Hitachi Virtual Storage Platform G1000-storage for System z

An Analyst Product Review

Josh Krischer, December 2014
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Announcement

On April 22nd, 2014, Hitachi Data Systems, a fully owned subsidiary of Hitachi Ltd., Japan, announced a new, enhanced model of its high-end Virtual Storage Platform, the VSP G1000, as the follow-on model for its technology leading VSP subsystems announced in 2010. As did its predecessor, the new VSP supports all major operating systems, including IBM System z (or mainframe) and is designed for large data centers and deployment infrastructures for public clouds. The new model supports larger scalabilities and delivers much higher throughput and performance (x4 improvements) in comparison to the original VSP.

Users’ Requirements and Challenges

The world of IT and communication is changing at a pace which we have never experienced before. Billions of people worldwide communicate on mobile devices and social networks, creating daily enormous amounts of data. IT organizations are changing as well with the adaption of cloud and mobile computing, and deployment of applications which benefit from “big data” analysis.

What does this mean for users? Organizations have used IT to manage and improve operational efficiencies for five decades. What is new is the volume of data, the variety of data (e.g., unstructured data), velocity and uncompromising demand for availability, business continuity, and security. Despite the latest buzz word of “Software Defined Storage”, a robust, reliable and secure storage infrastructure is required today more than ever. New technologies such as thin provisioning and Solid State Disks (SSD) are gaining in popularity. New criteria such as virtualization, cloud-readiness, energy consumption, and cost containment have emerged. The mainframe, declared dead many times, is “alive and kicking” and serves the largest and the most important organizations across all geographies.

What do users typically require from a storage subsystem?

- **Availability and Business Continuity:** These remain on top of the list of requirements. The non-stop global economy, the fierce competition, and new levels of service requirements raise the requirements for business continuity. In addition to complete fault-tolerance and data protection, requirements still not met by some products include
service, capacity upgrades, testing, etc., which need to be performed non-disruptively, and completely transparent to users.

- **Scalability**: A storage subsystem should scale seamlessly in capacity, connectivity, and performance without impacting service levels. The capacity should support multi-tier storage media: SSDs, Flash, performance HDDs in different capacities, and high capacity “near-line” disks – in simple words, tiered storage “in-a-box”.

- **Performance**: This has two aspects: throughput measured in I/Os per second (IOPS), and response time measured in milliseconds. Performance should be at the SLA level regardless of capacity and workload. Erratic performance levels irritate users more than a slightly slower but constant response time.

- **Secure Multi-Tenancy**: Server virtualization creates situations where multiple tenants are using the same physical infrastructure, which requires new techniques to address security issues.

- **Virtualization**: The ability to virtualize internal and external storage, including heterogeneous storage and bring it into a common singly managed set of internal and external pooled storage. This is the key and underpinning to software defined storage architectures.

- **Functionality and automation**: These are required to cope with storage management. The average organization’s storage capacity grows by approximately 50-60 percent per year while the size of the storage management staff generally remains the same. Datacenters which supported terabytes at the end of the previous decade today support petabytes. And there is a constant need to reconfigure and adapt to changing requirements over time. The only way to cope with this is sophisticated functionality, advanced automation, and user-friendly management tools and interfaces.

- **Storage Efficiency**: in usage and energy consumption is equally important: Storage efficiency can be achieved by using thin provisioning, tiered storage, automated data placement, compression, small-factor HDDs, SSDs, Flash and virtualization. Efficient subsystems allow for better storage utilization, which translates to lower capacity and lower CaPex and OpEx, reduced floor space requirements, lower energy consumption, and effective usage of people.

**Management Summary**

The VSP G1000 is the industry leader in every aspect: reliability, functionality, performance, scalability and sustainability. In the Gartner's latest “Critical Capabilities for General-Purpose, High-End Storage Arrays” report, Gartner positioned the VSP G1000 as the leading product in this category.

Three vendors manufacture high-end enterprise storage systems that connect to System z: EMC with VMAX, Hitachi Data Systems with VSP G1000 (also OEMed by Hewlett-Packard Company), and IBM with the DS8000 series. All three systems are multi-platform products; however this paper will concentrate on features support, synergy, and compatibility with
System z. The latest EMC high-end product, the VMAX3, currently does not support FICON channels. HP’s market share on System z is negligible.

Hitachi has a long tradition of delivering plug-compatible storage systems for IBM mainframes. The first exported devices in late 1970ies were compatible to IBM 3350 disk and OEM-ed by BASF, Olivetti, and National Advanced Systems, the predecessor of Hitachi Data Systems. Over more than 36 years Hitachi remained compatible with this critical platform, delivering storage systems, which delivered value-add features such as virtualization. Today Hitachi has a large installed base of storage systems connected to IBM S/390, zSeries and System z mainframes via IBM ESCON and FICON channels as well as mainframe-based Linux environments via Fiber Channel networks.

IBM owns the System z mainframe architecture, which from time to time allows it to offer exclusive features for at least a limited period. EMC and Hitachi purchase the specifications for these features to remain compatible. IBM provides EMC and Hitachi with technical specifications but not the code, which the competing companies have to develop. Typically, Hitachi delivers the compatible features 6-24 months after IBM and ahead of EMC. In addition to providing support for IBM-compatible replication solutions such as Metro Mirror (PPRC), Hitachi delivers its own alternative high-performance replication solutions.

IBM successfully completed qualification testing of the Virtual Storage Platform with IBM GDPS using Hitachi support for PPRC, XRC and, in 2012, also qualified Hitachi Universal Replicator (HUR) for use in combination with GDPS. This qualification testing is one more way organizations can be confident in the Hitachi commitment to providing compatibility with essential mainframe storage features. Customers gain full support of unique, innovative, Hitachi value-added replication solutions, including Hitachi TrueCopy, Hitachi Universal Replicator (HUR), and Hitachi ShadowImage Replication. As mentioned above, Hitachi VSP is the only virtualized storage in the mainframe environment. It includes the ability to virtualize external multivendor storage.

