Abstract

As the chip design process becomes increasingly complex, more and more time is spent during the logical and physical verification of a chip design. Both analog and digital analysis and implementation of chip designs demand high performance and low latency for the jobs to complete at the application layer during various simulations and test benches. Apart from large investments in maintaining application license costs every year, the main stakeholders of the engineering teams or chip developers should also focus on an optimized infrastructure below the design application layer that can considerably reduce the design cycle time and enable faster time to market (TTM).

High-end NetApp® storage controllers such as FAS8080EX and solid-state drives (SSDs) are aptly designed as a shared storage infrastructure that can provide scalability, reliability, and predictable performance. This report focuses on the benefits of using FAS8080EX and SSD, which can provide a higher service-level offering (SLO) to certain projects that are very critical and time sensitive and require much lower latency and predictable performance during the lifetime of the project.
TABLE OF CONTENTS

1 Introduction ........................................................................................................................................... 3
2 Target Audience and Objectives ............................................................................................................. 3
3 NetApp Flash Portfolio for EDA Workloads ............................................................................................ 3
4 How Much Performance Boost Do AFF Arrays Provide? ...................................................................... 5
  4.1 Application Layer Analysis .................................................................................................................. 5
  4.2 Storage Layer Analysis ....................................................................................................................... 6
5 EDA Verification Workload Testing on AFF Arrays ............................................................................. 6
  5.1 Test Environment .............................................................................................................................. 7
  5.2 Test Results ..................................................................................................................................... 7
  5.3 Observations .................................................................................................................................. 8
6 Best Practice Recommendations ............................................................................................................ 8
  6.1 Storage Controller and Shelf Setup .................................................................................................... 8
  6.2 File System Optimization .................................................................................................................. 9
  6.3 SSD Shelves and RAID Group Recommendations .......................................................................... 9
  6.4 Flash Cache Recommendations ...................................................................................................... 10
7 Conclusion .......................................................................................................................................... 10

LIST OF FIGURES

Figure 1) EDA verification workloads and flash. .......................................................................................... 5
Figure 2) Synopsys VCS test with SAS vs. SSD comparison over NFSv3. .................................................. 7
Figure 3) Active-active loop configuration between the controller and the SSD shelves. ............................ 9
1 Introduction

Feature device sizes keep shrinking, from 90nm a few years ago to 16nm and FinFET, which means that design complexity and number of design elements are growing tremendously. As sizes keep getting smaller, longer times are spent on the logical and physical verification phases, in which a lot of simulations and test benches are run to validate design functions and integrity. Given that the cost of implementation is rising, design verification is becoming a major component of the overall design cycle. Although various tool vendors have come up with faster applications to run these simulations, an equally robust and optimized infrastructure is required to complement the performance with more predictability.

It is very important to understand the file system layout and workload requirements of the verification tools before considering any storage platform to store and manage the design files that are part of different intellectual properties (IPs) and chip design projects. Understanding the workload profile of the verification application helps to identify the right storage platform and different components of the storage subsystem. The right storage configuration and sizing can enhance performance to provide the required tiering of hot and active workloads on extremely fast disks that are latency and time sensitive compared to cold and less active data on slower and denser disks with different performance and archival objectives.

NetApp clustered Data ONTAP® has been successfully providing a high degree of scalability, reliability, manageability, and performance to many EDA tool makers and chip design companies. Data ONTAP in its earlier form has been very popular with almost all the semiconductor companies. The NetApp controllers are used as a shared infrastructure to access design and binary files over Network File System (NFS).

With clustered Data ONTAP, the chip design data has become permanent. The volumes that belong to different chip design projects can move seamlessly through different tiers of storage—SSD, serial access SCSI (SAS), and SATA—as projects change from hot and active to cold and inactive states. Policies can be set to manage different performance service-level objectives (SLOS) from very fast and expensive enterprise multilayer cell (eMLC)—based SSDs to less costly and denser SATA disks. Based on the project requirements, the different tiers of storage disks in the same cluster namespace can optimize and provide:

- Better value with respect to performance, because fewer SSDs are required compared to spinning disks for verification workloads
- Improved return on investment (ROI), because the SSDs are reused for multiple different design IPs when active data moves into other storage tiers after the project gets completed

2 Target Audience and Objectives

Flash technology has been on the market for some time. Until recently SSDs that use flash technology have been getting increasingly denser and less costly and have an improving program-to-erase ratio. This report is mainly targeted to help storage administrators and architects to understand the verification workload and to determine the right way to size and optimize SSDs for best performance results:

- The main objective of this report is to highlight the SSD performance test results obtained from tests run on verification workloads compared to spinning disks using NFSv3. This report describes where and how all Flash FAS (AFF) can make a difference to EDA verification workloads.
- This report also attempts to provide best practices while setting up AFF arrays using SSD aggregates.

