laptops , memory, and storage arrays, etc.

However, the form of SSD limits the effective advantage of flash memory. On the hardware interface, the internal flash memory can access bandwidth aggregation effectively, but SATA standard interface can not meet the need of the system anymore. The hardware interface flash memory storage system becomes the bottleneck of storage system. On the storage subsystem, the system software on the disk storage management file system mostly optimizes the system on disks other than flash memory features. It is hard to get full use of the advantages of flash memory storage system. Software system deficiencies exist mainly in the following aspects:

1) Redundant work

File System management of files include both file directory tree maintenance, but also include a mapping for the logical block file to a storage device physical block, but also include a storage device space management. Internal flash memory devices need to provide address mapping in order to achieve the updated data block. In the file system from the file logical block to physical block mapping equipment, and flash memory devices conversion layer logical address to physical address mapping, mapping constitutes a double flash system. Double appeared both increased mapping metadata

management and storage costs, it may result in a conflict between the double optimization.

2) Voice Missing

Flash memory devices conversion layer encapsulates many operations to flash media, and provides uniform interfaces to upper devices. Internal devices receive data in units of pages, but can not understand the relationship between data pages, it will difficult to optimize the data page read and write operations and distribution. In addition, it is difficult to perceive a flash device file system operations, which will impact associated operation next. For example, the file system erases operation only correspondence metadata, and flash memory devices, which affect garbage collection efficiency of flash devices, only perceived data erase operations until.

3) Feature Missing

Flash memory device provides remote update feature updates the distribution of such data flash write new pages, the old flash page has been retained to garbage collection at the moment. The file systems, database management systems, and other upper applications provide atomic operations, usually use WAL (write ahead logging) way by applying for a new storage space to record data updates as redo logs, and then updating the data in place. Consideration of such a write operation to the two atomic guarantees, not only increase

delay, but also undermines the flash life. Also, the multi-version information of file system can not be indexed directly to the old flash pages.

4) Division Defect

With the increasing capacity of flash memory devices, processing power and memory needs are growing rapidly. This not only enhances the manufacturing cost of the storage device, but also the energy consumption of the equipment impacting the advantages of flash memory .However, while waiting for the host when the flash memory device id doing read and write operations, the host CPU and memory have many additional space. In addition, multi-processing and cache access latency can also cause problems with the reliability of the data. The host and flash memory devices in data processing ,data storage cache should find a best way of division of functions in order to achieve optimal overall system.

Simply replace the disk storage system with a solid-state flash disk can not make full use of flash advantages, and thus the direct management of flash memory storage systems tend to flash media, redesign or adjust hardware structure and optimize access paths , abundant storage semantics and functional enhancements to improve the overall performance of the flash storage systems.

2. Flash memory storage systems

Construction of flash memory storage system based on direct flash media is the most popular research topic. The building forms include flash accelerator opening lead , flash array and the recent proposed flash-based distributed cluster system.

2.1 Flash Flash Accelerator

Flash Accelerator works for servers , mainly for local data cache handling. Compared to traditional PCIe SSD RAID card, PCIe flash cards provided by FusionIO effectively reduces the memory access latency and expanded memory access bandwidth.

Access to the disk array need to go through a host HBA, network switches , array controllers and access modules, as shown in 2 (a);. PCIe, SSD and RAID card also need to go through RAID controller and then access the data, as shown in 2 (b); FusionIO using bare flash PCIe cards, the host directly access flash memory chips, cut down the I/O transmission path, and provides a very low access latency .