Hitachi enterprise storage platforms are used by most Fortune 100 organizations today. These represent some of the most critical mainframe environments in the world.

**VSP G1000 and the Storage Virtualization Operating System Design**

**System Design**

The Virtual Storage Platform G1000 is an all-new Hitachi enterprise storage system that includes the new **Hitachi Storage Virtualization Operating System - SVOS**. Hitachi SVOS is integrated storage system software that provides system element management and advanced storage system functions such as storage virtualization, thin provisioning, storage service level controls and performance instrumentation across multiple storage platforms.
The Virtual Storage Platform (VSP) G1000, unlike EMC’s VMAX storage subsystems, is a purpose-built storage array. The architecture and many of the components are specially designed and produced by different divisions of Hitachi Ltd. Each VSP G1000 storage controller is in effect a clustered system with a flexible set of paired components. The ‘tailored’ design is one of the factors in achieving its very high performance, large scalability, and unmatched reliability.

With SVOS the VSP G1000 is a highly scalable storage system, with the following characteristics within the system (without any external in-band or out-of-band devices required to manage storage):

- A VSP G1000 solution scales **Up** for increased performance and connectivity. This applies to the hardware of a single controller system.
- A VSP G1000 solution scales **Out** for doubled internal capacity, connectivity, and performance. This applies to upgrading from a single controller to a dual controller system.
- A VSP G1000 solution scales **Deep** with virtualization of external storage systems thereby incorporating additional tier-2 and tier-3 performance and capacity

**Scale Up – Single Controller**

Within the basic single controller system, the number of controller boards, drive chassis, and drives is highly scalable. A system can initially comprise a single rack and the minimum set of controller boards in one controller chassis along with one (optional) drive chassis. Drive chassis options include types that hold up to 96 LFF, 192 SFF, or 96 Accelerated Flash Module (FMD) drives in 8 drive trays per drive chassis. A diskless system\(^1\) can be configured with the minimum set of controller boards and no internal storage, only using virtualized storage attached to Front End Director (FED) Open Fiber (FC) ports.

This system can then be expanded with more controller boards (up to 20 in all per controller), 3 racks, and more drive chassis (up to 6 in all). A single controller system can support a maximum of 6 drive chassis using any combination of the three chassis types. In a pure Small Factor (SFF) drive configuration, the G1000 can support up to 1152 drives (including 192 SSD drives) in six drive chassis. If using only Large Factor (LFF) drives, the limit is 576 drives in six LFF drive chassis. There can be total of 288 Flash Module drives in three FMD drive chassis in each single controller.

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\(^1\) Only for Unix, Linux and Windows
Scale Out – Dual Controllers

A VSP G1000’s resources can be greatly extended by adding a second controller system with up to six racks in all. A dual controller system can start with a minimum set of controller boards and drive chassis and later scale out to a full configuration of up to 40 controller boards and 12 drive chassis in 6 racks.

A minimal (very high IOPS) dual controller storage system can be configured as a single rack with two controllers and two FMD drive chassis. Perhaps a more typical smaller configuration would include two controller chassis, two racks, and four drive chassis. This can be expanded by four more racks to add up to 8 more drive chassis (12 in all).

Each expansion rack supports two drive chassis, with each containing up to 96 LFF, 192 SFF, or 48 FMD drives. The two controller racks can be separated by up to 100 meters using longer optical connection cables. The two controller chassis are the same and are populated with the same types and numbers of controller boards. The two controller chassis are cross-attached at the cache path control (CPC) adapter board level, thus creating the global HiStar-E system.

Note that any front-end port on a dual controller storage system can access any internal (or mapped external) LUN as there is no division within the system. The only hardware division is that each controller’s Back End Director (BED) boards have their own set of directly attached drive chassis. Any Virtual Storage Director (VSD) processor can manage a back-end I/O operation on any BED board in the system. Any Front End Director (FED) or BED board can access all installed CPC boards and communicate with every VSD board. In a system configured solely with SFF drives, a dual controller chassis G1000 can contain up to 2304 SFF drives (including up to 384 SSD drives) in 12 SFF drive chassis; or if using only LFF drives, the limit is 1152 drives in 12 LFF drive chassis. It can also have up to 576 FMD drives in 6 FMD chassis (three per controller). See table 1 for capacity options.

Scale Deep – Virtualization

The Storage Virtualization Operating System for the VSP G1000 provides the Hitachi Virtualization functionality (the Universal Volume Manager feature) as found on the previous VSP and Universal Storage Platform V generations. Existing customer storage systems (usually repurposed upon being replaced by newer storage systems) may be directly attached to some of a VSP G1000’s FED FC ports (now operated in External Initiator Mode). The LUNs that are supplied by these external storage systems are accessed via hosts that are attached to other FED FC or FICON ports (operated in Target Mode) on the same G1000 system. As far as any host is concerned, all virtualized LUNs passed through the VSP G1000 external ports to the host target ports simply appear to be internal LUNs or Volumes from the VSP G1000. The VSP G1000’s FC FED ports that attach to the external
storage system’s front-end ports are operated in “external” or “SCSI initiator” mode (attached to storage), rather than the usual “SCSI target” mode (attached to hosts).

One advantage of virtualization is greatly simplified management of LUNs and hosts. Another advantage is the ability to dynamically and transparently relocate LUNs from Tier-1 RAID Groups down to Tier-2 or Tier-3 using other RAID levels, drive types, or even virtualized storage. These migrations are able to proceed while the original source remains online to the hosts, and the VSP G1000 will seamlessly switch over the mapping from the original LUN to the new LUN when completed. No changes on the host mount point are required.

