WHITE PAPER
Virtualization

Virtualizing Resource-intensive Applications

An Enterprise Case Study with Intel, SAP, and VMware

EXECUTIVE SUMMARY

At the request of a major enterprise customer, Intel, SAP, and VMware® jointly conducted proof-of-concept (PoC) testing of virtualized SAP® applications at SAP Co-Innovation Lab in Palo Alto, California. The test configuration and workload closely modeled the customer's existing IT environment.

Results demonstrated that new virtualization technologies from Intel and VMware deliver near-native performance, enabling virtualized SAP applications to support larger numbers of users with excellent performance and scalability.

The virtualized configuration, based on Intel® Xeon® processor 5500 series and VMware vSphere™ 4, supported up to 1,700 concurrent users with sub-second response times—a scalability difference of less than 13 percent compared with non-virtualized software.

The PoC and previous SAP application benchmark tests demonstrate that Intel Xeon processor 5500 series and VMware vSphere deliver both horizontal scalability (as the number of virtual machines is increased) and vertical scalability (as more virtual CPUs [vCPUs] are assigned to a single virtual machine).

These results remove a key performance concern, allowing IT organizations to reap the benefits of virtualizing SAP applications—including reduced total cost of ownership (TCO) and the ability to focus on areas such as operations and management of virtualized environments.

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Virtualization of Business-Critical Applications: Adoption and Key Questions

Enterprise adoption of virtualization has taken place in several waves, as shown in Figure 1. Most large enterprises have already realized benefits from the first wave—using virtualization to consolidate simple, standard applications, resulting in reductions in server TCO, server footprint, and data center power and cooling costs.

After these initial successes, many enterprises are now focusing on larger, more complex business-critical applications, such as enterprise resource planning (ERP) software.

These applications are typically CPU-, memory-, and I/O-intensive. Because of this, many organizations are concerned about performance when virtualizing and consolidating these applications, especially given IT infrastructure constraints such as network bandwidth.

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A key question is whether newer server and virtualization technologies can deliver virtualization performance that approaches native performance levels, enabling IT organizations to virtualize business-critical applications and use these virtualized implementations to support large numbers of users.

Benefits of Virtualizing SAP Applications

Virtualizing SAP applications offers significant potential benefits.

Landscape Consolidation

Non-virtualized SAP software deployments can result in significant server sprawl due to the use of multiple paths to production and the tiered software architecture.

To provide maximum flexibility in meeting business needs, IT organizations often create separate paths to production, each supporting a different SAP application. A path includes multiple servers supporting different stages, such as development, testing and quality assurance, production, and support. For a single stage, multiple servers may be used to support different SAP application tiers.

Because of this, a large SAP application environment may include hundreds of servers with low utilization, resulting in high capital expenditure and operational support costs.

Virtualization enables enterprises to consolidate these environments, eliminating server sprawl, increasing utilization, and reducing support requirements. Consolidation can greatly reduce capital and operating expenses; some enterprises have reduced overall TCO by more than 80 percent over three years.[1]

Improved Energy Efficiency

By enabling consolidation of workloads onto a smaller number of more scalable, energy-efficient servers, virtualization can substantially reduce an enterprise's energy consumption and carbon footprint. A single server based on Intel Xeon processor 5500 series may replace nine four-year-old servers based on single-core processors, resulting in more than a 90 percent reduction in utility cost due to dramatically lower power and cooling requirements.[2] In tests using the SAP sales and distribution (SD) workload, using a single server based on newer quad-core Intel® Xeon® processors to replace servers based on older single-core processors resulted in estimated power savings of more than 7,800 kilowatts (kW) per year, with a corresponding decrease in carbon emissions.[3]

Improved Availability

In a non-virtualized environment, applications are typically unavailable during scheduled physical server maintenance. Virtualization effectively eliminates the need for this downtime: When a physical server needs maintenance, its resident applications can simply be migrated to other servers using VMware vMotion™ while continuing to run unaffected.

Faster SAP Software Upgrades

IT organizations can quickly create virtualized test environments and mirror production environments without the need for additional hardware. This accelerates delivery of new software releases and fixes.