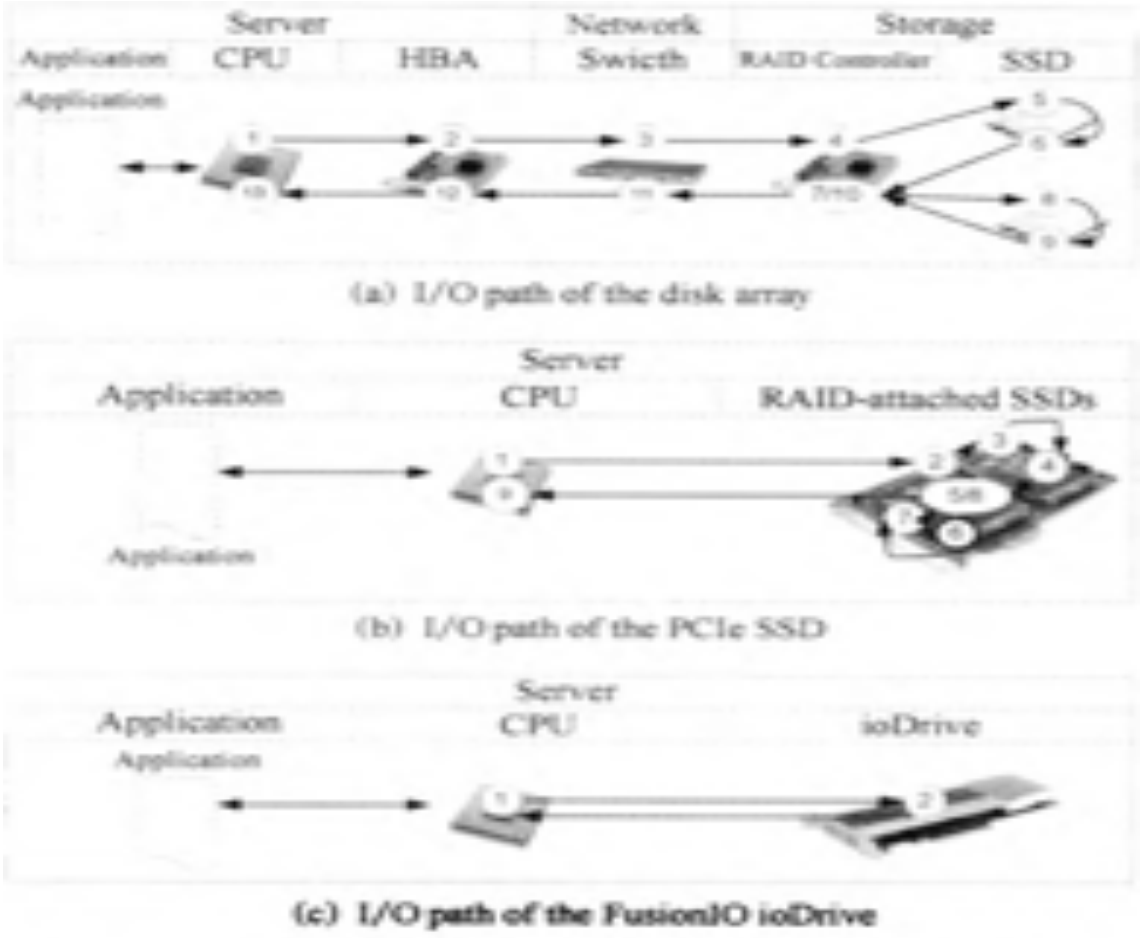

Fig. 2 IO path comparison of the disk array, the PCIe SSD a FusionIO ioDrive.

2.2 Flash Array

Flash Accelerator is difficult to achieve expansion and storage of shared storage capacity. Similar to traditional disk array design, a number of storage vendors introduced a flash array , including the use of solid-state disk array controller with traditional evolutionary design , and the use of flash memory chips and innovative design new array controller.

Violin Memory cooperation with Toshiba flash array design, They apply Violin flash array controller flash media with particle level optimization design. Pure Storage Features Security redesigned based on flash memory controller logic, make full use of flash memory parallel features within the array using global wear leveling algorithms to provide better overall performance and lifetime. XtremeIO, the Israeli flash arrays company which has just been acquired by EMC, believes that traditional disk array controller optimizes the system mainly focus on the characteristics, such as sequential I/O, etc. In order to solve this issue, XtremeIO designed a new type of flash memory array controller, display a better random access performance, and make full use of the flash remote update feature in the array to implement the reduces of redundancy, snapshots, mirroring, thin provisioning, and many other features .