**Processors**

Architecturally each VSP G1000 Controller has tightly-tied multiple system Virtual Storage Directors (VSDs) sharing a global cache linked by a non-blocking, crossbar architecture connecting the front- and back-end processors. The Hi-Star crossbar switch-based architecture is 7th generation Hitachi innovation and has 896 GB/sec aggregate internal bandwidth. The control unit is based on a three-level processing structure (see fig. 1 and 2):

- **VSD** processor boards (8-core Xeon CPU)
- **CPC** Cache Path Control Adapter board provides the internally used HiStar-E ports as well as the Cache Path Controllers. All controller boards now have four PCIe3 paths to the central HiStar-E grid (with one path per CPC board within the same controller).
- **FED** front-end director boards (16x 8Gbps or 8x16Gbps FC or FICON ports each)
- **BED** back-end director drive-controller boards (16x 6Gbps SAS ports each, utilizing a proprietary high speed Data Acceleration ASIC for parity and formatting operations),
- **BKM** battery back-up units for each CPEX.

All of the controller boards within a system are connected via the Hitachi HiStar-E network paths.

VSP G1000 separates the management and control processing from the front-end and back-end-processing. It is internally connected by a Hi-Star crossbar switch. This structure separates the data and control paths and delivers improved performance for the unique processing requirements of different data types (see Figures 1 and 2).

The Virtual Storage Director (VSD) is a powerful data movement engine and the heart of the Storage Subsystem. The 2-16 VSDs are installed in pairs to ensure redundancy. Each board contains an 8-core Xeon processor. These boards manage the VSP G1000’s operation outside of the data path. The difference between the two and larger VSDs configuration is in performance and is unrelated to the number of installed FEDs or BEDs. In case of a failure, the other VSD (out of the pair) reads the control table information and meta data from a
master control-memory copy maintained in the system cache and takes over the functionality of the failing module. This procedure is reversed after a VSD swap.

The operational control memory of VSP G1000 is physically located on the virtual storage director pairs (VSDs) which enables the main processors to access the control data memory at internal memory speeds eliminating interface latency delays. It also means that there is no internal bandwidth usage for access to control data, which results in faster processing. The maximum control bandwidth is 128 GB/sec. There can be a total of 16GB of control data memory on a single VSD (8 GB per processor) and a total of 128GB of control data memory in a single controller chassis. This control data is not mirrored so the memory capacity available for operations in a single chassis is 128GB. However, this control data is backed up in cache on the first data cache adapter pair, which is mirrored, creating three copies of the control data, ensuring redundancy. The separation of the control memory and the data memory (cache) eliminates the possible contention among multiple accesses to the cache for fetching control and users’ data and increasing performance.

Figure 1: VSP G1000 Structure and Bandwidths (source: Hitachi Data Systems)
Figure 2: VSP G1000 Controller Components (source: Hitachi Data Systems)

**Data Cache**

A Cache Path Control adapter is included with each controller. The Cache Path Control adapter is the combination cache memory and 4 HiStar-E switch boards, with up to 256GB of cache each, with 16GB being the minimum and 1024GB being the maximum. Each CPC board provides 16 HiStar-E paths to the FED, BED, and VSD boards, 6 paths to the other CPC if installed.

An additional cache path control adapter may be added to each controller, expanding the total data cache capacity supported to 2048TB. The data cache memory is used to cache user data blocks that are fetched from disk drives during a read and written to cache data as part of a data write operation. All write data is simultaneously mirrored to a paired CPC cache by the FED data accelerator processor handling the request. The cache is not fully mirrored, only the individual write blocks are mirrored, which means that users have more cache for their applications. Each cache board also has embedded SSDs for use in backups of the control-memory regions, the cache directories, and all write-pending buffers, which are important in the event of an array failure or shutdown. In the case of any failure, a recovery mechanism is used to back up cached user data that has not been de-staged to disk and the control memory by temporary storing this data on the embedded 128GB or 256GB SSD devices. The cache path control adapter has an onboard battery that allows the cache adapter microprocessor to de-stage the data to SSDs on system shutdown or loss of power.

VSP G1000 uses several advanced cache algorithms and software to deliver the required performance and ensure optimal cache capacity usage. For example, if data is being accessed sequentially, the VSD processors allocate additional cache slots and will pre-fetch the data in parallel so that subsequent read requests will be satisfied immediately from the cache, thus speeding up I/O.
Hi-Star crossbar switch

If the VSDs are analogous to the heart of the subsystem, then the Cache Path Control cache-switches (CPEX) represent its blood vessels. The HiStar-E Network is a fully fault-tolerant, high-performance, truly non-blocking switched architecture. The HiStar-E network provides the high-speed cross-connections among all controller boards with 768GB/sec bandwidth.

Front-end Directors (FED)

The 2-24 Front-End Directors (FEDs) board controls the connection between the array and servers attached to the host ports, as well as connections to external storage (see virtualization) or remote copy products (TrueCopy and Hitachi Universal Replicator). Three types of FED boards are available (always installed in pairs of the same type), providing up to 176 FICON channels for IBM System z, up to 192 Fiber Channel 8Gb/sec or 16Gb/sec host ports for other platforms, and 176 Fiber Channel over Ethernet (FCoE) host ports.

The various types of interface options can be mixed on a pair basis. In addition to the host and remote copy connections, the FEDs also support Hitachi or third-party storage-subsystems with their embedded virtualization functionality. This feature provides the ability to configure, manage, and access external volumes as if they were VSP G1000 internal volumes.

The FEDs use their own processing power and therefore don't “steal” cycles from the VSDs. The total maximum bandwidth of the FEDs is 256 GB/s.

Back-end Directors (BEDs)

The 2-8 BEDs boards act as the interface to the HDDs, SSDs or Flash Modules installed in the drive control chassis. Two or four BED boards can be installed per chassis. Each BED board has sixteen 6Gbps SAS links. A standard-performance single-chassis configuration uses one BED pair with 32 back-end 6Gbps SAS links. The high-performance single-chassis uses an additional pair for a total of 64 6Gbps SAS links.