Improved Disaster Recovery Strategy

If a physical server fails in a non-virtualized environment, the result may be unplanned downtime. In contrast, if a physical server fails in a virtualized environment, the applications running in virtual machines can be automatically started on another physical server. Using VMware High Availability (HA), IT organizations can implement high availability for the entire virtualized IT environment.

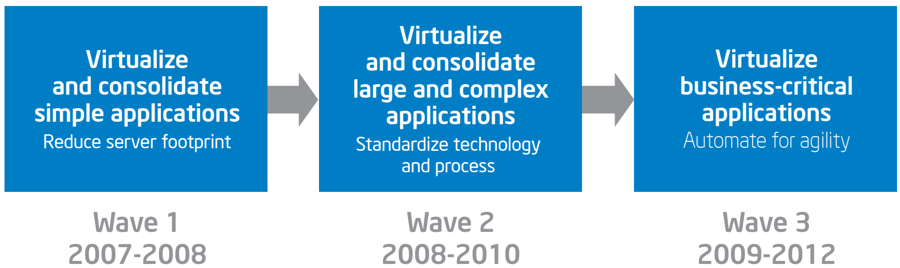

Figure 1. Waves of Enterprise Adoption of Virtualization

Better Maintenance of Legacy Applications

Running an application in a VMware virtual machine allows that solution to remain stable for the supported duration of its virtual hardware version, eliminating the need to upgrade the application. The supported duration of virtual hardware versions can be quite long—for example, virtual hardware version 3 has a supported duration of more than 11 years. During this period, users can upgrade the VMware ESX® release and the physical hardware with no impact to the application. In other words, users no longer need to maintain older hardware, incur the costs of procuring and storing older spare parts, or perform upgrades for legacy applications that are better left untouched due to stability, cost, or certification issues.

Virtualization Performance with SAP Applications: Key Questions

Despite the benefits of virtualization, some enterprises are hesitating when it comes to virtualizing business-critical applications such as SAP applications. Performance remains a key area of concern. Specific questions are:

- How do virtualized applications perform in a real IT environment, with the constraints imposed by current enterprise infrastructure?
- Can the latest server and virtualization technologies deliver virtualized application performance that approaches native performance levels?

At the request of a multinational Fortune 500* company, Intel, VMware, and SAP jointly conducted a proof of concept (PoC) designed to answer these questions by analyzing performance and scalability of virtualized SAP applications in a real-world configuration.

New Virtualization Technologies

The PoC utilized servers based on the Intel Xeon processor 5500 series and VMware vSphere software. These technologies include multiple capabilities designed to increase virtualization performance and scalability.

Intel® Xeon® Processor 5500 Series

Two-socket servers based on the latest generation of Intel Xeon processors, the Intel Xeon processor 5500 series, support approximately twice as many virtual machines in the same data center thermal envelope compared to servers based on previous-generation Intel® Xeon® processor E5450.[4] They also offer up to 2.05x better performance per watt and 2.6x better performance overall.

New features in the Intel Xeon processor 5500 series that contribute to these performance gains include 45nm Intel® microarchitecture (formerly codenamed Nehalem) and Intel® QuickPath Interconnect, which provides up to 25.6 gigabyte per second (GB/s) bandwidth between the CPU and other components. A schematic representation of a server based on Intel Xeon processor 5500 series is shown in Figure 2.

In addition, the Intel Xeon processor 5500 series includes multiple technologies that enhance virtualization performance, including end-to-end hardware virtualization support.

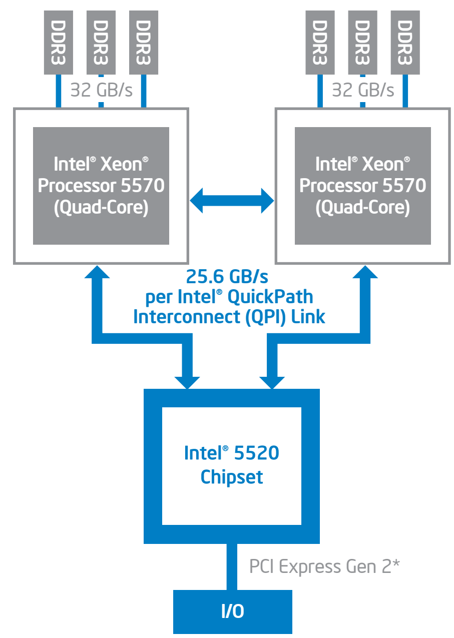

Figure 2. Schematic Representation of Two-socket Server Based on Intel® Xeon® Processor 5500 Series