2.3 Flash-based distributed cluster system

2.3.1 FAWN

FAWN (a fast array of wimpy nodes) is the Carnegie Mellon University (CMU) flash-based media expandable and low-power high-performance cluster system. Differ from flash memory and flash array accelerator which only focus on I/O subsystem performance and reliability, the FAWN consider matching flash memory and processor design from the perspective of the whole cluster to reduce overall system power consumption.

Under the data-intensive computing environments, the I/O processing speed is far less than CPU processing speed. CPU wastes a lot of time in waiting state. Meanwhile the energy consumption of the CPU with increasing frequency presents ultra low-power low-frequency linear growth .FAWN match low energy cost CPU with flash memory, providing data-intensive computing cluster system, improving the utilization of the various components of the system , and reducing energy consumption. FAWN can provide up to 364 times requests per Joule, the system enhance the performance hundreds of times than the desktop disk system.

2.3.2 Gordon and Moneta / Onyx

Gordon system is designed by UCSD (University of California, San Diego, UCSD) and similar to FAWN, it apply low frequency and low-power processor to build a data center cluster system performance and storage systems. Compared to FAWN key and low-power concern, Gordon's main job is to design Flash Translation Layer match processors and flash memory chip performance and power consumption. Gordon Flash Translation Layer apply various measures on concurrency features of flash memory chips, including the address dynamic mapping, combination of larger and more physical page physical page, as well as with the concurrent mechanism. Gordon integrated flash memory in single-board 2.5 GB of DRAM and 256 GB flash memory. We know that a 16 snowboard package node provides 4TB flash storage and u 14.4 GBps aggregate

bandwidth. Gordon system has been used for San Diego Supercomputer Center, the mainly applied in astrophysics, genome sequencing and other data-intensive computing, and deployed it in the TeraGrid. When fully configured and deployed, Gordon will have 300TB flash storage. With1024 Intel 710 Series of high-performance solid-state storage composition, it will have 16,384 processor cores, reach a peak theoretical performance to 340Tfps.

Moneta and Onyx are UCSD PCM -based storage systems. Moneta believe that low-latency storage media latency plays a increasing proportion in storage system. Thus, the software system needs to be reconsidered in order to reduce the overall access latency. Moneta use DRAM to simulate PCM, and it bypasses the operating system during operation IO scheduling. Moneta is a PCM storage systems using simulated PCIe interface and Onyx is an improved second -generation prototype of Moneta. Onyx replaces PCIe interface as DIMM, and uses a custom PCM module, to further enhance the system performance.

2.3.3 RAMCloud

Besides using the non-volatile memory devices to build storage systems, University of California, Berkeley (University of California, Berkeley, UC Berkeley) proposed a distributed storage system using DRAM. RAMCloud use a server cluster to build a

unified server DRAM namespace storage systems, all data stored in the DRAM, and the disk is just for backup purposes only. Compared to a traditional disk storage system network that access a remote disk in 5 ~ 10 MS delay, the delay access RAMCloud can reach 5 "s, reach 100 ~ 1 000 times. Although flash memory storage system “F1ashCloud” provides slightly lower performance system than RAMCloud, but in the case of higher throughput needs, RAMCloud has lower cost.

Persistence and availability are the most concerned issues of RAMCloud. RAMCloud uses disk as a backup storage, maintains in memory logging , records each update by using bulk write brush into the disk to provide persistence. On availability, RAMCloud placed three copies on different servers and different copies of data distributed to different servers. In the case of a crash, you can recover from the other nodes in parallel, the experimental prototype can be restored 64GB data within 1 ~ 2 s.

2.4 Conclusion

These systems refactor and adjust the software in low-latency, low power ,multi-device wear leveling and many other considerations. To build a new flash -based storage systems storage system, such as Table 1, We found that the flash accelerator cards , flash memory arrays adjust the memory management module based on memory characteristics, improved subsystem efficiency and scalability, but not optimal. FAWN and Gordon by

matching with I/O and CPU power, build a distributed systems from the cluster of energy-saving point of view. Most importantly, it is possible to ask the multi-node further study on the flash characteristic collaborate. PCM-based Moneta / Onyx use reconstruction of software system to achieve a very low latency of I / O access. RAMCloud DRAM constructed based distributed storage systems to reduce storage system I / 0 delayed.