In addition to data transfers, the BED boards generate RAID-5 and RAID-6 parity and perform drive rebuilds by an embedded Data Acceleration ASIC and data encryption with a dedicated Encrypting Processor. The VSP G1000 supports RAID-10 (mirrored data striping), RAID-5 (data striping with distributed parity) and RAID-6 (data striping with two distributed parity disks. Any disk can be configured for any RAID technique, though it is recommended to configure SSDs as RAID-5 and high-capacity near-line disks as RAID-6.

Hitachi Storage Virtualization Operating System

The Storage Virtualization Operating System (SVOS) of the VSP G1000 is the sixth generation of HDS' enterprise storage array operating software. The SVOS software
provides software-defined storage management for both Open and Mainframe environments. Hitachi SVOS abstracts information from storage systems, virtualizes and pools available storage resources and allows automating key storage management functions. This unified environment maximizes the utilization and capabilities of the storage resources and significantly reduces operations costs and risk. Standards compatible for easy integration into IT environments, SVOS advanced storage virtualization and management capabilities enable the utmost agility and control required to build infrastructures that are continuously available, automated and agile. SVOS supports both Mainframe and Open storage environments and includes functionalities for mainframes and other platforms such as:

- **Hitachi Storage Navigator**, which obtains system configuration and status information and sends user requested commands to the VSP G1000.
- **Universal Volume Manager**, which enables virtualization of external heterogeneous storage.
- **Dynamic Provisioning**, which provides thin provisioning for simplified provisioning operations, automatic performance optimization and storage space savings.
- **Device Manager**, which provides single-point management for all Hitachi physical and virtualized storage and acts as the interface for integration with other management systems.
- **Resource Partition Manager**, which supports secure administrative partitions for multi-tenancy requirements.
- **Cache Partitioning**, which supports up to 32 cache partitions to ensure multi-tenancy performance.
- **Performance Monitor** feature assists with performance configuration planning, workload balancing, and analyzing and optimizing storage system performance.
- Along with other useful storage system utilities.

SVOS includes Storage Navigator for low level storage system management and is the foundation for many VSP G1000 mainframe compatibility features. SVOS provides and manages customer-defined non-disruptive data migration workflows between storage tiers and between virtualized physical systems among and across data centers for true workload mobility.

**Capacities and Scalability**

VSP G1000 is available with a choice of standard high-performance disk drives, high-capacity near-line drives and high performance Hitachi Accelerated Flash storage. A fully populated six-rack design holds up to 2,304 drives. In addition to the industry standard enterprise HDD’s, the VSP G1000 support high-speed flash SSDs. Hitachi Accelerated Flash (HAF) storage is an enterprise-class, solid-state storage option which combines the unique Hitachi embedded flash controller and enterprise MLC flash memory to deliver superior performance at acceptable price. The HAF controller is a custom-designed ASIC featuring a quad-core processor. This ASIC delivers processing power needed for housekeeping.
management that eliminates performance bottlenecks. It runs Error Correction Code to ensure data integrity, manages wear leveling increase endurance, and adaptively refreshes data to secure data availability.

Table 1: HDD, SSD and Flash options

<table>
<thead>
<tr>
<th>Functionality</th>
<th>2,656TB [1.2TB 2.5” serial-attached SCSI (SAS)], 4,511TB [4TB 3.5” nearline-SAS (NL-SAS)], 2,026TB [3.2TB flash module (FMD)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Internal Raw Capacity</td>
<td></td>
</tr>
<tr>
<td>Flash Storage Options</td>
<td>400GB 2.5” SSD, 800GB 2.5” SSD, 1.6TB FMD, 3.2TB FMD</td>
</tr>
<tr>
<td>Flash Module Raw Capacity (GB)</td>
<td>393.85, 787.69, 1759.21, 3518.43</td>
</tr>
<tr>
<td>Hard Disk Drive (HDD) Options</td>
<td>300GB 2.5” SAS, 600GB 2.5” SAS, 900GB 2.5” SAS, 1200GB 2.5” SAS, 4TB 3.5” SAS</td>
</tr>
<tr>
<td>HDD Raw Capacity (GB)</td>
<td>288.2, 576.39, 864.64, 1152.79, 4,511.35</td>
</tr>
<tr>
<td>Speed (RPM)</td>
<td>15K, 10K, 10K, 10K, 7.2K</td>
</tr>
<tr>
<td>Minimum to Max. Hard Drives</td>
<td>0–2,304 2.5” and/or 0–1,152 3.5”, including spares</td>
</tr>
<tr>
<td>Max. SSDs</td>
<td>384</td>
</tr>
<tr>
<td>Max. Flash Modules</td>
<td>576</td>
</tr>
</tbody>
</table>

Table 1: HDDs and SDDs options

System z functionality and compatibility

Hitachi and IBM share APIs to ensure compatibility between Hitachi storage and IBM mainframes. For more than 36 years Hitachi, Ltd. has provided mainframe technology to business and industry, supporting all mainframe operating systems, including MVS, z/OS, z/VM, z/VSE, z/TPF and Linux for z. During this time, license agreements have provided Hitachi with access to IBM APIs and interface specifications for mainframe storage platforms as well as IBM access to selected Hitachi APIs. These APIs enabled Hitachi storage systems to support remote mirroring such as PPRC, XRC and other functionalities such Parallel Access Volumes (PAV), HyperPAV, Multiple Allegiance (MA), High Performance FICON (zHPF), TPC-R, and Geographically Dispersed Parallel Sysplex (GDPS), and HyperSwap (a full list of supported features is in appendix 1). The license agreements have also given IBM access to Hitachi APIs for NanoCopy disaster recovery manager technology from Hitachi Data Systems and Hitachi ShadowImage Replication. This licensing agreement also enables Hitachi and Hitachi Data Systems to develop and deliver storage management software for
mainframe environments. Hitachi participates in the IBM Early Ship program for z/OS, which means that Hitachi has early access to z/OS versions for testing. This access enables Hitachi to ensure compatibility with new versions of z/OS when they become generally available.

