

# Recommended Hyperconverged Infrastructure

## Solutions with Intel® Processors and SSDs, Windows Server\* 2016, and Storage Spaces Direct



**Solution Brief**  
What's it all about?

**YOU ARE HERE** → **Reference Architecture**  
Getting the full-functional and technical picture

**Implementation Guide**  
Putting it all together

**What You'll Find in This Solution Reference Architecture**

This solution provides a starting point for developing a hyperconverged compute and storage infrastructure.

If you are responsible for:

- **Investment decisions and business strategy...**  
This reference architecture shows how Intel and Microsoft technologies and on-premises, private cloud services enable simple, cost-effective operations and on-site control of data assets.
- **Figuring out how to design software-defined infrastructure solutions...**  
You'll learn about the architecture components and how they work together to create a cohesive business solution.

### Executive Summary

Today's enterprises face the challenges of ever-growing volumes and variety of data that must be processed, stored, and easily accessed. Their IT solutions must be available, secure, and provide a decent ROI. And companies must use these solutions to stay agile and control costs.

Increasingly, enterprises are looking to hyperconverged technology and on-premises, private cloud services to satisfy this demanding list of requirements. This approach offers simple, cost-effective operations and on-site control of data assets, which appeal to both business and IT decision-makers.

This reference architecture describes:

- Intel and Microsoft hyperconverged compute and storage technologies.
- Function of hyperconverged infrastructure (HCI) solution components.
- Guidance for choosing HCI solution components for specific situations.
- The benefits of using all-flash configurations with the NVMe\* interface in HCI solutions.
- A performance comparison of three HCI solution configurations used in different workloads.

## Table of Contents

|                                                                 |    |
|-----------------------------------------------------------------|----|
| Executive Summary .....                                         | 1  |
| Introduction .....                                              | 2  |
| Solution Architecture .....                                     | 3  |
| Architecture Details .....                                      | 3  |
| Recommended Configurations & Architectural Considerations ..... | 5  |
| Windows Server 2016                                             |    |
| HCI Performance .....                                           | 7  |
| Configuration 1 .....                                           | 7  |
| Configuration 2 .....                                           | 9  |
| Configuration 3 .....                                           | 10 |
| Summary .....                                                   | 12 |
| Solutions Proven by Your Peers .....                            | 12 |

## Introduction

This reference architecture shows how enterprises can deploy software-defined infrastructure solutions based on technologies from Intel, Microsoft, and other partners in a range of workloads.

Written for IT managers and decision-makers, as well as OEM, OXM, and channel partners, this document describes system features, capabilities, and resource requirements of HCI solutions. These resources support hosted private cloud services and enable IT professionals to build and maintain on-premises private cloud services more easily.

### Software-Defined Storage Solutions

Software-defined storage (SDS) is the latest trend in the evolution of storage systems. In the past, storage deployments used expensive, proprietary storage-area networks (SANs). With digital data in the enterprise growing rapidly, companies that deployed traditional, proprietary SANs saw a significant amount of their budget allocated for storage purchases.

### Storage Spaces Direct Capabilities

The hyperconverged architecture of Storage Spaces Direct (S2D) in Windows Server\* 2016 is a giant leap forward for many key IT business applications. Many IT professionals see the promise of HCI and are rethinking how it can help them from compute and storage points of view.

Intel collaborated with Microsoft to develop three HCI solution configurations. These span a range of requirements, from the most latency- and IOPS-sensitive business processing applications to capacity-hungry data warehousing. These configurations also provide enterprise IT with performance data relevant to different workloads, each of which emphasizes performance and reliability.

Companies are using IT to stay competitive. That means becoming more agile, simplifying and automating IT management, controlling costs, and processing huge volumes of increasingly diverse data. Many organizations seeking cost control and agility have discovered the on-site private cloud delivery option. Using Windows Server 2016 and S2D enables IT pros to create a hyperconverged private cloud. These HCI solutions consolidate compute, storage, and virtualization functions onto a common set of servers.

### S2D in On-Premises or Hosted Environments

S2D provides SDS located on premises for enterprises or in hosted environments used by service providers. S2D has two deployment modes:

- **Hyperconverged:** The hyperconverged deployment scenario puts Hyper-V\* (compute) and S2D (storage) components in the same cluster. Virtual machines run on local cluster shared volumes (CSVs). By using this approach, IT can scale Hyper-V compute clusters with the storage they are using. When S2D is configured, and CSV volumes are available, configuring and provisioning Hyper-V is the same process and uses the same tools as any other Hyper-V deployment on a failover cluster.
- **Converged:** The converged (also known as disaggregated) deployment option layers a scale-out file server (SoFS) atop S2D to provide network-attached storage over SMB3 file shares. This approach enables IT to scale compute and workload independent of the storage cluster. This is an essential way to perform larger-scale deployments for service providers and enterprises.

## Solution Architecture

The HCI solution discussed here is based on Intel® hardware and Windows Server 2016. The solution's software-centered structure tightly integrates compute, storage, networking, and virtualization resources in industry-standard servers. A hyperconverged solution enables these integrated technologies to be managed as a single system. Hyperconverged systems can be expanded easily and cost-effectively by adding standard server building blocks. These elements combine processing, storage, and virtualization capabilities to the basic cluster.

### Architecture Details

This section describes the major components of HCI solutions and how they work in recommended configurations.

#### Windows Server 2016

Microsoft developed Windows Server 2016 with a focus on helping companies use the latest cloud and mobile capabilities. Windows Server 2016 enables IT pros to set up and maintain private, on-premises cloud services. With it, IT organizations can use traditional storage (SAN/NAS) or faster, more cost-effective SDS solutions, such as S2D.

Windows Server 2016 features storage-related innovations that:<sup>1</sup>

- Protect data while keeping it accessible to users.
- Increase speed and reduce latency.
- Keep data available in the event of storage disruption.
- Enable IT professionals to upgrade the operating system quickly and avoid downtime penalties against service level agreements (SLA).

Features that are new or changed in Windows Server 2016 Datacenter Edition include:

- **Windows Server Containers and Hyper-V\* Containers.** Windows Server Containers will run directly on the OS but are isolated from each other. Hyper-V Containers provide enhanced isolation and run from a Hyper-V virtual machine. Windows Server 2016 also provides built-in support for Docker\*, which can be used to manage both types of containers.
- **Nano Server.** Windows Server now has an updated module for building Nano Server images. This enables more separation of physical host and guest virtual machines. Improvements to the Recovery Console include separation of inbound and outbound firewall rules and the ability to repair WinRM configurations.

#### Storage Spaces Direct

S2D in Windows Server 2016 pools server storage to build highly available and scalable storage for virtual machines. S2D creates available storage by using industry-standard servers with local, direct-attached storage media. This approach is a significant step toward SDS. It enables fast and simple setup, high performance, fault tolerance, and easy scalability.