3 NetApp Flash Portfolio for EDA Workloads

Spinning drives such as faster SAS or the slower and denser SATA disks store data on magnetic spinning media with a moving head to read and write data. These drives are always associated with a seek and access time that adds to the latency for performance-driven workloads.

The solid-state drives store an electric charge in a cell. There is no seek time while accessing the data. The access time is in microseconds, compared to milliseconds for spinning media. The eMLC drives have
better write amplification, greater endurance, and far more write cycles to increase the longevity of the SSDs. The writes are mostly striped across the entire SSD and written to new locations.

NetApp has been innovating and integrating various flash technologies such as the PCIe-based Flash Cache™, hybrid storage (Flash Pool™), and All Flash FAS arrays in its portfolio over the years to improve performance for various different workloads such as OLTP databases, virtual machines, engineering applications, and so on. Each part of the flash portfolio encompasses different use cases:

- **PCle-based Flash Cache.** Flash Cache is a PCIe-based card that works as an extended buffer to the main or base memory. It works mainly as a read cache. It does not use any power to store data. The cache is invalidated across storage controller reboots. After the data is evicted out of the base memory, it is moved to Flash Cache. Flash Cache has been extremely effective in providing low latency to metadata and read workloads. Because EDA verification workloads consist of millions of small files, high metadata, and lots of sequential reads, Flash Cache caches the metadata and data to expedite the I/O requests and reduces the back-end disk access. This improves the overall EDA design application run time. This has been a common choice by most of our EDA customers.

- **Flash Pool.** This is also referred to as a hybrid array. Flash Pool is a combination of SSD and HDD. The HDD could be the faster SAS disks or the slower SATA disks. Both the scenarios fulfill different use cases and price-to-performance ratios. The SSD works as a cache and a staging area for reads and writes. However, EDA verification workloads mostly consist of sequential reads and writes. New cache policies and optimizations in clustered Data ONTAP 8.3.1 provide performance improvement with Flash Pool over spinning drives for verification workload. The new caching policy set “ALL” allows caching all the random and sequential writes along with metadata and reads. Flash Pool helps significantly as a virtual storage tier for other workloads. Flash Pool aggregates can coexist with regular aggregates that consists of spinning drives.

- **All Flash FAS (AFF).** This is NetApp’s latest offering in its flash portfolio. The SSD shelves are connected to the controller with a SAS loop in the back end. The speed of the SAS back-end loop also determines how quickly the data bits can move from the SSD shelves and the controller. The RAID groups created in the aggregates consist of all SSDs. SSDs use power to store the data permanently unless the data is deleted. SSDs with no seek time and very low access times becomes a compelling architecture to provide predictable performance with consistent latency for mission-critical workloads. Random read workloads benefit a lot from AFF. A PCIe-based Flash Cache aggregate is no longer required with SSD aggregates. In clustered Data ONTAP 8.3.1, the read performance is further optimized for All Flash FAS arrays. The incoming I/O request from the network layer goes to WAFL® and to the storage layer. It bypasses the RAID layer because the new code of flash arrays is capable of performing the error correcting in the data path. On the way out, the I/O request is served from the storage layer directly to the network. The RAID and WAFL layers are completely bypassed. This improves the read performance to a great extent. This optimization in clustered Data ONTAP 8.3.1 only works with AFF. This optimization does apply to controllers with spinning media.

Figure 1 illustrates that FAS arrays with faster SAS disks and PCIe-based Flash Cache have been extremely successful with EDA verification workloads and widely used by many semiconductor companies. Recent testing at a very large EDA tool vendor indicated that Flash Pool does provide performance improvements with verification workloads, and we validate the test results on AFF later in this report.
4 How Much Performance Boost Do AFF Arrays Provide?