Hitachi storage systems and features are tested and qualified with IBM mainframes, operating systems, and critical features. This testing and qualification includes features such as support for GDPS/HyperSwap, FlashCopy and zHPF. IBM successfully completed qualification testing of Virtual Storage Platform with IBM GDPS using Hitachi support for PPRC, XRC and, in 2012, qualified Hitachi Universal Replicator (HUR) to be used in combination with GDPS. The Hitachi VSP G1000 family, Virtual Storage Platform, Hitachi Universal Storage Platform V (USP V) and Hitachi Universal Storage Platform VM (USP VM), are qualified and supported on the IBM z196, Z9, z10, z114, zEC12 and zBC12 processors. They are also supported under the latest z/OS version. Hitachi has implemented technologies that are compatible with IBM’s Metro Mirror (PPRC), FlashCopy V2, and FlashCopy Space Efficient on Hitachi storage systems. Hitachi is the only storage vendor to go through this qualification. Hitachi also successfully completed the qualification tests for GDPS/XRC and a 3-data-center (3DC) multitarget replication configuration using VSP GDPS/HyperSwap support and HUR with delta resync along with Hitachi Business Continuity Manager.

The license agreements ensure that as IBM announces and delivers new features and functions for mainframe environments, Hitachi Data Systems will be able to support these new features. In addition, Hitachi has its own testing facilities to ensure that its products and features are compatible with the IBM solutions.

Hitachi Data Systems and IBM have a long-term agreement to provide assistance to each other to quickly resolve any joint customer issues related to Hitachi storage and IBM mainframes and mainframe operating systems. The focus is on determining the source of the problem, with the root cause and solution being provided by the vendor whose product or products are identified as the source of the problem.

**General Functionality**

In addition to the compatible features, the VSP G1000 systems support a wide range of storage management features which ease storage management and ensure better storage economics. The most important features are:

**Hitachi Dynamic Provisioning** (HDP) for the mainframe and other platforms complements existing mainframe storage provisioning processes while improving performance and simplifying performance and capacity optimization. In addition to thin provisioning, HDP improves performance by automatically segmenting the content of physical disks in the storage pool, distributing I/O activity across available HDDs and SSDs. Striping the data among a large number of physical devices practically eliminates hot spots and allows parallel access to disks, SSD’s and Flash Modules, which results in almost uniform performance.
Thin provisioning enables the option of allocating virtual storage as needed without having to dedicate the full physical disk storage capacity up-front. Additional capacity can be allocated without any disruption to mission-critical applications from existing or newly-installed capacity. The Zero Page Reclaim and Write Same functions return unused storage blocks back to the storage pool and reclaim storage space, while Automatic Dynamic Rebalancing automatically re-stripes existing virtual volumes when physical volumes are added to the pool for workload rebalancing. Hitachi is the only high-end storage vendor that offers automatic rebalancing of the virtual volume pages through active re-striping in order to take advantage of new disks when the pool is expanded. Dynamic Provisioning capabilities can also be used with external third-party attached storage systems. In addition to improving performance Hitachi Dynamic Provisioning increases installed capacity utilization, defers upgrades, and saves storage management tasks, thus reducing CapEx and OpEx.

Complimenting Hitachi Dynamic Provisioning is Hitachi Dynamic Tiering (HDT). On average, 20 percent of data accounts for 80 percent of activity, which justifies tiered storage deployments. Users require features that simplify the building of tiered storage infrastructures. Hitachi Dynamic Tiering is a dynamically automated data placement feature that constantly classifies and migrates data to the most suitable tier based on actual usage. This is especially important as users move from HDD to SSD or Flash Modules for tier 1 storage. SSDs and Flash are an order-of-magnitude faster on average in reads and writes but are also high-cost, making it vital to migrate data to less-expensive storage as its use decreases.

The optimal usage scenario for Hitachi Accelerated Flash Modules or SSDs is for data that is cache-unfriendly to read (random access, non-sequential). Typical candidates include hot database tables, database temporary areas, metadata, indices, control areas, etc. The question is how to identify such data? Placing a whole volume or LUN on SSD may be not economical, and partial data placement cannot be manually controlled by operators. The answer is automated data placement.

Hitachi’s VSP G1000 is a tiered storage in-a-box: it supports Accelerated Flash Modules, SSDs, several performance SAS HDDs, capacity near-line disks, and various RAID techniques. HDT is an automated methodology that attempts to move the most active back-end data to drives with higher performance, while migrating less active data to slower, less expensive drives. Mainframe storage data chunklets of 38MB are dynamically placed in the appropriate tier based on host access and usage patterns, media type, and speed, RAID level and sustained I/O level requirements. This feature helps maintain peak performance under dynamic conditions without manual intervention at optimal CapEx and OpEx savings. The time of the data placement and the sampling frequency can be user-set, and, in addition, users retain the
option to move data manually to a selected platform if required (e.g., high-performance financial application running once a month). The system automatically optimizes the use of storage by keeping the higher tiers fully utilized.

Hitachi Dynamic Tiering for Mainframe complements existing mainframe storage provisioning processes, such as DFSMS. At the same time it offers the full benefits of Hitachi Dynamic Provisioning to improve performance and simplify performance and capacity optimization. Existing SMS storage groups and ACS routines can be aligned to differently tiered storage pools.

In addition, Hitachi Tiered Storage Manager (HTSM) for Mainframe is a z/OS software management product for Hitachi Dynamic Tiering for Mainframe that enables a user to control service levels based on performance and/or time to facilitate meeting mainframe service level agreements (SLAs). HTSM offers 32 levels of fine grain policy control to control storage service levels in an auto-tiered environment. A key differentiator with the competition is that HTSM for Mainframe runs on the mainframe, not in the storage control unit. HTSM for Mainframe enables management of HDT for mainframe via REXX Functions within REXX Scripts and/or an ISPF Dialog at the volume level or through the DFSMS Storage Group construct and provides a familiar interface for mainframe storage administrators. It allows setting tiering policies by SMS Storage Group or individual devices and provides reporting capabilities for ongoing monitoring of the dynamic tiering environment.