A feature of Windows Server 2016, S2D extends the existing SDS stack for Windows Server. S2D uses SMB3 for all intra-node (east-west) communications, such as SMB Direct and SMB Multichannel for low-latency, high-throughput storage.

S2D also integrates with features of the Windows Server SDS stack. These features include SoFS, CSV File System (CSVFS), Storage Spaces, and Failover Clustering.

Microsoft proposes using S2D as a new way to build and maintain scalable, cost-effective storage for private cloud services. S2D supports familiar types of server storage:

- SAS HDDs and SSDs
- SATA-based drives (HDDs and SSDs)
- PCIe\* SSDs using the Non-Volatile Memory Express\* (NVMe) interface

This solution architecture combines the components and performance of Windows Server 2016 with S2D and standard Intel® processor-based servers and storage media.

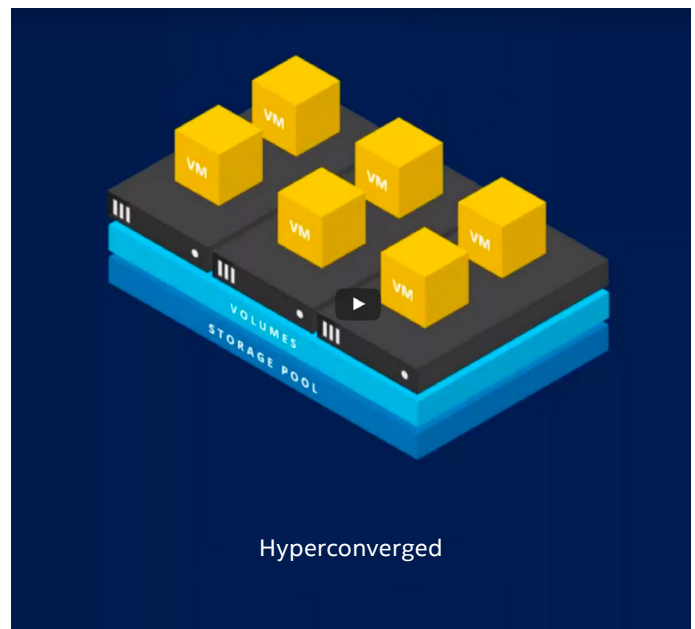


Figure 1. HCI based on clustered storage using S2D.

## The S2D Stack

Starting from the bottom, the S2D stack includes:

- **SMB network.** This application-layer network protocol, composed of servers containing hard-disk drives and SSDs, is used mainly to provide shared access to files, printers, etc.
- **Software storage bus.** This S2D-specific, virtual software storage bus (SSB) spans all the servers in the cluster. The SSB uses SMB 3.1.1 networking with RDMA (SMB Direct) between the S2D cluster nodes for communications.
- **Storage pools.** Up to 416 drives can be placed in a single pool and shared by up to 16 file servers.
- **Storage spaces/virtual disks.** Virtual disks are created from the aggregated disks. This architecture provides resiliency against disk or enclosure failure and enables SSD/HDD-tiered storage and write-back caching.
- **Cluster Shared Volumes.** Virtual disks are converted into CSVs, which makes them available across the entire file server cluster.
- **Scale-Out File Server.** Traditionally, SoFS has been used mainly as a shared storage tier, an alternative to a shared SAN for Hyper-V virtualization hosts. Networks that use network interface cards (NICs) to support remote direct memory access (RDMA), as recommended by Microsoft, deliver extremely high throughput, low latency, and low CPU utilization. These capabilities enable remote file servers in the cluster to resemble local storage from a performance perspective. S2D makes it easier and less expensive to deploy an SoFS cluster.

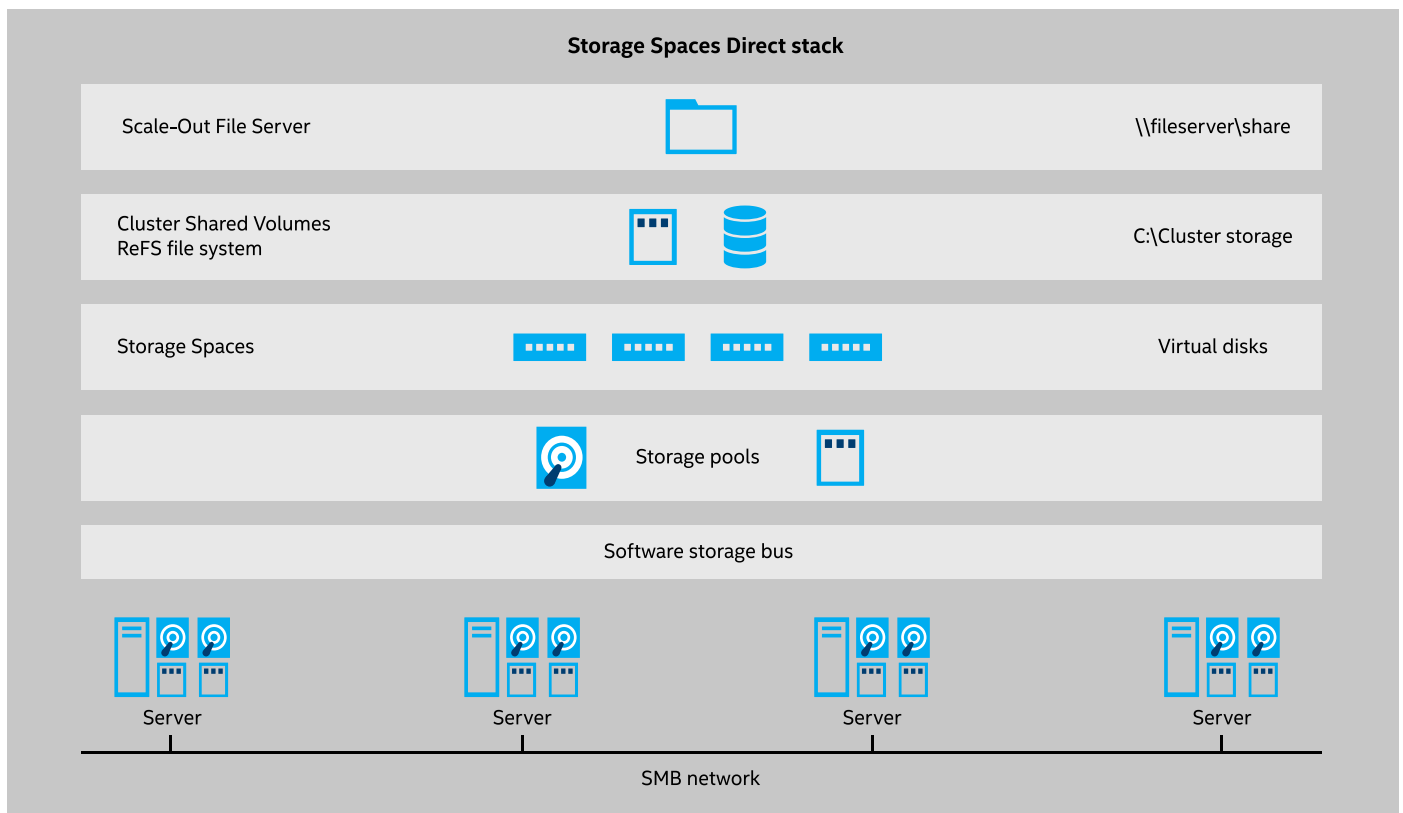


Figure 2. Components of the S2D stack.