The answer to the question “How much performance boost do AFF arrays provide?” needs qualifying. The short answer is “it depends.” Many variables can determine if there is any performance improvement with AFF based on $/GB of storage and the $/IOPS compared to the fast SAS or slower SATA disks. The pure SSD aggregates can be used to provide the highest SLOs over other spinning disks for EDA workloads. Using SSDs where they might not be needed adds to the infrastructure cost and increases the capital expenditure (capex) if the SSDs are used for one set of projects or team or line of business (LoB). If the SSDs are used for multiple different projects and the disk space is reused, they can be provided as a tiered service offering to different LoBs or customers, optimizing the use of resources for the best overall cost and performance. However, with the prices of the SSDs on the decline, the deciding factor is mainly targeted on $/IOPS.

4.1 Application Layer Analysis

Let us start from the application layer at the top to understand the requirement to use SSDs in EDA workloads:

- What is the current job completion or the wall clock time for verifications running on design workloads?
- What is an acceptable latency for certain projects that are mission and time critical?
- How many design projects demand a very low consistent latency and predictable performance? There might not be too many of those.
- Are those designs compute or I/O intense? If the designs are too compute driven, then very little I/O goes to the storage. SSDs might not be a good choice in that scenario. If the design generates too much I/O, then faster disks such as SSDs make more sense.
- Understanding the nature of the workload that some of the EDA tools generate is very important to determine the use of SSD.
Tools such as Cadence Virtuoso, which generates a lot of random read and write, and Synopsys PureCov, which has high sequential reads and writes with very little metadata, may benefit from AFF. These tools may be good candidates for a proof of concept with AFF/SSD aggregates in the future.

However, this report focuses on the verification phase of the design cycle, in which a project typically spends the majority of its time. For the purpose of his paper we performed tests using the Synopsys VCS verification tool.

4.2 Storage Layer Analysis

Now let us look into the storage part of the infrastructure, which can influence the use of all-SSD aggregates:

- It is important to understand the technology and some inherent behavior of SSDs. The SSDs have write amplification. For example, consider a software control management (SCM) application or tool that manages the different versions of a software release. The different software versions only store the delta changes instead of a full copy change. Deduplication is turned on for the storage for space savings. This adds a lot of overhead if the software depot or the repository is stored in the SSD aggregates. However, the database that controls the software management of the different versions can be a good candidate on SSD aggregates.

- Tools such as Bitkeeper that do lots of deletes affect the endurance of the SSDs. The program to erase ratio is very high and thus reduces the write cycle of the SSDs. However, the optimizations in clustered Data ONTAP 8.3.1 to handle the deletes mitigate the delete issue to some extent.

- NetApp controllers are already doing a great job improving write performance with NVRAM. The application gets an acknowledgement as soon as the write is logged in to the NVRAM. The write buffers are later flushed to the back-end disk subsystem in the next consistency point (CP). The type of disks (SAS/SATA or SSD) does not matter much, but the rotational speed of the spinning disk does make a difference compared to SSDs. The back-to-back CPs are reduced considerably with SSDs.

- There is a difference in the way the writes are performed in SAS vs. SSDs. EDA verification workloads are high file count in nature. As the file system ages, the spinning disks tend to fragment the file system, and a lot of time is spent in computing parity to identify free space. However, with SSDs, the writes are striped across the disks, and the data blocks are written in new locations.

- EDA application workloads are mostly CPU intensive. The cores on the storage run at maximum most of the time. The SSDs benefit most with disk-intensive workloads. AFF can provide better $/IOPS for mostly read workloads such as tools and binaries and also for scratch space where a lot of transient data is created and deleted.

- SSDs provide consistent latency and predictable performance. Important and critical chip design project volumes can exist in the SSD aggregates and can be moved out seamlessly after the project is over and the priority drops to be reused by some other projects.

It is very important for the NetApp account team to engage with the EDA core team to have conversation with the customer to use the SSDs the right way.

5 EDA Verification Workload Testing on AFF Arrays

There is always a need to improve the application run time through optimizing or having better storage infrastructure to provide the extra performance mileage for various reasons: design complexity, faster time to market, and/or optimizing licensing cost. The AFF array offering from NetApp is another compelling product that needs some investigation of EDA workloads and validates if all-SSD aggregates add any value to application run time.
5.1 Test Environment

The tests were performed with the Synopsys VCS 11.3 application with 104 cores in the NetApp Lab on one single chipset design. This design generates a lot of I/O to the storage. All the best practice recommendations documented in section 6 below followed in the NetApp cluster setup to test verification workload. The verification test scenario consists of:

- FAS6290 with 450GB 15k RPM SAS disks and compared with FAS8080EX with 800GB eMLC SSDs.
- Two 28-disk RAID groups created in each of the aggregates on FAS6290 and FAS8080EX.
- There is 512GB Flash Cache in the FAS6290 controllers with SAS aggregates, but there was no Flash Cache (recommended) on the FAS8080EX with SSD aggregates.
- The FAS6290 along with Flash Cache cluster nodes were running on clustered Data ONTAP 8.3.1. The tests run on these nodes were identified as baseline. Further test runs on FAS8080 with SAS and SSD were compared to the baseline from FAS6290.
- The FAS8080 was also tested with 900GB SAS disks over NFSv3 for a more fine-grained performance baseline.
- The same chip design volumes were present in the FAS6290/SAS and FAS8080EX/SSD aggregates. A FAS6290, SAS, and Flash Cache configuration was identified as the baseline for this test. A 20Gbe network connection to both the FAS6090 and FAS8080EX controller was configured.
- Clustered Data ONTAP 8.3.1 was used for the baseline testing. The AFF testing was also performed on clustered Data ONTAP 8.3.1.
- All the compute nodes had 10GbE connection to the storage cluster.
- The compute nodes were running on the RHEL6.4 kernel.

5.2 Test Results

Two different tests were performed: FAS6290 with SAS disks over NFSv3 an AFF with FAS8080 over NFSv3. The wall clock time at the application layer was measured after the commencement of each test. The improvements are based on the VCS run time.

Figure 2) Synopsys VCS test with SAS vs. SSD comparison over NFSv3.

![Synopsys VCS wall clock time validations](image)

Figure 2 depicts that there AFF was the winner out of all the tests. There was about 29% improvement in wall clock time for simulation for one of the designs compared to baseline.
The improvement could vary from design to design. The improvement is never a static number based on all the testing that was done at NetApp and other EDA tool vendors such as Cadence and Mentor Graphics and customers on various different designs.

The results indicated that both the test designs had more I/O generated during compile compared to simulation. From all the storage performance data that was gathered, the simulation working set was cached in the base memory of the storage controller. That means most of the I/O requests were served from the memory. Very little I/O went to disk. However, with the limited I/O we still noticed some improvement for simulation, but not at the magnitude of compile I/O.

All the performance data gathered from the storage during the tests indicated that AFF provides a about 40% reduction in the storage latency for both the designs combined. This means more headroom on the storage for more workloads and thus better return on investment (ROI).

5.3 Observations

It was observed that all the Synopsys VCS tests run on FAS8080EX and SSDs compared to FAS6290 and SAS provided consistent low latencies and predictable performance for the jobs submitted in the compute farm. The SSDs are capable of a higher number of IOPS and lower CPU utilization over spinning disks. This is an important data point for EDA verification workloads because they are very CPU intensive and need more CPU headroom to scale.

Design verification workloads are a high–file count environment. Ideally, high-metadata sequential read and write workloads are more dominant in the verification workloads. The metadata is normally cached in the base memory to provide submillisecond response to the application.

With the absence of Flash Cache on the FAS8080EX compared to the FAS6290 with Flash Cache and SAS disks, the aggressive readahead algorithm in clustered Data ONTAP 8.3.1 is really doing a great job with the SSDs for the sequential read workloads. This is going to get better with the best practice recommendations documented in section 6.

With the sequential write improvements that were achieved in this test, the improvement number might look small, but think about it without the NVRAM. When you are writing directly to spinning disks and then write to SSDs, the writes are going to be lot faster when writing to the SSDs. With NVRAM in the critical data path, the writes are already faster irrespective of the type of the disks in the back end. The applications get an acknowledgment as soon as the write logs in to the NVRAM. With no seek time and access time in microseconds, the writes are committed to the SSDs much more quickly than the spinning disks. So the recommended best practices documented in section 6 allow improvement to sequential write performance.

Controlled performance tests validated at various EDA customers indicated that the FAS8080EX storage controller with loads of memory, lots of cores, and larger NVRAM with SAS disks is capable of more than 50% greater IOPS compared to a FAS6290. As the number of cores grows in the compute farm and the volumes increase in the storage controller, the performance scales linearly compared to the FAS6290.

The FAS8080EX stays relatively flat much longer before the sharp, steady increase compared to FAS6280 in a throughput vs. latency graph. The SSDs and NFSv4.1/pNFS further complement the performance with what is already achieved by FAS8080EX over FAS6280 with SAS disks over NFSv3.

6 Best Practice Recommendations

The test results that were obtained so far look promising with a decent performance boost from AFF array and SSD aggregates. The percent of improvement varies from design to design and different application workloads. However, there are some best practice recommendations that need to be followed in order to achieve better performance with SSD aggregates in an AFF array.