Existing Interesting or Unique Features

A unique feature is the Hitachi Universal Volume Manager introduced with the first version of the USP in 2004. The Hitachi Universal Volume Manager software configures, manages, and accesses external volumes as if they were VSP G1000 internal volumes. Externally-connected storage may use the same functionality as internal storage, which means that data replication software, transparent data movements, dynamic provisioning, and other high-end subsystems features can be used in the same way, regardless of whether the data resides on internal or external volumes. The virtualization of heterogeneous storage systems simplifies storage management, enables easier migrations, reduces the complexity of disaster recovery schemes, and allows the building of tiered storage without compromising on functionality. Users may extend the life of outdated storage subsystems by giving them high-end storage functionality.

Another unique feature of VSP and USP systems is storage system partitioning by Hitachi Resource Partition Manager (HRPM). Enterprise storage is often connected to multiple hosts and shared by multiple divisions in a company or by multiple companies. This means that a storage system may have multiple storage administrators. As a result, isolation and compartmentalized management of the storage system are required. HRPM software addresses this need by enabling administrative partitioning of storage system resources. Creating isolating environments on a physical storage system solves security, audit, and compliance issues of shared storage assets used by different groups. Public cloud-shared
storage needs to ensure stringent security for each user’s data, otherwise the users require separate subsystems, which increases service costs and makes the concept less attractive. Therefore this feature is an ideal solution for External Service Providers and cloud storage providers.

A hardware-based (storage controller) encryption option encrypts the internal drives using strong encryption (AES-256) without impacting throughput or latency. Hitachi’s data-at-rest encryption feature also includes integrated user-friendly key management functionality.

**Availability and Resiliency**

**Hardware reliability**

**Availability, Business Continuity and Disaster Recovery** remain on top of the list of requirements. The non-stop global economy, the fierce competition, and new levels of service requirements raise the requirements for business continuity and 24/7 non-disruptive operations. The requirements from any data center are providing non-disruptive data access, movements, provisioning, and protection of the organization’s data.

The VSP G1000 series provides full redundancy, non-disruptive upgrades and maintenance, hot-swappable components, and online microcode changes. Hitachi storage subsystems were the first devices to support non-stop operation, and the VSP G1000 maintains HDS’s position as the industry’s availability leader for many storage subsystem generations already. The base configuration is non-disruptively and flexibly upgraded by adding components such as Virtual Storage Director (VSD) pairs, data cache, front-end directors, back-end directors, Cache Path Control cache-switches, and disk drives to the existing chassis. Upgrades also include adding a second controller chassis and adding cabinets with disk modules.

Data migration, in general, is one of the most complicated storage-related tasks. It can cause data loss, generally takes a long time, and is usually very expensive. It may require retaining obsolete subsystems for longer than planned and additional costs through leasing rates and maintenance. The virtualization functionality of the VSP G1000 can significantly simplify data migrations.

The HDDs are carefully screened before installation. In addition to the three RAID techniques mentioned above, Hitachi uses extensive error correction techniques for the HDDs and the SSDs. For example: Eight bytes of error correction code (ECC) are stored with each 512 byte HDD data sector and are used by the drive when trying to reconstruct lost bits of data during a read operation. Pre-emptive techniques detect drive malfunctions as early as possible, which allows copying of a suspected drive, avoiding having to perform an entire RAID rebuild. Write operations are simultaneously duplexed into VSD G1000 cluster in both

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2 To copy a 2 TB HDD may take 2-3 hours, to rebuild without load ca. 48 hours. A rebuild with 80% CU load can more than a week.
Cache-A and Cache-B by the FED Data Accelerator processor processing the request. In case of a main power loss or malfunction, the on-card batteries maintain power to enable flushing the outstanding write blocks to the internal SSDs.

The Hitachi multi-core embedded flash controller introduces multiple unique capabilities designed for enterprise workloads and extended endurance. Zero block write avoidance compresses, in real time, any data stream of zeroes or ones by up to 94% capability, thus speeding writes, improving performance and saving writes to the flash. It also reduces array setup time by performing flash formatting 5x faster and extends endurance by avoiding unnecessary erases. Error correction corrects up to 42 bits of errors per 1.4KB of data, ensuring data integrity better than HDDs. To manage the uneven wear characteristic, the flash controller performs a memory block analysis function. This continuous scanning and diagnostic assessment of each block effectively manages its optimal time for reclamation and ensures the expectations for enterprise data. The program decreases background task overhead and improves sustained performance while extending flash cell longevity.

The VSP G1000 supports a variety of Hitachi proprietary or IBM System z-compatible local and remote mirroring techniques. The management of the Hitachi replication solutions for high-end storage has remained consistent across the last three generations of devices, which eliminates the need to build new scripts and procedures and time and money investment in training.

**Local Mirroring**
The VSP supports three techniques of local (in system) mirroring:

- **Hitachi Compatible Mirroring for IBM FlashCopy** provides support compatible with IBM FlashCopy V02 and enables application-aware, near-instant copies and restores capability.

- **Hitachi Compatible Software for IBM FlashCopy SE (FCSE)** provides an in-system solution for data protection that is IBM mainframe compatible. This solution combines snapshots, virtual data management and dynamic provisioning to create logical point-in-time (PiT) copies.

- **Hitachi proprietary ShadowImage Replication software** provides non-disruptive, host-independent data replication to create copies of any customer-accessible data within a single Hitachi storage system. These copies can provide immediate access and sharing of information and optimize tape backup operations. ShadowImage copies provide nearly instant recovery from logical data corruption.

All these techniques may use consistency groups to ensure consistency of cross volume data when replicating or making point-in-time copies. **Multiple tiers** provide the ability with ShadowImage to make 1st- and 2nd-generation copies of volumes that are being copied by ShadowImage. The copies can be on different storage tiers, either internal or externally.
virtualized storage. This capability supports disk-based backup as well as additional copies for testing or backing up to tape.