Intel® Processors on Industry-Standard Servers

Each of the configurations described in this document uses servers based on the Intel® Xeon® processor E5-2600 v4 product family. These processors deliver more efficient processing power than previous generations. This efficiency makes it faster and less expensive to scale very large workloads up and out.<sup>2</sup> Plus, hardware-enhanced Intel® technologies help monitor, secure, and orchestrate data center resources more quickly with less IT effort.<sup>2</sup> These processors also offer greater control of IT environments by optimizing compute, storage, and networking functions.

The master configurations of the Intel and Microsoft hyperconverged storage solution also use the Intel® Xeon® processor E5-2600 v4 product family. They provide up to 22 physical cores per socket and have up to 55MB of shared L3 cache and DDR4 2400 memory support.

Table 1 summarizes the features and capabilities of the Intel® Xeon® processor E5 v3 and v4 families.

Intel® Data Center SSDs on Industry-Standard Servers

Intel® SSD Data Center Family storage is strongly recommended because it provides data integrity that protects against undetectable errors, maintains superior measured annual failure rates, and contributes to the high reliability of S2D configurations. The Intel® SSD DC P3520/P3500 Series (PCIe) and Intel® SSD DC S3610 Series (SATA) were selected for capacity storage in all-flash configurations, while the Intel® SSD DC P3700 (PCIe) was selected for cache storage in all configurations.

Each server in an S2D configuration must have the same total number of storage devices. If the server has a mix of storage device types (e.g., SSD and HDD), then the number of each type of device must be the same in each server.

Recommended Configurations & Architectural Considerations

This section provides guidance in configuring hyperconverged infrastructure (HCI) solutions.

Storage Spaces Direct

S2D requires at least four servers for full functionality. A three-server configuration is possible in mirroring setups, but it will lack certain features and does not support parity or multi-resilient virtual disks. Each server should have the same configuration—that is, identical CPU and memory configurations as well as identical network interface cards, storage controllers, and devices.

Using at least 4 and up to 16 servers provides the best storage resiliency and availability. This configuration satisfies the requirements for mirrored configurations, with two or three copies of data, and for dual parity, with erasure-coded data (Table 2).

| FEATURES                   | PROCESSOR FAMILY                                                             |                    |
|----------------------------|------------------------------------------------------------------------------|--------------------|
|                            | Intel® Xeon® E5 v3                                                           | Intel® Xeon® E5 v4 |
| Cores per Socket           | Up to 18 cores                                                               | Up to 22 cores     |
| Threads per Socket         | Up to 36 threads                                                             | Up to 44 threads   |
| Last-Level Cache (LLC)     | Up to 45MB                                                                   | Up to 55MB         |
| Intel® QPI Speed (GT/s)    | 2x 1.1 channels 6.4, 8.0, 9.6 GT/s                                           |                    |
| PCIe* Lanes / Speed (GT/s) | 40 / 10 / PCIe* 3.0 (2.5, 5.0, 8.0 GT/s)                                     |                    |
| Memory Population          | 4 channels of up to 3 RDIMMs or 3 LRDIMMs                                    | +3DS LRDIMM        |
| Memory RAS                 | ECC, Patrol Scrubbing, Demand Scrubbing, Mirroring, Lockstep Mode x4/x8 SDDC | +DDR4 Write CRC    |
| Max Memory Speed           | 2133MHz                                                                      | 2400MHz            |
| TDP (W)                    | 160 (workstation only), 145, 135, 120, 105, 90, 85, 65, 55                   |                    |

Table 1. Capabilities of the Intel® Xeon® processor E5 v3/v4 families.

| STORAGE CONFIGURATION        | RESILIENCY |
|------------------------------|------------|
| 3-way mirror                 | 2 nodes    |
| 2-way mirror                 | 1 node     |
| Dual parity (erasure coding) | 1 node     |

Table 2. S2D server configurations and associated resiliency.

## Intel® Xeon® Processors

The standard servers in systems using S2D are generally configured with a dual-socket CPU to maximize flexibility.

Specific CPU requirements depend on the workloads supported. Keep in mind that the CPU supports the VM workload as well as the storage and networking requirements, so HCI architectures generally require more CPU horsepower. More cores and higher-frequency processors enable the hosting of more VMs on the system.

Medium core-count processors are adequate for capacity-optimized configurations that support less demanding workloads, such as data warehousing, SharePoint\*, Exchange\*, and backup and recovery. Higher core-count processors are recommended for general virtualization, infrastructure as a service (IaaS), decision support, or database workloads.

## Intel® Data Center Family SSDs

S2D connects with three types of storage devices:

- **Non-Volatile Memory Express (NVMe) interface devices**, which are connected via PCI Express (PCIe), offer much lower latency than legacy interface devices and deliver higher performance with proven reliability.
- **SATA and SAS devices**, which can be SSDs or HDDs. All SATA and SAS devices must be attached to a SAS host bus adapter (HBA).

This HBA must be simple. That is, the devices appear as a SAS device in Windows Server 2016. The HBA must be attached to a SAS expander. Finally, the SATA or SAS devices must be attached to the SAS expander.

Not all off-the-shelf SSDs should be used in an S2D configuration. Data-center-class SSDs are recommended for lower failure rates. The Intel® SSD Data Center Family provides a data integrity mechanism that protects against undetectable errors and maintains superior measured annual failure rates, which contribute to the high reliability of S2D configurations.

To maintain a reliable storage system, it is important to select storage media devices with the best blend of read and write performance, drive reliability, and endurance. S2D automatically detects the type of storage device present and tiers the devices based on their performance and endurance levels.

Higher-performance and higher-endurance devices are assigned to the cache tier. High-endurance devices in the cache tier are critical to delivering the reliability and performance that is required. NVMe devices provide the lowest latency and highest performance and are available with 10 drive write per day endurance levels for proven reliability.

Standard-to-mid-endurance SSDs or HDDs can be used in the capacity tier behind the high-endurance cache drives. In general, consistent performance is an important attribute needed to support all enterprise applications and more users and virtual machines in Hyper-V virtualized environments. SSDs will deliver much more predictable and consistent performance than HDDs, as the following test results will show.

The choice between NVMe, SATA, and SAS for capacity storage depends on the performance and latency sensitivity of the applications and the capacity required. Intel tested a range of devices. The results, which are provided below, can be used to select devices that meet requirements of different workloads.