6.1 Storage Controller and Shelf Setup

All of the EDA workloads in the design workflow can run on All Flash FAS (AFF). However, configuring the back-end SAS loop between the controller and the SSDs plays an important role to handle various different workloads. The sequential reads and writes constitute a big chunk of the overall workload apart.
from the metadata operations. The random reads and writes are not a significant part of the design workload. As pointed out in section 5.3, sequential workloads can saturate the back-end SAS loop between FAS8080 controllers and SSD subsystem. An active-active path between the controller pair and the SSDs is highly recommended. One-half of the disks in the shelf are software owned by one node, while the other half of the disks are owned by its partner for each SSD shelf. The random read and write workloads can be a subset of this setup. This does not require a separate configuration.

Figure 3 illustrates the active-active connection between the controllers and the SSD shelves. Make sure that software ownership of the disks is split equally between the controllers for each SSD shelf.

6.2 File System Optimization

AFF arrays are not for all workloads and for all EDA chip design projects. The SSD aggregates host some of the mission-critical and time-critical projects to drive faster time to market and optimize license costs. The file system optimizations for SSD aggregates are the same as the ones recommended for spinning disks. With FAS8080EX it is highly recommended to have a minimum of four or a multiple of four volumes for more parallelism and improved performance.

File System Optimization Best Practices

- NetApp always recommends setting up an alarm that triggers as soon as the aggregate reaches 80% capacity. The critical chip design volumes that need more space can automatically use WFA or manually be moved to another aggregate on a different controller.

- NetApp recommends thin provisioning the volumes. This can be done when the volumes are created, or they can be modified later. It can also be done using System Manager 3.0 from a graphical user interface.

  ```bash
  bumblebee:~$> vol modify -vserver vs1_eda_vcs -volume CMUSERVOLSSD -space-guarantee none
  (volume modify)
  Volume modify successful on volume: CMUSERVOLSSD
  ```

6.3 SSD Shelves and RAID Group Recommendations

Having the SSD shelves on different SAS back-end loops is recommended. That means that if you have three SSD shelves, then there are three different SAS back-end loops. The FAS8080EX controllers are
very fast, and so are the SSDs. Having all three shelves on a single loop saturates the back-end SAS loop, restricting the sequential write performance.

Having at least two RAID groups of 22 (20+2) disks in a single aggregate for better volume affinities is also recommended.

6.4 Flash Cache Recommendations

Not having any aggregates with spinning disks on the controller along with all-SSD aggregates is highly recommended.

Do not use Flash Cache of any capacity along with SSD aggregates. It is disabled by default. Even if the card is physically present and is in a disabled state, it occupies some amount of base or main memory in the controller. That is a waste considering that base memory helps to serve the metadata traffic from the memory with submillisecond latency. Therefore, it is strongly recommended to not have any Flash Cache card physically in the controller in an AFF array with SSD aggregates.

7 Conclusion

As we go through the different phases of flash technology, solid-state drives have gone through a lot of evolution in recent years, from single-layer cell (SLC) disks, which were very expensive, to multilayer cell (MLC), which was less expensive, to eMLC, which is moderately priced. While we await the less costly consumer MLC (cMLC) version of the SSDs to be available and ready to be consumed by the data centers and cloud, eMLC-based SSDs are best value for predictable performance and consistent latency.

Based on all the verification test results, it evident that All Flash FAS arrays provide a significant improvement in wall clock performance over completely optimized controllers with spinning disks. The best practice to cable the shelves in an active-active configuration provides better performance gains with AFF arrays for different chip designs. There are about more than a dozen tools used in an EDA chip design cycle. Understanding the key workloads generated from different tools and applications, for example, verification in the test report mentioned earlier, is the way to approach AFF arrays in the data center. Performing a proof of concept (PoC) on those test designs in a more real environment with the proper guidance from the respective NetApp account teams and the EDA core team yields promising results with AFF arrays and SSD aggregates. The end goals are always to achieve better job completion times with shorter wall clock times and to optimize the license costs for the EDA tools.
Refer to the **Interoperability Matrix Tool (IMT)** on the NetApp Support site to validate that the exact product and feature versions described in this document are supported for your specific environment. The NetApp IMT defines the product components and versions that can be used to construct configurations that are supported by NetApp. Specific results depend on each customer’s installation in accordance with published specifications.

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