Storage System	Storage Media	Distributed	I/O Stack Redesign	Latency	Energy	Semantic Aware	Global Wear Leveling	Scalability
FusionIO	Flash	No	Yes	Low	Medium	No	No	Low
FlashArray	Flash	No	Yes	Medium		No	Yes	Medium
FAWN	Flash	Yes	Yes	Medium	Low	No	No	High
Gordon	Flash	Yes	Yes	Medium	Low	No	No	High
Moneta/Onyx	PCM	No	Yes	Extremely Low	Low	No	No	Low
RAMCloud	DRAM	Yes	Yes	Low		No	No	High
Mangix	Flash	Yes	Yes	Medium	Medium	Yes	Yes	High

Notes: The latency of distributed systems includes the network latency. And the energy of FusionIO includes the host energy.

In short, the appearance of flash memory brings a great challenge to the original flash disk optimization software system. In order to make full use of the flash memory's advantages like low latency, high concurrency, remote updates and other features, most flash systems redesign or changed the array controller and software modules to make use of these advantages.

3. Flash memory storage system key technologies

Compared with the disk media access, flash media access presents features such as low latency and write asymmetrical. Traditional storage system optimization technologies always bring many unnecessary redundancy functions to the software system. On the

other hand, it hides the potential advantages of the flash disk. The difference between flash disk devices with traditional disk devices is the a limited number of erase flash unit. The erasure count increases reliability and decrease the reliability of flash memory. In addition, the features like flash memory, small size and low power consumption bring opportunities to low-power system design.

For the characteristics of flash memory , flash memory storage systems research currently focuses on the following three aspects.

3.1 Optimization of storage performance based on I/O stack adjustment and reconstruction

In the new storage system, access delay to the storage medium is becoming lower, the corresponding proportion of the cost of software is increasing. The report notes that traditional disk storage system software overhead proportion accounted 0.3%, PCIe memory card system accounting for 21.9%, and with the development of the non-volatile devices, software overhead is expected to be as high as 94.09% percentage, shown in Figure 3:

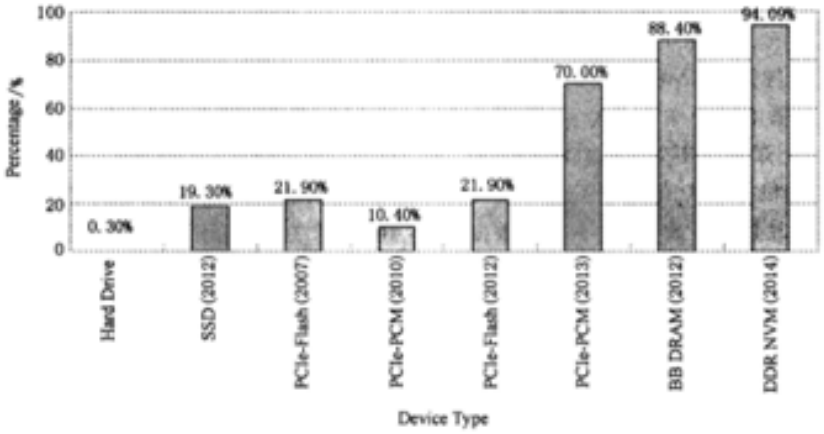

Fig. 3 Trend of software contribution to latency[18].

Software overhead, on the one hand, due to a software design in the level of abstraction, hierarchical design I / O storage path is longer; on the other hand, the sequential disk seek optimal design also brings unnecessary software overhead. In addition to the delay caused by software overhead by flash feature provides a specific function.