## System Memory

In systems running S2D, the recommended minimum is 128GB of memory per node. This requirement also enables memory to be used by the base OS and the SSD cache in S2D.

128GB memory supports a disaggregated deployment or a hyperconverged deployment with fewer VMs. Hyperconverged deployments with a larger number of VMs require additional memory. How much more memory depends on the number of VMs and how much memory each VM consumes.

## Network Interface Cards

S2D requires at least one 10GbE network interface card (NIC) per server. Most configurations, such as a general-purpose HCI, will perform most efficiently and reliably if a 10+ GbE NIC with RDMA capability is used. RDMA should be either RDMA over Converged Ethernet (RoCE) or Internet Wide Area RDMA Protocol (iWARP). iWARP has some advantages in HCI in its use of the TCP/IP protocol.

- If the configuration is used primarily for backup or archive workloads (sequential large I/O), a 10GbE NIC without RDMA capability is appropriate.
- If the configuration is used for more demanding workloads, or if high traffic between nodes in the cluster is likely, then NICs capable of higher throughput, such as 40GbE, would be recommended. This is especially helpful when VMs on different servers read data from other servers in the cluster.

In all cases, a single dual-ported NIC provides the best



## Windows Server 2016 HCI Performance

This section describes performance testing results of three recommended HCI solution configurations. Figure 8 summarizes the results of these performance tests.

### Configuration 1:

#### Capacity Optimized Hybrid NVMe\* SSD + HDD

The hybrid configuration was designed to optimize gigabyte-per-dollar efficiency. It uses NVMe SSDs for the cache and HDDs for high-capacity data storage.

The hybrid NVMe and HDD configuration setup consisted of four 2U Intel® Server Systems equipped with Intel® Server Board S2600WT2R. The configuration for each server consisted of these elements (Figure 3):

- Processor:**  
 2x Intel® Xeon® processor E5-2650 v4 (30M cache, 2.2GHz, 12 cores, 105W)
- Storage:**  
 Cache Tier: 2x 2TB Intel® SSD DC P3700 Series (PCIe)  
 Capacity Tier: 8x 6TB 3.5" Seagate\* HDD ST6000NM0024
- Memory:**  
 256GB DDR4-2133MHz (16GB x 16 DIMMS)  
 Micron\* memory
- Network:**  
 1x 10GbE dual-port Chelsio\* T520 adapter
- VMs:**  
 24x VMs per node  
 60GB OS VHD + 500GB Data VHD per VM (53.76TB total space used from shares)  
 Spillover: 4x 98GB DISKSPD files per VM  
 Cached in: 2x 10GB DISKSPD files per VM

For testing purposes, there were 24 VMs per node for a total of 96 VMs for the entire S2D cluster. Microsoft\* DISKSPD workload generated IOPS results.

### Test Results and Conclusions

Hybrid storage configurations, such as NVMe SSD + HDD, perform well for workloads where the active, working data set fits within the NVMe SSD cache, so most reads come from cached data on the SSDs. Also, this configuration may be suitable for workloads in which the level or consistency of performance is not a key concern.

Looking at the high-capacity configuration of HDDs, the performance was 176,613 IOPS, as shown in Table 3. This reflects a large capacity cluster and a diverse set of read requests, with performance gated by the IOPS of the HDDs. However, by setting up a caching layer in S2D on PCIe SSDs, the performance can increase substantially.

When the entire working set is resident within the capacity of the cache, aggregate I/O performance measured 954,240 IOPS (4K 100% random reads) and 641,979 IOPS (8K 70/30 read/write), with no manual priority selection, migration, or management by the user (Table 4).

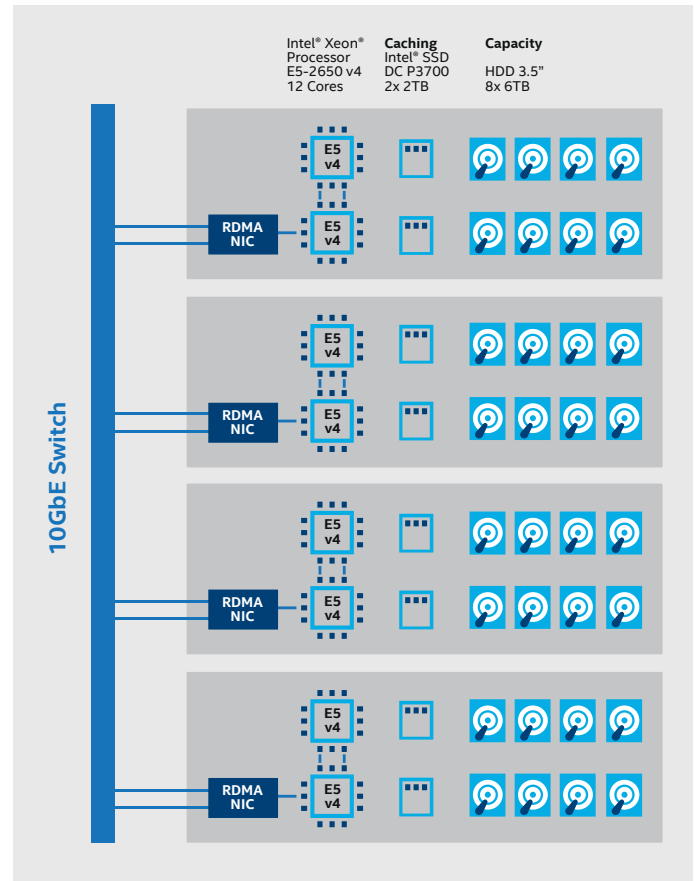


Figure 3. Capacity Optimized Hybrid NVMe + HDD configuration.

|                          | 4K 100%<br>RANDOM READS | 8K 70/30<br>READ/WRITE |
|--------------------------|-------------------------|------------------------|
| VMs                      | 96 VMs                  | 96 VMs                 |
| Aggregate IOPS           | 176,613                 | 135,365                |
| Avg. CPU Utilization (%) | 21.89                   | 16.42                  |

Table 3. Results when 78% of the total storage capacity of the cluster was in use.

|                          | 4K 100%<br>RANDOM READS | 8K 70/30<br>READ/WRITE |
|--------------------------|-------------------------|------------------------|
| VMs                      | 96 VMs                  | 96 VMs                 |
| Aggregate IOPS           | 954,240                 | 641,979                |
| Avg. CPU Utilization (%) | 80.23                   | 88.6                   |

Table 4. Results when the entire working set is resident within the capacity of the cache.

Reference Architecture | Recommended Hyperconverged Infrastructure

Expected performance on this configuration is likely to be between these two extremes. As the size of the active working data set increases (or a multi-tenant configuration changes the request profile on the storage), expect a higher percentage of reads to come off the HDDs than the cache. By using Windows Server 2016 Storage QoS to predefine a performance minimum and maximum for virtual machines, a level of consistency can be achieved. To support a growing working set of data and maintain consistent performance across all nodes, it is more effective to deploy SSDs in the capacity tier.