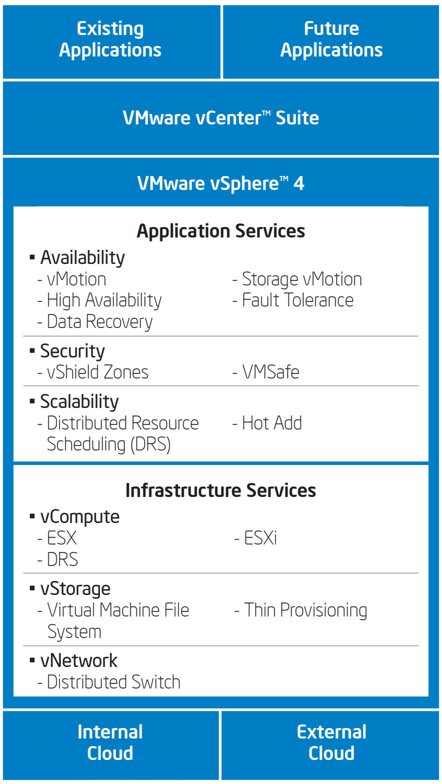

Figure 3. VMware vSphere 4

Intel® Platform Virtualization Technologies

Servers based on Intel Xeon processor 5500 series are the first to include end-to-end hardware virtualization support using Intel® Virtualization Technology (Intel® VT).

- **Within the processor:** Intel® Virtualization Technology (Intel® VT-x)
- **Within the chipset:** Intel® Virtualization Technology for Directed I/O (Intel® VT-d)
- **Within the network interface:** Intel® Virtualization Technology for Connectivity (Intel® VT-c).

Intel VT-x includes Intel VT Extended Page Tables (EPT), which can substantially increase virtualization performance with memory-intensive SAP application workloads. Previously, VMware vSphere translated memory addresses in software with a technique called shadow page tables. This could result in overhead, as VMware vSphere needed to monitor the page tables of a guest OS. Intel VT EPT optimizes and accelerates memory virtualization by enabling a guest OS to modify its own page tables. This reduces memory requirements because there is no need to hold shadow page tables, and it reduces the number of virtual machine entries and exits due to page table changes. The result is improved application performance.

Intel® Hyper-Threading Technology

Intel® Hyper-Threading Technology (Intel® HT Technology) enables simultaneous multi-threading within each processor core, up to two threads per core or eight threads per quad-core processor. This enables greater consolidation ratios by supporting more virtual machines, or a greater number of vCPUs assigned per virtual machine.

VMware vSphere

VMware software solutions constitute the most flexible and cost-effective virtualization platform for SAP software implementations. VMware vSphere, the latest generation of VMware software, supports servers based on Intel Xeon processor 5500 series.

Each generation of VMware software has supported significantly greater application performance requirements, as shown in Table 1.

VMware vSphere, shown in Figure 3, is business virtual infrastructure, a new category of software specifically designed to holistically manage large collections of infrastructure—including CPUs, storage, and networking—as a seamless, flexible,

Table 1. VMware Software Generations

	VMware ESX Server 3	VMware ESX 3.5	VMware ESX 4
Server Platform	▪ Intel® Xeon® processor 5300 series, Intel® Xeon® processor 7300 series	▪ Intel® Xeon® processor 5400 series, Intel® Xeon® processor 7400 series ▪ Virtual Machine Device Queues (VMDq) ▪ Intel® Virtualization Technology FlexMigration (Intel® VT FlexMigration)	▪ Intel® Xeon® processor 5500 series - Extended Page Tables - Intel® Hyper-Threading Technology - Intel® Turbo Boost Technology ▪ Intel® Virtualization Technology for Directed I/O, Intel® Virtualization Technology for Connectivity, VMDq ▪ Intel VT FlexMigration
CPU	1 to 2 CPUs	4 virtual CPUs (vCPUs)	8 vCPUs
Memory	<4 GB at peak	64 GB per virtual machine (VM)	256 GB per VM
Network	<2.4 Mb per second	9 Gb per second	20+ Gb per second
Input/Output Operations per Second (IOPS)	<100 at peak	100,000	200,000+

and dynamic operating environment. Analogous to the operating system that manages the complexity of an individual machine, the business virtual infrastructure manages the complexity of a data center. VMware vSphere includes the VMware ESX hypervisor.

