In Intel IT server tests, the 45nm Quad-Core Intel® Xeon® processor 5400 series delivered substantial increases in power efficiency and performance compared with processors based on 65nm technology. Results are shown in Figure 1.

When running 16 CPU-intensive virtualized workloads, a server based on the 45nm Quad-Core Intel Xeon processor E5440 completed each workload by as much as 14 percent faster, using 29 percent less power, than a server based on the Quad-Core Intel Xeon processor X5355 (65nm). The 45nm processor was up to 43 percent faster and used up to 44 percent less power per workload than the Dual-Core Intel Xeon processor 5160 (65nm).

Results show the strong potential of the 45nm Quad-Core Intel Xeon processor 5400 series for server virtualization and consolidation. We estimate that a medium-sized data center with 6,000 concurrent jobs could save more than USD 316,000 annually due solely to reduced power consumption, compared with using 65nm dual-core processors.

Figure 1. Intel IT server test results. Intel internal measurements, September 2007.
Business Challenge

At Intel, as at other large organizations, servers have proliferated but are often underutilized, leading to higher capital, support, maintenance, and power and cooling costs. Intel IT is using server virtualization to substantially reduce these costs by consolidating multiple workloads onto servers based on energy-efficient Intel multi-core processors.

We wanted to determine whether adoption of Intel 45nm process technology could deliver additional benefits by further improving virtualization performance while reducing power consumption. Energy-efficient 45nm quad-core processors include performance-enhancing features such as 12 MB Level 2 cache, compared with a maximum of 8 MB in 65nm processors. To assess 45nm process technology, we ran server tests comparing the 45nm Quad-Core Intel Xeon processor 5400 series with previously introduced processors based on 65nm technology.¹

Test Methodology

We employed a CPU-intensive test database application representative of enterprise applications such as business intelligence and financial forecasting, as well as technical applications such as seismic analysis.

¹ See the IT@Intel brief “Comparing Multi-Core Processors for Server Virtualization” on www.intel.com/it for previous performance test results.

We compared three processors:
- 45nm Quad-Core Intel Xeon processor E5440
- Quad-Core Intel Xeon processor X5355
- Dual-Core Intel Xeon processor S160

We ran all the tests on a single server with a dual-socket motherboard based on the Intel® 5000P chipset, capable of accommodating any of the three processors. To test each different CPU model, we simply swapped in two of the appropriate processors. This approach illustrated the ease of introducing new Intel multi-core processors into an existing IT environment and ensured that any performance differences we observed could be attributed to the processor alone. Configurations are shown in Table 1.

To test each processor, we progressively added workloads, each consisting of a virtual machine (VM) with one copy of the application. Each time we increased the number of VMs, we ran all workloads to completion. We recorded runtime for each workload, as well as server power consumption. We continued adding VMs to each server until the ratio of VMs to processor cores reached 2:1. This resulted in a maximum of 8 VMs for the configuration with two dual-core processors and 16 VMs for the configurations with two quad-core processors.

Our application effectively utilized all the allocated cores in each test, driving CPU utilization to more than 90 percent.

Table 1. Test System Configurations

<table>
<thead>
<tr>
<th>Processor</th>
<th>Clock Speed</th>
<th>Level 2 Cache per Processor</th>
<th>Cores per Processor</th>
<th>Number of Processors</th>
<th>Total Cores</th>
<th>Front Side Bus</th>
<th>Chipset</th>
<th>RAM</th>
<th>RAM per VM</th>
<th>Local Disk Drives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quad-Core Intel® Xeon®</td>
<td>2.83 GHz</td>
<td>12 MB</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>1333 MHz</td>
<td>Intel® 5000P</td>
<td>32 GB</td>
<td>2 GB</td>
<td>8 x 10,000 RPM RAID 10</td>
</tr>
<tr>
<td>Processor E5440</td>
<td>2.66 GHz</td>
<td>8 MB</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>1333 MHz</td>
<td>Intel® 5000P</td>
<td>32 GB</td>
<td>2 GB</td>
<td>142 GB disks RAID 10</td>
</tr>
<tr>
<td>Dual-Core Intel Xeon</td>
<td>3.0 GHz</td>
<td>4 MB</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>1333 MHz</td>
<td>Intel® 5000P</td>
<td>32 GB</td>
<td>2 GB</td>
<td>142 GB disks RAID 10</td>
</tr>
<tr>
<td>Processor S160</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

VM = virtual machine
Results

At all workload levels, the server configured with the 45nm Quad-Core Intel Xeon processor E5440 used considerably less power and completed workloads faster than the same server configured with the Quad-Core Intel Xeon processor X5355, as shown in Table 2 and Figure 1.

With 16 VMs, the server with 45nm quad-core processors used up to 29 percent less power per job than the server with 65nm quad-core processors, and completed each job by as much as 14 percent faster on average.

There were even greater differences in performance and efficiency between the 45nm Quad-Core Intel Xeon processor E5440 and the Dual-Core Intel Xeon processor 5160.