To estimate the effect on IOPS performance versus working set size and understand likely cluster IOPS performance as the working set starts to spill out of the caching tier, testers conducted a theoretical analysis based on internal results. The charts below highlight estimated results for 4K 100% random reads and 8K 70/30 read/write scenarios (Figures 4–5).

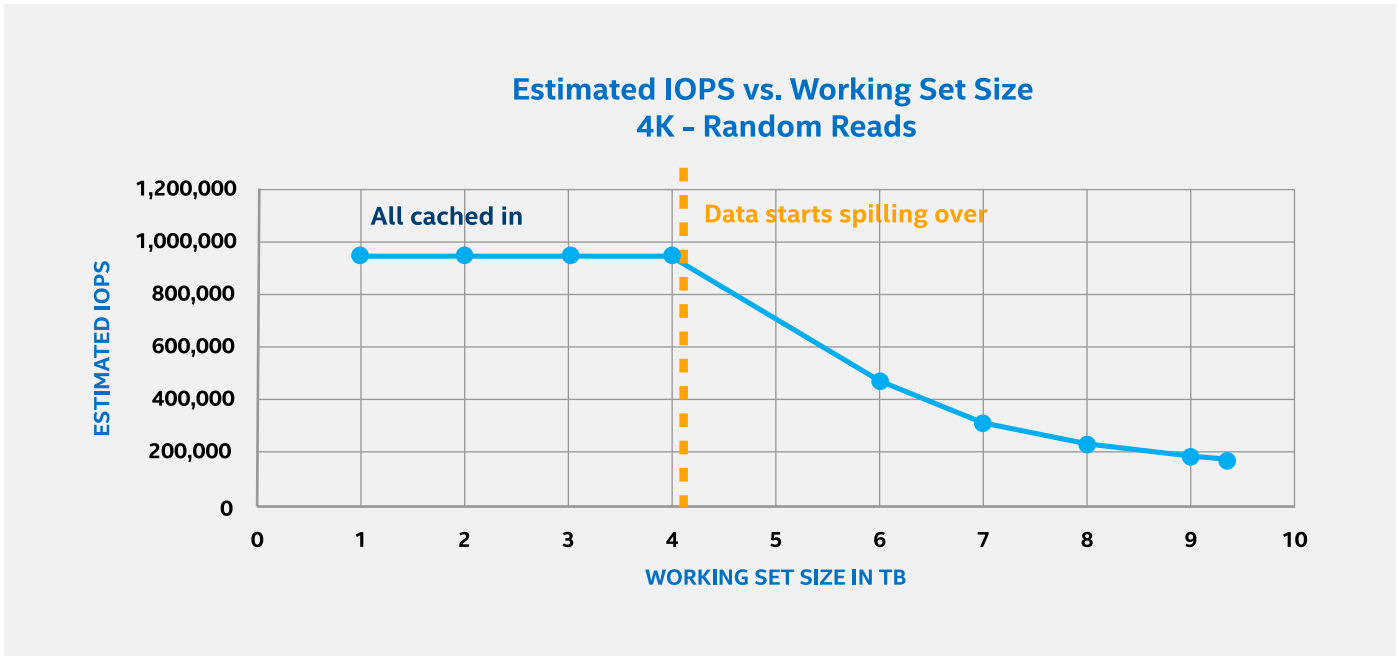


Figure 4. Estimated IOPS vs. working set size for 100% 4K random reads.

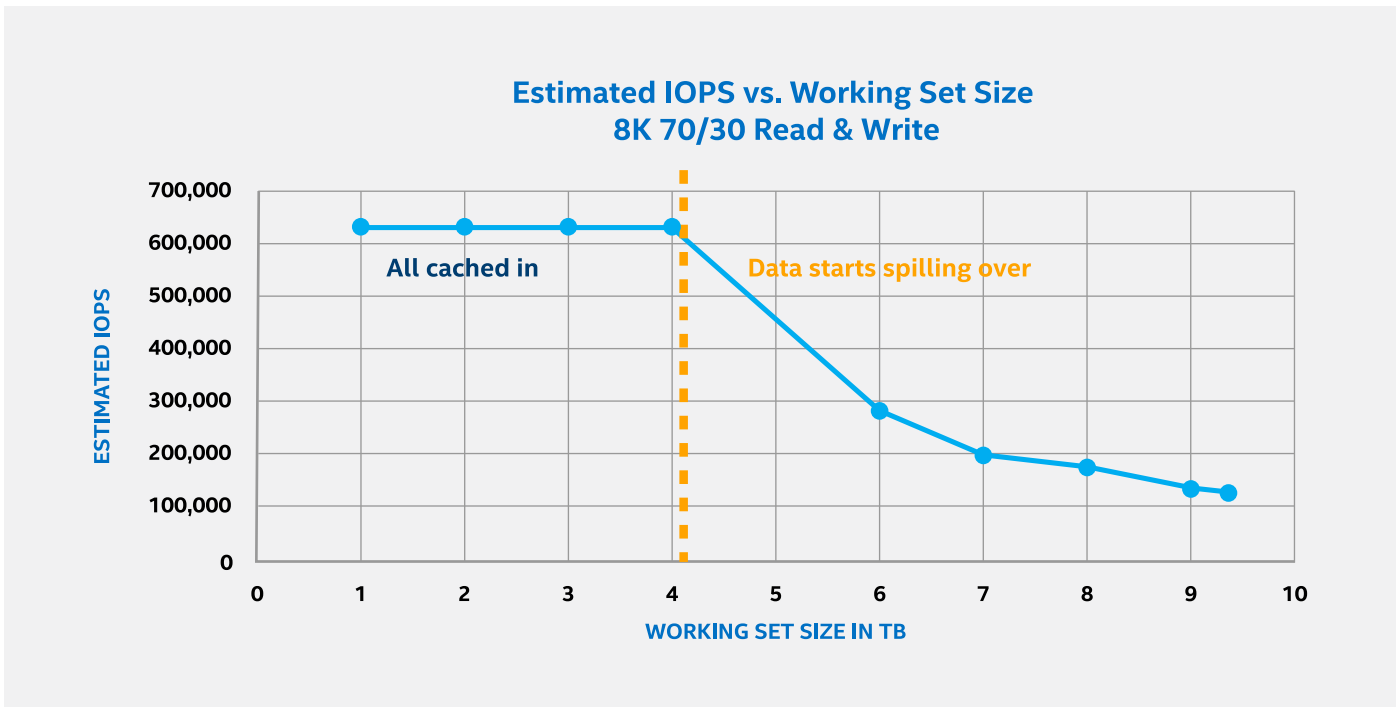


Figure 5. Estimated IOPS vs. working set size for 8K 70/30 read/write.