Proof of Concept

The PoC was designed to analyze how new technologies from Intel and VMware affect performance and scalability of virtualized SAP applications in a real-world configuration.

To achieve this, the PoC used Intel Xeon processor 5500 series-based servers and VMware vSphere in an environment that closely modeled the customer's SAP application workloads and existing infrastructure.

SAP Co-Innovation Lab

Intel and VMware worked with SAP to conduct the PoC at SAP Co-Innovation Lab in Palo Alto, California. This global network of labs accelerates innovation of SAP-related solutions by providing SAP partners with lab resources and access to leading-edge—and sometimes pre-release—software and hardware.

The innovative solutions developed at SAP Co-Innovation Lab help customers to increase the value they derive from their SAP software deployments.

PoC Goals

Specific goals of the PoC were to:

- Evaluate VMware vSphere performance and scalability for SAP applications on Intel Xeon processor 5500 series-based servers in a real-world configuration.
- Compare virtualized and native performance in this environment to analyze the impact of Intel® and VMware technologies on virtualization performance.
- Determine whether the virtualized software offers adequate scalability and performance to meet the customer's needs.

PoC Landscape Configuration

The PoC modeled the customer's actual infrastructure, which included dual gigabit Ethernet (GbE) connections and Network File System (NFS)-based storage. The SD workload in the SAP application was selected because it closely resembled the customer's actual workloads. PoC criteria also included meeting the customer's requirement for sub-second response time. The PoC environment is shown in Figure 4.

PoC Workload: Sales and Distribution Workload

The SD workload covers a sell-from-stock scenario, which includes the creation of a customer order and the corresponding delivery, with subsequent goods movement and invoicing.

Key SAP application components include:

- A single central instance (CI). The CI connects to the database instance and can also support user processes, as shown in Figure 4.
- Dialog instances (DIs). These are primarily responsible for supporting users who are executing the transactions.

The number of DIs is the primary factor determining scalability; increasing the number of DIs enables more users to be supported.

SAP Application Virtualization Configurations

To emulate the real customer environment, an early version of the SAP ERP application, SAP ERP Central Component 5.0, was used in this PoC. The SAP application components

Hardware

- **Intel® Xeon® Processor 5500 Series-based Server**
  - 2x Intel® Xeon® Processor X5570 CPU (Quad-core)
  - 52 GB of RAM
  - 2x 1-GB Network Interface Card (NIC)
- **Sales and Distribution (SD) Load Generator**
  - HP Proliant DL380*
    - 2x Intel® Xeon® Processor X54xx CPU (Dual-core)
    - 8 GB of RAM, 1-GB NIC
- **Storage**
  - NetApp 6070*
  - Network File System (NFS) Attached Volumes
- **Network**
  - 2x 1-GB Virtual LAN (vLAN)
  - Dedicated vLAN for NFS

Software

- **SAP Software**
  - SAP ECC 5.0
  - SAP SD Benchmarking Toolkit
- **Operating Systems**
  - SUSE Linux Enterprise Server 10* SP2
  - VMware vSphere 4
  - Microsoft Windows 2003* R2 SP2 for SD Load Generator
- **Database**
  - Oracle Database 10G Release 2*