3.1.1 hardware interface and notification mechanism

Bandwidth limitations of the hardware interface affect the performance of flash memory devices. The rotational speed of the mechanical parts turn up 15000 turns, but read and write bandwidth still can not be significantly improved. as shown in Table 2. Currently Seagate 15K.3 enterprise-class disk read and write bandwidth up to 202 MBps, which uses SAS 6.0Gbps hardware interface. Therefore, the bottleneck in the flash memory device is the internal read and write operations. Single-chip flash memory can provide 330 MBps read bandwidth and 33 MBps write bandwidth. Internal flash memory devices provide an external high parallel access bandwidth through multiple channels

concurrently, as well as inter-chip instruction execution pipeline, as shown in Table 2. Intel X25-E read bandwidth is up to 250 MBps, SATA3 Gbps. PCIe interface becomes a bottleneck. Fusionl0 uses PCIe hardware interface, ioDrive Octal can reach 6 GBps read bandwidth and 4.4 GBps write bandwidth.

Besides the bandwidth, delay is also need new high-speed access to the hardware interface, FusionIO use DMA to transfer data between the flash memory and the memory directly through the PCIe interface, thereby avoiding the processing delay and other SAS / SATA HBA and RAID modules. FIG. As shown in Fig 1, FusionIO can be reduced from 2 to 8 modules handle delays. UCSD upgrade Moneta in PCM prototype system PCIe interface to Onyx DIMM connector, which further reducing the access latency.

3.1.2 Software Storage Path

In the I/O path layer, due to the modular needs, software system software contains multilayer, including virtual file system layer, the block layer, and a SCSI device driver layer. In all levels of the software, the specific file system, equipment, drives in order to achieve the correct data transfer. Software heterogeneous multi-level shield properties, but also led to unnecessary processing and conversion.

In the device layer FusionIO use DMA to transfer data directly via PCIe interface between the flash and memory, thus avoiding the conversion and processing 3-layer transport model of traditional SCSI 3-layer transport model .SCSI between commands brought both delay overhead, but also limits the extended command set.

In the block device layer, existing IO scheduling policies are based on sequential disk access and other issues. Thus the use of SSDs, many people make use of noop scheduling policy, which does not using I/O scheduling. Flash memory access also has a unique feature which can not take full advantage of read and write requests concurrency features internal flash memory devices will result in wasted bandwidth. The paper proposed FIOS scheduling algorithm by selecting the appropriate time slice, and the separation between the interference read. It not only make the use of concurrency features flash devices, but also ensure the fairness of access requests.

In the file system layer, Princeton researchers cooperated with FusionIO. The FusionIO equipment achieved a new flash file system. The file system uses the VSL managing flash memory feature of FusionIO, thus avoiding the file system space management and flash memory devices FTL redundant administrative overhead management.

At the application layer, UCSD PCM based prototype system a realized directly in user mode data access system Moneta-D. Moneta-D hardware achieves the permission validation, and supports equipment from the notification application mechanism to achieve a user's IO request. Thus it avoided the user mode-witching overhead and file system permissions verification overhead.

3.2 System Reliability

Erase the flash unit will undermine the ability to save an electronic flash unit, resulting in data storage susceptible to interference, which could reduce reliability. Between 10,000 ~ 100,000 times, the increase in the number of erase flash density flash unit flash unit reliability becomes lower. To extend the life of flash memory devices within FTL wear leveling strategies to achieve the mouth. With different disk, flash memory is closely related to the load and the upper system of life. It becomes an important way to reduce the amount of data to write the upper application. Thus, to achieve load balancing optimization and wear from a system perspective, the reliability of flash memory system has important significance.

3.2.1 Channel reliability

In a single system, to improve the reliability of the channel by optimizing I/O path inside the upper application and the underlying reliability of the devices. The channel includes

two aspects: delete redundant system data compression and multi-release mechanism inside the device.