Configuration 2:

Throughput/Capacity Optimized All-Flash NVMe and SATA SSDs

The all-flash configuration using PCIe NVMe SSDs for the cache tier and high-capacity SATA SSDs for the capacity tier blends performance and capacity for a wide range of workloads, such as decision support, VDI, IaaS, and general virtualization environments.

Testers set up a four-node cluster of the all-flash NVMe and SATA SSD configuration, which consisted of four 2U Intel® Server Systems equipped with Intel® Server Board S2600WT2R. The configuration for each server consisted of (Figure 6):

- **Processor:**  
2x Intel® Xeon® processor E5-2695 v4 (45M cache, 2.10GHz, 18 cores, 120W)
- **Storage:**  
Cache Tier: 4x 2TB Intel® SSD DC P3700 Series (PCIe)  
Capacity Tier: 20x 1.6TB Intel® SSD DC S3610 Series (SATA)

- **Memory:**  
256GB DDR4-2133MHz (16GB x 16 DIMMS)  
Micron memory
- **Network:**  
1x 10GbE dual-port Chelsio T520 adapter
- **VMs:**  
36x VMs per node  
60GB OS VHD + 150GB data VHD per VM (30.24TB total space used from shares)  
Spillover: 2x 70GB DISKSPD files per VM  
Cached in: 1x 70GB DISKSPD files per VM

The test used Windows Server 2016 with 36 VMs per node, a total of 144 VMs. Testers ran DISKSPD in the same way as on the NVMe + HDD configuration, with each VM having 4 threads and 32 outstanding I/O operations.

Test Results and Conclusions

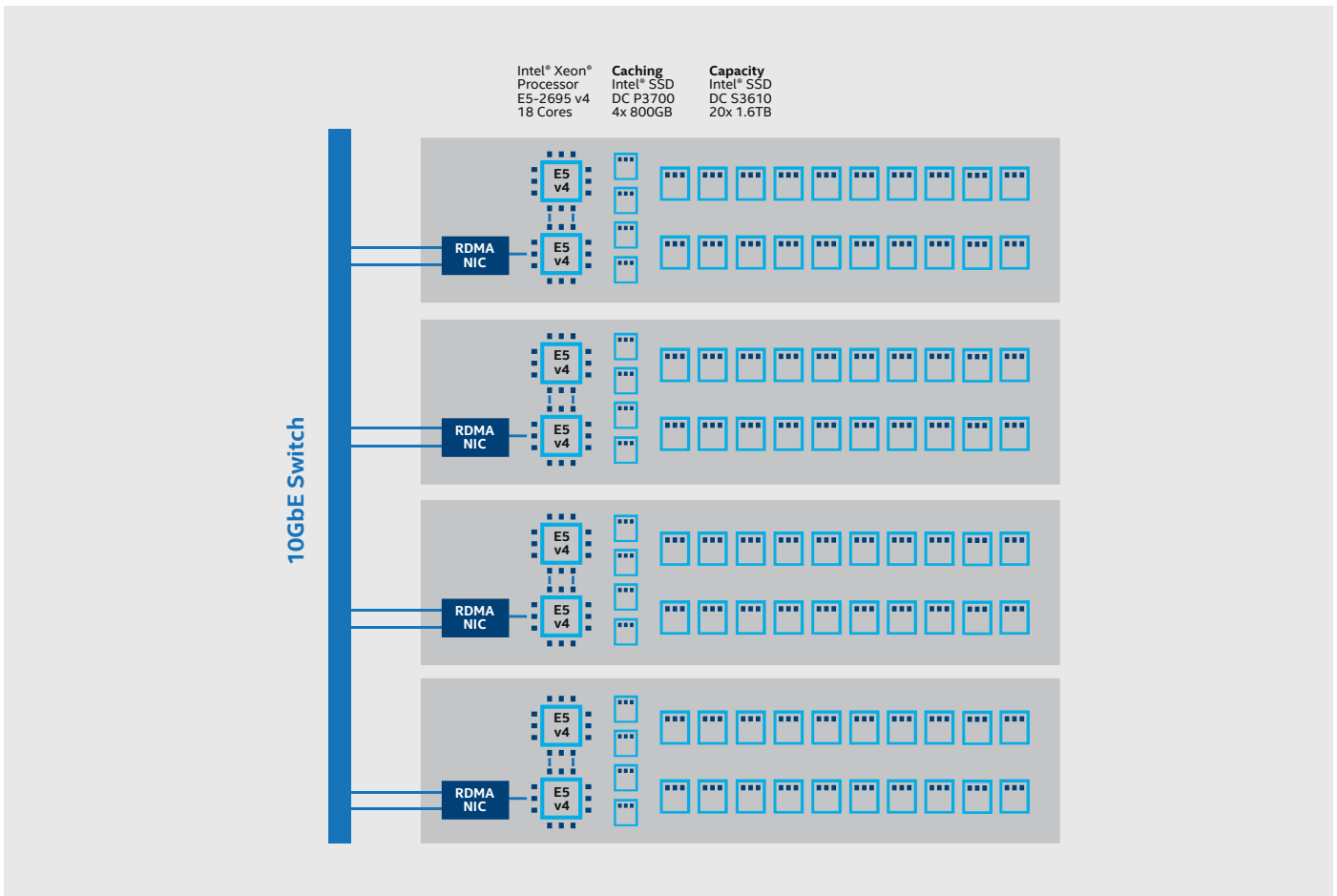


Figure 6. Throughput/Capacity Optimized All-Flash NVMe and SATA SSD configuration.

**Reference Architecture | Recommended Hyperconverged Infrastructure**

Results demonstrate that on an all-flash configuration, such as NVMe + SATA SSD, IOPS performance is very consistent across all nodes in the cluster and is well suited for a variety of workloads.

Overall IOPS performance is not gated by the size of the caching tier as it was in the Capacity Optimized Hybrid NVMe SSD + HDD configuration, which used HDDs in the capacity tier.

These were the results when the entire working set was contained within the SSD caching tier (Table 5).

Increasing the working set to 75% of total storage on each node with the same configuration as above produced the following results (Table 6).

**Configuration 3:  
IOPS Optimized All-Flash NVMe SSD Configuration**

The all-flash PCIe NVMe SSD configuration is targeted for IOPS- and latency-sensitive business processing applications that demand the best QoS. This configuration used PCIe SSDs on both caching and capacity tiers at different endurance levels. Its performance shows how well S2D is optimized to support all-NVMe-based configurations (Figure 7).