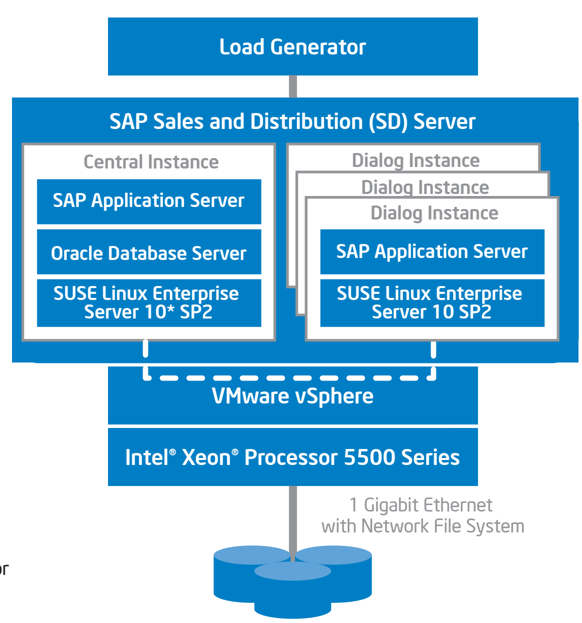

Figure 4. Proof of Concept Environment

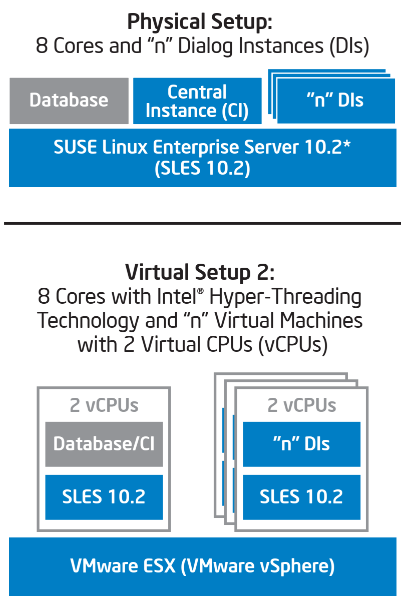

Figure 5. SAP Application Configurations Used in the Proof of Concept

can be configured in a variety of ways. The PoC used a single physical server with two quad-core Intel Xeon processor 5500 series CPUs, for a total of eight cores. Possible configurations included:

- Physical (non-virtualized) configuration, with the CI and DIs running on a dual-socket server based on Intel Xeon processor 5500 series, as shown in Figure 5.
- Virtualization option 1, which replicates the physical setup within a single virtual machine with eight vCPUs assigned to it. Because the hypervisor requires some additional processor cycles, Intel HT Technology is enabled to support more than eight concurrent threads and to improve performance.
- Virtualization option 2, which virtualizes each instance (whether CI or DI) within its own virtual machine, which is assigned two vCPUs. Intel HT Technology is enabled to improve performance as the number of DIs increases, resulting in oversubscription of the available physical cores.

The hypothesis was that virtualization option 2 would provide the best virtualization performance. This hypothesis was based on past experience with how VMware ESX schedules virtual machines with different numbers of vCPUs and on virtual machine configuration best practices.

Virtualization option 2 was therefore chosen for the PoC to compare virtualization performance with the performance of the physical configuration. We allocated 12 GB of RAM to the two-vCPU virtual machine running the CI, and 6 GB of RAM to each virtual machine running a DI; we reserved 10 percent of the server's total 52 GB of RAM for the VMware ESX hypervisor.

PoC Procedure

The primary goal of the PoC was to determine the maximum number of users that could be supported while maintaining a response time of less than one second.

The scalability of the configuration was calibrated by progressively increasing the number of DIs, one at a time. Each time the number of DIs was increased, response time was tested at different loading levels. Users were added until the response time exceeded one second.

The results obtained with the virtualized configuration were then compared with the results of identical tests conducted with the physical configuration.

PoC Results

The virtualized configuration scaled extremely well. As shown in Figure 6, the PoC configuration continued to scale as the number of DIs increased, up to a total of six to seven DIs.