Remote Replication Techniques

The remote mirroring techniques ensure continuous or near-continuous operation in cases of major malfunction, power loss, fire, or other disaster. Hitachi replication solutions for mainframe environments support all of the latest generations of Hitachi enterprise-class storage systems, including the VSP G1000, VSP, USP V, and USP VM. It allows use of previous storage generations on the recovery site to control costs.

Data consistency means that, from an application's perspective, the secondary disks contain all updates to a specific point in time, and that the write update sequence is maintained. Recovery time can be significantly affected by the consistency of the remote data. Databases, catalogs, volume table of contents (VTOC) and indices are only a few examples of files that are vulnerable to "out-of-sequence writes" or "lost writes" because of rolling disasters. Database restart logic performs resolution of the "in flight and in doubt" transactions, typically in seconds or minutes. If data consistency is not maintained, then a database recovery process must be performed. This involves restoring image copies and logs, if they exist, to disk and executing forward recovery utilities to apply updates to the image copies. Database recovery is a time-consuming task and may take several days. Hitachi also provides support for extended consistency groups, providing consistency of data during replication across multiple storage systems to the storage systems at the remote location.

GDPS and consistency groups ensure data consistency and fast recovery. As mentioned above, Hitachi data replication solutions for mainframes fully support GDPS, GDPS/HyperSwap or Basic HyperSwap. Many of the world’s largest organizations in financial services and other key industries have deployed GDPS to protect mission-critical applications. It manages application availability in and across sites for both planned maintenance and unplanned situations such as site failures or full-blown disasters.

Another option popular with major financial institutions is the ability to deploy three-data-center solutions with the option to synchronize the data at the alternate sites using delta resync if the primary site should be unavailable. This can all be managed using Hitachi Business Continuity Manager software. Hitachi Business Continuity Manager enables single-point management of Hitachi remote mirroring products from mainframe environments. It provides the ability to manage complex distributed two and three data center environments easily from a single point of control. Like HTSM for Mainframe, it supports both TSO/ISPF and standard REXX scripting to customize and automate:

- Hitachi TrueCopy synchronous remote replication software, which provides a continuous, nondisruptive, host-independent, zero-data-loss solution. This technique is deployed for distances within the same metropolitan area. For mainframe environments, TrueCopy synchronous is compatible with IBM Metro Mirror (a.k.a. PPRC) and is eligible to participate in GDPS and HyperSwap deployments. This
technique supports consistency across multiple storage systems (up to 12x12) and provides 3 data center configurations.

- Hitachi **Universal Replicator (HUR)**, which enables hardware-controlled asynchronous remote copying between heterogeneous storage platforms. HUR offloads the majority of processing for asynchronous replication to the remote storage system using unique Hitachi pull technology which significantly reduces the overhead on the primary storage system. HUR minimize the Recovery Point Objective (RPO) by a proprietary technique using an internal storage system journal-based method. TrueCopy and HUR support multi-volume and multi-storage system consistency groups up to 12 by 12 in a 2DC and 12 by 12 by 12 in a 3DC environment. GDPS is supported in both two and three-site configurations.

### 3-Data-Center (3DC) Replication

The 3DC replication solution uses both Hitachi TrueCopy synchronous replication and Hitachi Universal Replicator asynchronous replication. It provides a synchronous copy to a separate Hitachi storage system within metro distances using TrueCopy and an asynchronous copy to a second Hitachi storage system that can be located at any distance from the primary site. There are two implementations of 3DC replication: cascaded replication and multitarget replication:

- **Cascaded replication** provides synchronous replication from a production Hitachi high-end-class storage system (such as VSP G1000, VSP or USP V) to a secondary storage system using TrueCopy synchronous replication software. It then asynchronously replicates the data from the secondary storage system to an out-of-region Hitachi enterprise storage system using HUR.

- **Multitarget (Concurrent) Replication** synchronously replicates data from the production site using TrueCopy synchronous software to a local site (within metro distance) and concurrently replicates to an out-of-region remote site using HUR. With multitarget replication, protection can be resumed with no data loss between the two backup sites (hot standby site and remote site) using delta resync if the primary data center is lost. Delta resync dramatically reduces the times required for recovery from a disaster. If the production site experiences a failure, the hot standby (local) site can take over and use the remote site for disaster recovery; it only has to copy differential data. A full copy of the data is normally not required. As a result, disaster recovery protection for the hot standby site resumes within minutes instead of hours.

- Some cautious users require four site infrastructure (4DC) which is supported by Hitachi Data Systems. It is a 3DC multitarget solution plus an additional HUR asynchronous copy from the hot standby site to a separate fourth remote location.

### Performance

Hitachi has not yet submitted Storage Performance Council (SPC) measurements figures, however early Hitachi measurements show significant performance improvements in comparison to the VSP. See the preliminary results in table 2.
<table>
<thead>
<tr>
<th>VSP(IOPS)</th>
<th>VSP G1000</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back-end Read (8KB) IOPS</td>
<td>1026600</td>
<td>3977972</td>
</tr>
<tr>
<td>Back-end Write (8KB) IOPS</td>
<td>270476</td>
<td>1190209</td>
</tr>
<tr>
<td>Sequential Read (256 KB) GB/s</td>
<td>13.1</td>
<td>48.8</td>
</tr>
<tr>
<td>Sequential Write (256 KB) GB/s</td>
<td>6.84</td>
<td>25.79</td>
</tr>
</tbody>
</table>

**Table 2: Performance improvements comparison**

These figures position the VSP G1000 at the winner in performance and throughput in the high-end storage. The VSP’s G1000 huge performance improvements compared to the VSP are due to the enhanced control unit structure and the use of more powerful processing technology, which contribute to increased bandwidth and lower latency throughout the system. For example:

- VSDs as a third layer of processing (in addition to FEDs and BEDs) and the largest number of processing cores of any mainframe storage platforms in the industry,
- Special Data Accelerators processors and new ASICs for the FED and BED boards,
- The newly enhanced Hi-Star crossbar switch-based architecture has 768 GB/sec aggregate internal bandwidth,
- Separate caches and paths for control and data, and,
- A custom designed quad-processor ASICs in the HAF controller.