Testers set up a four-node cluster that used Supermicro Superserver\* 1028U-TN10RT+ as the test bed. The configuration for each Superserver 1028U-TN10RT+ server consisted of these elements:

- **Processor:**  
2x Intel® Xeon® processor E5-2699 v4 (55M cache, 2.20GHz, 22 cores, 145W)
- **Storage:**  
Cache Tier: 2x 800GB Intel® SSD DC P3700 Series (PCIe)  
Capacity Tier: 8x 2TB Intel® SSD DC P3500 Series (PCIe)
- **Memory:**  
384GB DDR4-2133MHz (16GB x 24 DIMMS)  
Micron memory
- **Network:**  
1x 40GbE dual-port Chelsio T580 adapter
- **VMs (Test Scenario 1):**  
24x VMs per node  
60GB OS VHD + 60GB Data VHD per VM (6.09TB total space used from shares)  
4x 10GB DISKSPD files per VM
- **VMs (Test Scenario 2):**  
44x VMs per node  
60GB OS VHD + 60GB Data VHD per VM (11.17TB total space used from shares)  
4x 10GB DISKSPD files per VM

**Test Results and Conclusions**

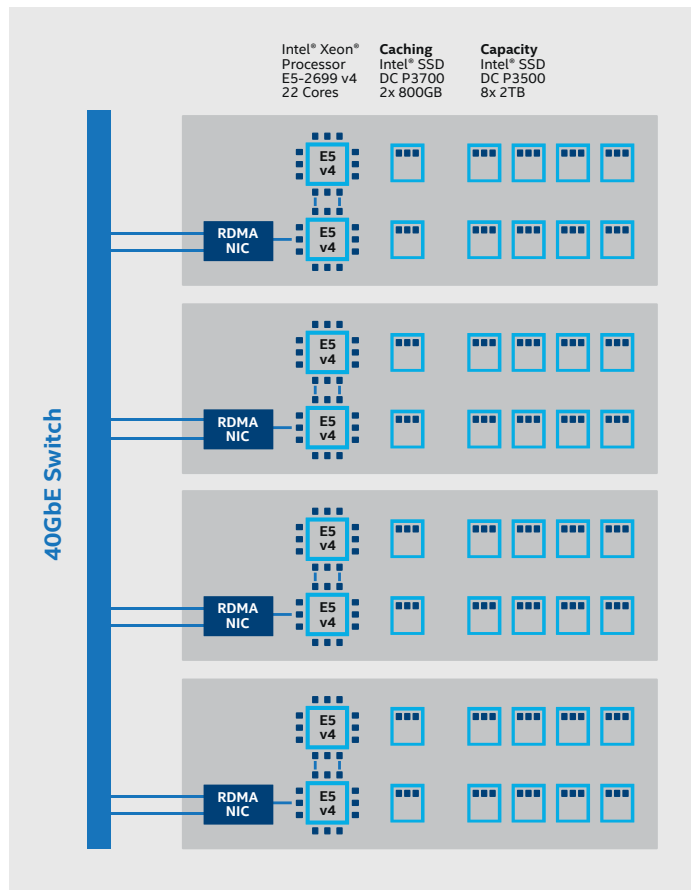
Two IOPS tests ran DISKSPD with Windows Server 2016 in

|                                 | 4K 100%<br>RANDOM READS | 8K 70/30<br>READ/WRITE |
|---------------------------------|-------------------------|------------------------|
| <b>VMs</b>                      | 144 VMs                 | 144 VMs                |
| <b>Aggregate IOPS</b>           | 1,543,857               | 641,979                |
| <b>Avg. CPU Utilization (%)</b> | 89                      | 88.6                   |

**Table 5.** Results when entire working set was contained within the SSD caching tier.

|                                 | 4K 100%<br>RANDOM READS | 8K 70/30<br>READ/WRITE |
|---------------------------------|-------------------------|------------------------|
| <b>VMs</b>                      | 144 VMs                 | 144 VMs                |
| <b>Aggregate IOPS</b>           | 1,221,010               | 518,079                |
| <b>Avg. CPU Utilization (%)</b> | 82.81                   | 60.31                  |

**Table 6.** Results when 75% of the total storage capacity of the cluster was in use.



**Figure 7.** IOPS Optimized All-Flash NVMe SSD configuration.

**Reference Architecture | Recommended Hyperconverged Infrastructure**

two test scenarios. One used 24 VMs per node to analyze performance when not all resources in the cluster were subscribed. The second used 44 VMs per node when the cluster resources were fully utilized. Results show consistently balanced IOPS performance across all nodes for both test scenarios.

Test Scenario 1: For 4K 100% random reads, the test achieved 3,031,190 aggregate IOPS and average CPU utilization of 92%. The 8K 70/30 read/write scenario measured an aggregate IOPS of 930,811 and an average CPU utilization of 55% (Table 7).

Test Scenario 2: For 4K 100% random reads, the test achieved 2,675,763 aggregate IOPS and average CPU utilization of 93%. The 8K 70/30 read/write scenario measured an aggregate IOPS of 905,660 and an average CPU utilization of 58% (Table 8).

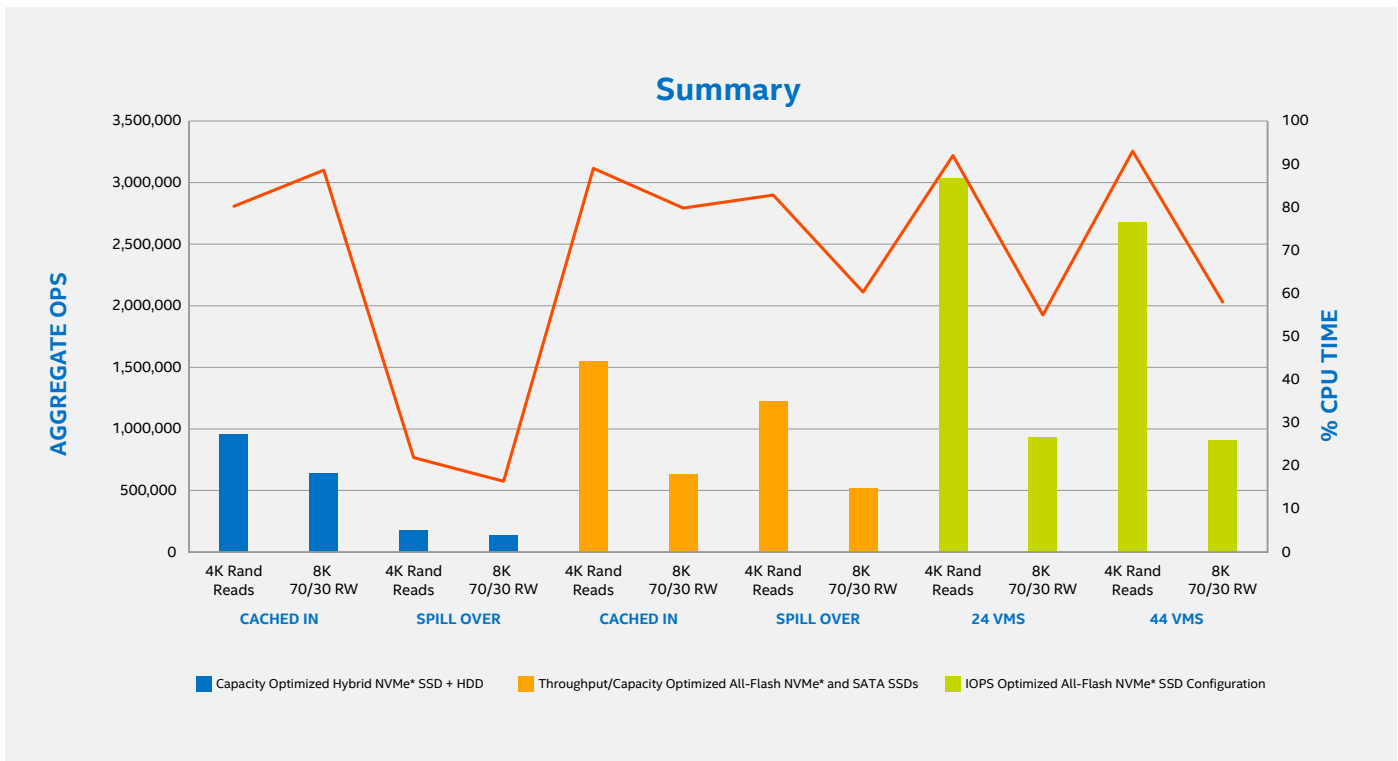
These results highlight how well S2D is optimized to support all NVMe SSD-based solutions in data centers. The S2D cluster scales linearly as it maintains consistent performance. This behavior helps data centers to grow their storage as needed for IOPS- and latency-sensitive workloads.