CAFT L detect updated data by the double redundancy in the FTL, and delete duplicate data and merge them to reduce the amount of data written to the SSD. CA-SSD will introduce content addressable storage, CAS into the SSD, the presence of reducing localized value write data amount, extending the life of SSDs. In the database system, physical size of records is much smaller than the size of the flash memory pages. Frequent record updates cause a large number of update flash physical page, causing flash life issues. To solve this problem, the literature proposed in-page logging (IPL) mechanism, by keeping the size of the log in area 8 KB flash block, appended to the log area. And by delaying the merger mechanism to update the data, reduce the overall update flash page write the same logical address of a page in most case. Delta FTL compared compressed the same logical page address. In order to reduce the flash update page at the same time, mapping table by maintaining the delta mapping table provide the latest data flash array. Pure Storage and XtremeIO reduced the amount of data written to the array by repeating data duplication technology.

The internal device data provide fault-tolerant multi-version from another angle to improve the reliability of flash memory systems. Flash remote update is not immediately erase the old version, the literature proposed to maintain the consistency of the two

individual files in the flash file system version, when the latest version is wrong by fall back on a consistent way to provide fault-tolerant version of the file.

3.2.2 Cross equipment reliability

The system overall error rate in Flash memory devices was not as the flash unit error rate, but for the replacement equipment online and consider the availability of data, maintaining redundant data across multiple devices is still necessary to improve reliability. However, suppose that the traditional fault-tolerant RAID the error between the disk are independent of the conditions. In the flash memory storage system, it is no longer valid due to load balancing as RAID, which leads to an approximate speed of wear. When multiple flash memory devices while approaching life limit, each device error probability rises, also cause increased overall probability of error. Diff-RAID adjust the calibration value (parity) in the distribution of different flash memory devices, differentiated wear the rate of each device, thereby reducing the probability of error of devices simultaneously, and will improve the reliability of SSD RAID storage array. Reliability and more equipment is also reflected in the error recovery rate. RAMCloud uses a multi- copy technique, the copy of the data distributed on different servers, and the copy of the data in different data evenly distributed all servers in the cluster.

3.3 Volume and energy consumption

Flash's features like low volume and low energy consumption provides the opportunity for the low-power computer systems or data center. EXCES use SSDs as a disk cache, caching, buffering SSDs, thus reducing disk access to achieve energy saving.

In the data center design, FAWN and Gordon have raised the computing power and I / O capabilities to match the cluster nodes. By using low-frequency and low-latency flash memory chip to reduce the computational CPU processing and I/O. CPU power consumption increases linearly with frequency super , high-frequency relative to the existing server CPU, low- power consumption is very low CPU required The server does not require the removal of redundant capabilities that enable cluster server board, thus greatly reducing the footprint of the data center. In addition, the use of flash drive or flash memory card in the server system can also reduce the traditional disk array or server the number of required, thereby reducing the size of the system to save energy.

4. Summary

This article describes the current set of typical flash memory storage systems, and from the aspects such as I / O stack adjustment and reconstruction and flash system reliability, size and power consumption. All of these key technologies and hot issues were discussed. Flash system presents to traditional disk systems are vastly different characteristics, a simple device replacement limits the play flash performance, it is difficult to overcome

the disadvantages of flash memory such as wear and tear, etc., Also it is not conducive to the use of flash memory new features such as atomic write.

How to take advantage of flash memory characteristics and by modifying or remodeling software systems to provide friendly support? To build a research focus flash system also needs further research directions. First, in the software system I/O on the stack, how to reduce software redundancy and cache scheduling I/O request to make full use of flash memory storage system is still big challenge. Secondly, flash reliability is closely related with the system load, from the perspective of how to load and systems Flash design reliability is worthy of study. Reliability Model with traditional flash disk is changed, the existing system to build less consideration flash life and reduce system construction from the perspective of data need to be considered when writing the flash memory to improve system life. Finally, a flash memory system design should consider the effect of the new memory device may bring the system to improve the system software in a variety of memory devices universality. Most existing file system are based on optimization of disk characteristics, With the division of labor and trade-offs appear flash memory and other new PCM memory devices, systems and between storage hardware and management system should provide a variety of storage devices as possible.

Flash memory has been more widely deployed, their reliability and cost issues is gradually being accepted. Construction of flash memory storage systems is still in its

infancy, but the system level by providing friendly support for Flash to make full use of the advantages of flash memory, and it will also brings important changes to computer system.

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