When the server was configured with the 45nm Quad-Core Intel Xeon processor E5440, it consumed slightly less power, at equivalent workload levels, than when configured with the Dual-Core Intel Xeon processor 5160, even though it had twice as many cores.

With a total of eight cores, the server with the 45nm Quad-Core Intel Xeon processor E5440 continued to deliver relatively uniform job completion times as the number of VMs increased to eight. In contrast, job completion times increased more rapidly on the server with the Dual-Core Intel Xeon processor 5160, which had a total of only four cores. As a result, with eight VMs, the 45nm Quad-Core Intel Xeon processor E5440 outperformed the dual-core processor by 43 percent and consumed up to 44 percent less power per job.

Based on our results, we project considerable financial benefits from using the 45nm Quad-Core Intel Xeon processor 5400 series to consolidate and virtualize CPU-intensive workloads. These include substantial savings due to reduced power consumption, as shown in Figure 2.

Our financial model was based on a busy medium-sized data center running 6,000 concurrent jobs in VMs. We made the following assumptions:

- **Consolidation.** A conservative consolidation ratio of 1.5 VMs per core. This translated into a 12:1 ratio for servers based on two quad-core processors and 6:1 for servers based on two dual-core processors.

- **Electricity.** USD 0.08 per kilowatt-hour. We multiplied server power consumption by two to include estimated data center cooling.

- **Capacity.** Data center runs 24x7—90 percent of the time with a VM to core ratio of 1.5:1 and 10 percent of the time with a light load of two VMs.

Using this model, running the workloads on servers based on the 45nm Quad-Core Intel Xeon processor E5440 would result in USD 316,721 annual savings due solely to reduced power consumption.

<table>
<thead>
<tr>
<th>Jobs</th>
<th>Quad-Core Intel® Xeon® Processor E5440</th>
<th>Quad-Core Intel Xeon Processor X5355</th>
<th>Dual-Core Intel Xeon Processor 5160</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Power</td>
<td>Average Runtime</td>
<td>Watt-Min/Job</td>
</tr>
<tr>
<td>2</td>
<td>453</td>
<td>4.40</td>
<td>997</td>
</tr>
<tr>
<td>4</td>
<td>465</td>
<td>4.53</td>
<td>526</td>
</tr>
<tr>
<td>6</td>
<td>480</td>
<td>4.84</td>
<td>387</td>
</tr>
<tr>
<td>8</td>
<td>480</td>
<td>4.89</td>
<td>293</td>
</tr>
<tr>
<td>10</td>
<td>491</td>
<td>6.03</td>
<td>296</td>
</tr>
<tr>
<td>12</td>
<td>491</td>
<td>6.58</td>
<td>269</td>
</tr>
<tr>
<td>14</td>
<td>508</td>
<td>7.57</td>
<td>275</td>
</tr>
<tr>
<td>16</td>
<td>498</td>
<td>8.31</td>
<td>259</td>
</tr>
</tbody>
</table>
consumption compared with using the Dual-Core Intel Xeon processor 5160, and annual savings of USD 61,358 compared with using the Quad-Core Intel Xeon processor X5355.

In addition to these savings, the greater performance of the 45nm Quad-Core Intel Xeon processor E5440 could result in higher consolidation levels than with the Quad-Core Intel Xeon processor X5355, resulting in further power reductions due to the need for fewer servers.

This model does not include many other potential “per-system” savings that could be achieved through consolidation. These include savings due to reduced capital and support costs; storage area network card depreciation; server room area equipment costs such as racks, network switches and routers, backup power supplies, and uninterruptible power supplies (UPSs); network drop and power run costs; and administrative and management costs within the operations center.

An additional advantage was compatibility. With the 45nm Quad-Core Intel Xeon processor E5440 and the Intel 5000P chipset, we were able to upgrade the processor platform by simply swapping in the new processors with no further changes to the server environment. All other hardware and software remained exactly the same from test to test, and we did not even have to reinstall the software. For Intel IT, which has a very rigorous certification procedure for new platforms, this demonstrated compatibility translates into a simplified certification process, smooth integration into our existing data center environment, and lower certification costs. Applications running on the Dual-Core Intel Xeon processor 5100 series and Quad-Core Intel Xeon processor 5300 series platforms ran seamlessly on the new 45nm Quad-Core Intel Xeon processor E5440, delivering enhanced performance and power efficiency without added complexity or compatibility issues.

Our results show that the transition to Intel Xeon processors based on 45nm technology translates directly into increased performance, power savings, and financial benefits for the data center.

Performance tests and ratings are measured using specific computer systems and/or components and reflect the approximate performance of Intel products as measured by those tests. Any difference in system hardware or software design or configuration may affect actual performance. Buyers should consult other sources of information to evaluate the performance of systems or components they are considering purchasing. For more information on performance tests and on the performance of Intel products, visit Intel Performance Benchmark Limitations at www.intel.com/ performance/resources/benchmark_limitations.htm.

Figure 2. Potential annual savings due to reduced power consumption.

Acronyms

UPS = uninterruptible power supply
VM = virtual machine