|                                 | 4K 100%<br>RANDOM READS | 8K 70/30<br>READ/WRITE |
|---------------------------------|-------------------------|------------------------|
| <b>VMs</b>                      | 96 VMs                  | 96 VMs                 |
| <b>Aggregate IOPS</b>           | 3,031,190               | 930,811                |
| <b>Avg. CPU Utilization (%)</b> | 92                      | 55                     |

**Table 7.** Results for test scenario 1.

|                                 | 4K 100%<br>RANDOM READS | 8K 70/30<br>READ/WRITE |
|---------------------------------|-------------------------|------------------------|
| <b>VMs</b>                      | 176 VMs                 | 176 VMs                |
| <b>Aggregate IOPS</b>           | 2,675,763               | 905,660                |
| <b>Avg. CPU Utilization (%)</b> | 93                      | 58                     |

**Table 8.** Results for test scenario 2.



**Figure 8.** HCI solution configuration performance test results.

## Summary

Many IT professionals see the promise of combining compute, storage, networking, and virtualization capabilities on the same server from an efficiency standpoint. Intel and Microsoft collaborated to develop and test three recommended S2D configurations spanning a range of workloads, from the fastest, latency-free operations to storage-capacity-hungry data warehousing.

This reference architecture describes the major components of HCI solutions. It also provides performance test results of Windows Server 2016 configurations that maximize throughput and reduce latency in highly reliable and scalable solutions.

To maintain a reliable storage system, testers selected SSD technology with the best blend of performance, reliability, and endurance for each configuration. They selected PCIe devices because the NVMe interface consistently provides the lowest latency and highest performance, as well as high-, standard-, and mid-endurance options appropriate for cache and capacity tiers. PCIe devices are also more CPU-efficient than their SATA counterparts.

Whether you are a DBA, developer, or storage architect, you can get up and testing quickly with one of these recommended Windows Server 2016 configurations.

## Solutions Proven by Your Peers

The hyperconverged storage solution is powered by Intel® Xeon® processors and Intel® Data Center SSDs. By moving to private cloud services, these technologies enable organizations to manage their on-premises infrastructure assets with less time, effort, and cost.

This and other solutions are based on real-world experience gathered from customers who have successfully tested, piloted, and/or deployed the solutions in specific use cases.

The solution architects and technology experts for this solution reference architecture include:

- Keerthi Palanivel, Performance Engineer, Intel Corporation
- Mihir Patel, Tech Lead and Engineering Manager, Intel Corporation
- Vivek Sarathy, Architect, Intel Corporation
- Hamesh Patel, Sr. Performance Engineer, Intel Corporation
- Christine McMonigal, Storage Software Ecosystem Manager, Intel Corporation

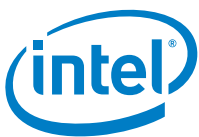
Intel solution architects are technology experts who work with the world's largest and most successful companies to design business solutions that solve pressing business challenges.

## Learn More

This solution reference architecture complements other product documentation. It's part of a solution kit filled with content that provides key insights and information. This content includes:

- **Intel IT Peer Network** blog posts. Vivek Sarathy, August 12, 2016 to September 22, 2016.
- **Implementation Guide: Intel® Optimized Configurations**
- You might also find these resources useful:
- **Microsoft Corporation: Storage Spaces Direct in Windows Server 2016.** October 12, 2016.

Find the solution that's right for your organization. Contact your Intel representative or visit [intel.com/microsofdatacenter](http://intel.com/microsofdatacenter).



1. O'Shea, Mark. "What's New in Windows Server 2016 Standard Edition Part 5 – Storage." Microsoft TechNet, August 24, 2016. <https://blogs.technet.microsoft.com/auoemteam/2016/08/24/whats-new-in-windows-server-2016-standard-edition-part-5-storage/>.
2. "The Engine for Digital Transformation in the Data Center: Intel® Xeon® Processor E5-2600 v4 Product Family." Intel, March 2016. <http://www.intel.com/content/www/us/en/processors/xeon/xeon-e5-brief.html>.
3. "Storage IOPS update with Spaces Direct." Server Storage at Microsoft, July 26, 2016. <https://blogs.technet.microsoft.com/filecab/2016/07/26/storage-iops-update-with-storage-spaces-direct/>.

All information provided here is subject to change without notice. Contact your Intel representative to obtain the latest Intel product specifications and roadmaps.

Intel® technologies' features and benefits depend on system configuration and may require enabled hardware, software, or service activation. Performance varies depending on system configuration. No computer system can be absolutely secure. Check with your system manufacturer or retailer or learn more at [intel.com](http://intel.com).

Software and workloads used in performance tests may have been optimized for performance only on Intel® microprocessors. Performance tests, such as SYSmark\* and MobileMark\*, are measured using specific computer systems, components, software, operations, and functions. Any change to any of those factors may cause the results to vary. You should consult other information and performance tests to assist you in fully evaluating your contemplated purchases, including the performance of that product when combined with other products. For more complete information, visit [intel.com/performance](http://intel.com/performance).

No license (express or implied, by estoppel or otherwise) to any intellectual property rights is granted by this document.

Copyright © 2017 Intel Corporation. All rights reserved. Intel, the Intel logo, and Xeon are trademarks of Intel Corporation or its subsidiaries in the U.S. and/or other countries. \*Other names and brands may be claimed as the property of others.