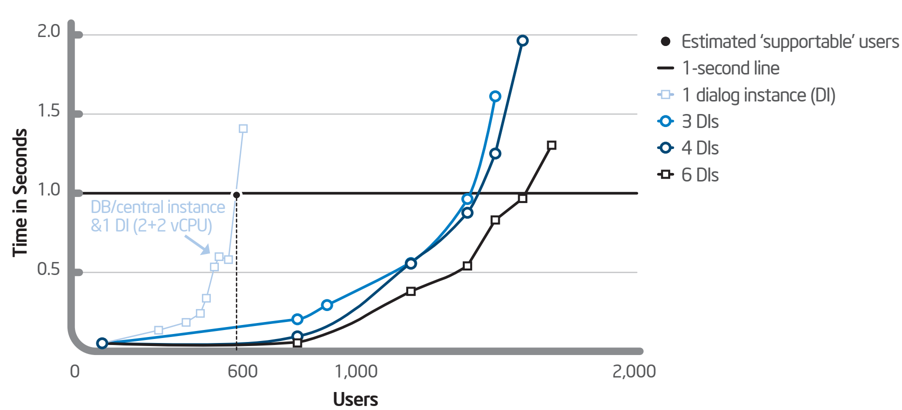

Figure 6. Virtualized scalability increases with the number of dialog instances (DIs). With each increase in the number of DIs, up to a total of six, the real-world configuration was able to support a greater number of users with sub-second response time.

With six DIs, the configuration supported up to 1,700 users while maintaining response times of less than one second.

PoC Performance Trends: Intel® Xeon® Processor Features Driving Scalability

The factors driving scalability can be analyzed by reviewing Figure 7, which shows the maximum number of supportable users—maintaining a response time of less than one second—with different numbers of DIs, each running within a two-vCPU virtual machine.

With one to three DIs, near-linear scalability was observed due to Extended Page Tables and Intel QuickPath Interconnect.

With four or more DIs, the number of threads begins to oversubscribe the number of physical cores. The test configuration continued to scale due to Intel HT Technology, which increases performance when oversubscription occurs.

In related tests with Intel HT Technology not enabled, a different trend has been observed: As the number of DIs increases, the number of supportable concurrent users flattens and may even decrease.

PoC Performance Summary

Results are summarized in Table 2. In the PoC, this real-world virtualized configuration showed excellent horizontal scalability, continuing to scale as DIs were added, up to a total of six.

Table 2. Summary of Proof of Concept Results

	NUMBER OF DIRECT INSTANCES (DIs) 2 VIRTUAL CPUs FOR VIRTUAL SYSTEMS					
	1 DI	**3 DIs**	**4 DIs**	**5 DIs Physical**	**6 DIs**	**6 DIs Physical**
Setup	Virtual	Virtual	Virtual	Physical	Virtual	Physical
Sustainable Users	570	1,406	1,433	1,550	1,700	1,950
DI Threads	2	6	8	8	12	16 (including database)
Database/Central Instance Threads	2	2	2		2	
Intel® Hyper-Threading Technology Active?	No	No[a]	Yes	No	Yes	Yes

Note: The number of DIs constitutes an application bottleneck.

[a] Since the VMware ESX console also requires some cycles, with eight vCPUs for the application (six for the DI and two for the database/CI), there is some usage of Intel® Hyper-Threading Technology even in this configuration.

The new technologies delivered virtualization performance close to native performance levels: With six DIs, the virtualized configuration supported 1,700 users with sub-second response time—only about 13 percent fewer than with the physical configuration.

Benchmark Results For SAP Applications

Our PoC results complement and support the results of previous virtualization benchmark tests (see the Appendix). While our results show very good horizontal scalability (as more virtual machines are added), the previous benchmark tests showed that virtualization with Intel Xeon processor 5500 series and VMware vSphere also delivers good vertical scalability, with performance increasing when more vCPUs are assigned to a single virtual machine.

Key Learnings

Our SAP application virtualization testing and experiences have resulted in a number of key learnings and best-practice recommendations.

Enable EPT. EPT improves performance and scalability. With servers based on Intel Xeon processor 5500 series, enabling Intel VT in the BIOS automatically enables EPT. VMware vSphere should be configured to use EPT—to use hardware memory management unit (MMU)—instead of shadow page tables.