**Technology**

The VSP G1000 is designed and manufactured by Hitachi Ltd., a huge leading international technology corporation with 320,725 employees at the end of business year 2014 and multi- (96) billions in revenue. It manufactures a wide range of products from medical equipment to fast trains, and turbines for electric plants. The corporation exploits synergies between the different divisions to produce state-of-art products. It takes several years to design a new storage subsystem, which is why only a company with close relations with semiconductor technology manufactures can plan for using the latest technologies. For example, Hitachi’s Telecommunication & Network division contributed knowledge in designing the Cache Path Controller switch, while the Micro Device division supplied the tailored ASICs and other components. Another Hitachi in-house developed technology is the embedded flash controller for Hitachi Accelerated Flash (HAF) storage to deliver superior performance at acceptable price.

**Integration with other Platforms and Server Hypervisors**

For mixed environments such as UNIX or Windows, the VSP G1000 provides full functionality support and integration. Storage virtualization amplifies the benefits of server virtualization. For example, HDS has been cooperating with VMware since 2002, becoming a VMware Premiere Global Partner in late 2006. The alliance as resulted in comprehensive interoperability via certifications and qualifications. VSP supports also other vendors’ hypervisors.
**Competition**

There are many storage subsystems on the market, but only few can be considered as real high-end or tier-1 and only two\(^3\) (last generation) are currently supporting the mainframe – Hitachi VSP G1000 and IBM DS8870.

The latest high-end EMC storage the VMAX3 is currently not supporting FICON channels and EMC has not announced any firm statement of direction of when it will deliver FICON capability. Mainframe users committed to EMC may purchase the outdated VMAX series 40K which delivers much lower performance than the VSP G1000 or the DS8870. Delivering Tier 1 products without FICON demonstrates EMC’s shortage of developers and the lack of commitment to mainframe storage. As opposed to EMC, Hitachi is continuing to show strong commitment to the System z customers. For example on October 20\(^{th}\), 2014 Hitachi announced improvements to the Hitachi VSP G1000 mainframe storage performance with added SVOS support for z/HPF features and new releases of two Hitachi mainframe storage products - Hitachi Tiered Storage Manager for Mainframe 8.1.0 and Hitachi Business Continuity Manager 8.1.0. Among the enhancements of Hitachi SVOS for the VSP G1000 microcode V02 are SVOS support for expanded z/HPF features such as zHPF for QSAM/BSAM, zHPF List Prefetch Optimizer, BiDi for List Prefetch Optimizer, zHPF for format writes, and mainframe support for SVOS Cache Residency Manager, including setting and releasing cache-based volumes from mainframe hosts.

**Summary and Conclusions**

Hitachi and Hitachi Data Systems are committed to providing industry-leading high-end storage for IBM mainframe computing environments. Hitachi has again created a state-of-the-art high-end storage system. The VSP G1000 is the industry leader in every aspect: reliability, functionality, performance, scalability and sustainability. In the Gartner's latest “Critical Capabilities for General-Purpose, High-End Storage Arrays” report, Gartner positioned the VSP G1000 as the leading product in this category.

Hitachi, Ltd., maintains the strong relationship with IBM ensuring its ability to support the latest features and functions of z/OS as they are delivered. The VSP is compatible to System z, fully supports GDPS, HyperSwap, other platforms, and hypervisors. Additionally, Hitachi has developed and continues to develop new technology and capabilities to enable customers to maximize the efficiency and utilization of their storage and the availability of their data. It offers impressive set of functionalities among them two unique features; the control unit partitioning and storage virtualization.

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\(^3\) Hewlett-Packard OEM the VSP G1000 as XP9500 but its market share is negligible.
The VSP’s virtualization layer offers the only storage architecture that flexibly adapts in terms of performance and capacity, and extends to multi-vendor storage. The Universal Replicator simplifies deployment of disaster recovery for heterogeneous storage infrastructures. Built-in intelligence and automation constantly adapt to changes ensuring that the data is available to satisfy changing business conditions. The net result is superior data center efficiency, manageability and cost savings, which should put the VSP G1000 on any shortlist of organizations searching for excellence⁴.

⁴ “Excellence is an art won by training and habituation. We do not act rightly because we have virtue or excellence, but we rather have those because we have acted rightly. We are what we repeatedly do. Excellence, then, is not an act but a habit”. Aristotle (384 BC-322 BC) Greek philosopher.
Appendix 1.

List of supported IBM compatible functions and features

Parallel Access Volumes (PAV).
HyperPAV.
Multiple Allegiance.
MIDAW.
Extended Address Volume (EAV).
Dynamic Volume Expansion (DVE).
Extended-Distance FICON.
IBM Metro Mirror (PPRC).
IBM z/OS Global Mirror (XRC)\(^5\)
FlashCopy V02.
FlashCopy Space Efficient (FlashCopy SE).
Remote Pair FlashCopy.
Geographically Dispersed Parallel Sysplex™ (GDPS) HyperSwap.
Basic HyperSwap and TPC-R.
High Performance FICON (zHPF).
zHPF multitrack.
zHPF DB2®
List Prefetch
zHPF Bi-directional channel program
zHPF List prefetch optimizer
zHPF BSAM/QSAM support
zHPF Format Write
zHPF and DB2I/O
z/OS Discovery and Auto Configuration (zDAC) support.
Latest zSeries processors including the z114, zEC12 and zBC12.

\(^5\) Hitachi support for z/OS Global Mirror (XRC) via Hitachi Compatible Replication for IBM® XRC® is only available on Hitachi VSP G1000 series as a migration aid for organizations moving to Hitachi Universal Replicator.