Enable Intel HT Technology. The PoC demonstrated that Intel HT Technology

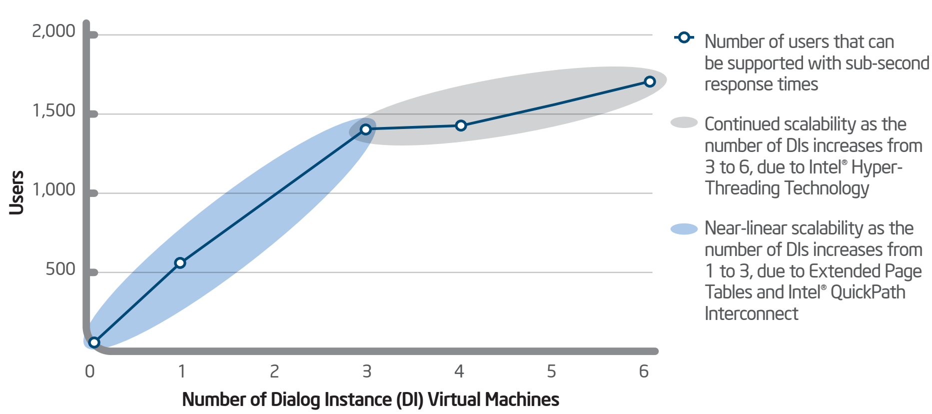

Figure 7. Dialog Instances and the Maximum Number of Users Supported

increases scalability in configurations with larger numbers of virtual machines and assigned vCPUs. Intel HT Technology is enabled in the BIOS; no additional configuration is needed in VMware vSphere.

Enable Non-Uniform Memory Access (NUMA) and Intel® Turbo Boost Technology. These capabilities were not used in the PoC, but they may deliver additional performance benefits.

Large Memory Pages. These may provide incremental performance benefits in benchmark tests, but are not recommended by SAP for use in customer systems.

Conclusion

Intel Xeon processor 5500 series and VMware vSphere deliver virtualization performance that is near native performance levels, enabling virtualized SAP application implementations that support larger numbers of users with excellent scalability and response times.

In testing of a real-world configuration using Intel Xeon processor 5500 series and VMware vSphere, the virtualized SAP workload scaled to support 1,700 users—a scalability difference of less than 13 percent compared with non-virtualized software.

Our PoC and previous benchmark testing show that, with SAP applications, these new Intel and VMware technologies deliver very good horizontal scalability (as more virtual machines are added) and vertical scalability (as more vCPUs are assigned to a single virtual machine).

These results remove a key virtualization performance concern for many enterprise IT organizations, allowing them to reap the benefits of SAP application virtualization—such as reduced TCO and the ability to focus on areas such as operations and management of virtualized environments.

Appendix: Certified Benchmarks For SAP Applications

Previous SAP application virtualization testing, conducted using the SD standard application benchmark with VMware vSphere 4 on servers based on Intel Xeon processor 5500 series, demonstrated excellent vertical scalability, as shown in Table 3. Doubling the number of vCPUs assigned to a single virtual machine resulted in a corresponding increase in the number of users that could be supported.

Table 3. Certified Benchmark Results for SAP Application

	VIRTUAL MACHINE SIZE FOR BENCHMARK DATABASE AND CENTRAL INSTANCES IN ONE VIRTUAL MACHINE	
	4 vCPUs	**8 vCPUs**
Sales and Distribution (SD) Users	1,144	2,056
Response Time	0.97	0.98
SAPS	6,250	11,230
Virtual Machine Utilization	98%	97%
Server CPU Utilization	25%	48%

Hardware: Fujitsu Primenergy RX300 S5*, 2 processors, 8 cores, 16 threads Intel® Xeon® processor 5500 series (Nehalem)
Software: SAP ERP 6.0, SUSE Linux Enterprise Server 10*, MaxDB 7.8*, VMware ESX 4

Certified benchmark results for SD standard application benchmark, conducted in Walldorf, Germany, August 2009. Certification numbers 2009028 and 2009029.

[1] "TCO and ROI Analysis of SAP Landscapes using VMware Technology." VMware, September 2009.

[2] Based on Intel internal analysis. Performance increase based on Intel comparison using SPECjbb2005* business operations per second (bops) between four-year-old servers based on single-core Intel® Xeon® processor 3.8GHz with 2M cache and new server based on Intel Xeon processor X5570. Electricity costs per year (365 days). Assumes USD 0.10 per kilowatt hour, 2x cooling factor.

[3] "Quad-Core Intel® Xeon® Processor 5400 Series' Proven Contribution to "Green IT"." Intel Corporation, October 2008. Based on testing by SAP Japan Co., Ltd.

[4] "Virtualization with the Intel® Xeon® Processor 5500 Series: A Proof of Concept." Intel Corporation, June 2009.