Analysis of the Influences on Server Power Consumption and Energy Efficiency for CPU-Intensive Workloads

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A typical server …

- has an average utilization between 10% and 50%,
- is provisioned with additional capacity (to deal with load spikes).

Power consumption depends on server utilization.
- Relationship of Performance and Power

- For transactional workloads:

\[
\frac{\text{transactions}}{\text{energy}} \left[ \frac{1}{J} \right] = \frac{\text{throughput}}{\text{power}} \left[ \frac{1}{s/W} \right]
\]

- Comparison of efficiency of different workload types is difficult
  - Different scales of transaction-counts / throughput
  - \( \Rightarrow \) normalization
Black-box models
- Simple
- Fine granular models are workload-dependent [2]

Decomposition into used hardware components [3,4]

What about different workloads targeting the same component?
Contributions

- Measure power consumption and performance for SERT’s 7 CPU worklets
- Explore change of power consumption and energy efficiency depending on load level
- Demonstrate that CPU-workloads can have significantly different power consumption at the same load level
- Explore impact of different hardware and software configurations on the power/load level functions
- Server Efficiency Rating Tool
- Tool for analysis and evaluation of energy efficiency of servers
- Provides focused transactional micro-workloads (called worklets)
  - Exercise selected SUT aspects at multiple load levels
- Tests SUT at multiple load levels
- Calibrates workload intensity for target SUT load levels
- Controller System runs
  - Chauffeur: Director
  - Reporter

- PTDaemon
  - Network-capable power and temperature measurement interface
  - Can run on controller system or separate machine

- System under Test (SUT) runs
  - SERT client, executes worklets
Utilization = \frac{t_{busy}}{t_{busy} + t_{idle}}

DVFS increases CPU busy time at low load
- increases utilization
- Power over load measurements need to compensate

How to compare?

SERT’s solution: Machine utilization
- 100% utilization at maximum throughput
- Load level = \frac{current \, throughput}{max. \, throughput}
- Separate measurement intervals at stable states
  - 15 second pre-measurement run
  - 15 second post-measurement run
  - 120 second measurement

- Temperature analyzer for comparable ambient temperature

- Power Measurements: AC Wall Power
7 CPU worklets:

<table>
<thead>
<tr>
<th>Worklet</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compress</td>
<td>Compresses and decompresses data</td>
</tr>
<tr>
<td>CryptoAES</td>
<td>Encryption and decryption</td>
</tr>
<tr>
<td>LU</td>
<td>Matrix factorization</td>
</tr>
<tr>
<td>SHA 256</td>
<td>Standard Java SHA-256 hashing and encryption/decryption</td>
</tr>
<tr>
<td>SOR</td>
<td>Jacobi Successive Over-Relaxation</td>
</tr>
<tr>
<td>SORT</td>
<td>Sorts a randomized 64-bit integer array</td>
</tr>
<tr>
<td>XMLValidate</td>
<td>Uses javax.xml.validation</td>
</tr>
</tbody>
</table>

Definition CPU Worklet: 100% load level at 100% CPU utilization. CPU is the bottleneck.
Baseline System:
- Tested for varying: CPUs, OS, JVM, ...

Other base systems:
- Fujitsu PRIMERGY RX600S6 (4 Socket, Westmere)
- Fujitsu PRIMERGY RX200S8 (2 Socket, Ivy Bridge)
- Dell PowerEdge R720 (2 Socket, Sandy and Ivy Bridge)
- HP ProLiant DL385p Gen8 (2 Socket, AMD Piledriver)
- **Biggest Consumer:** XMLValidate
  - 126 W @ 10%
  - 431.4 W @ 100%
- **Smallest Consumer:** SOR
  - 118.3 W @ 10%
  - 343.3 W @ 100%

### RHEL6.4_E5-2690_8x8GB Power

![Graph showing power consumption vs load level for different workloads.](image)
Throughput is always linear
Different throughput scales ➔ normalization
Maximum efficiency @ 70% or 80%

RHEL6.4_E5-2690_8x8GB Throughput/Power

RHEL6.4_E5-2690_8x8GB Performance
- Are observations based on 10% measurement intervals accurate?
  - Measurements at 2% measurement intervals
Introduction

SERT

Measurements

Conclusions
- # memory channels has a big impact.

- Big power consumption difference between min and max load is not always a sign of high energy efficiency!
- Xeon E5-2643 system is missing the power consumption increase between 80% - 90%
- Operating system has significant impact on power consumption per load level
  - More complex than simple constant power overhead
- JVM power impact through secondary attributes (such as instruction set support)
Worklet power consumption tops out earlier on Ivy Bridge

<table>
<thead>
<tr>
<th></th>
<th>Xeon E5-2690</th>
<th>Xeon E5-2657v2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Frequency</td>
<td>2.9 GHz</td>
<td>3.3 GHz</td>
</tr>
<tr>
<td>Turbo Frequency</td>
<td>3.8 GHz</td>
<td>4.0 GHz</td>
</tr>
<tr>
<td>TDP</td>
<td>135 W</td>
<td>130 W</td>
</tr>
<tr>
<td>Lithography</td>
<td>32 nm</td>
<td>22 nm</td>
</tr>
</tbody>
</table>
Both systems run Windows Server

<table>
<thead>
<tr>
<th></th>
<th>Opteron 6320</th>
</tr>
</thead>
<tbody>
<tr>
<td># Modules</td>
<td>4</td>
</tr>
<tr>
<td># Cores</td>
<td>8</td>
</tr>
<tr>
<td>Base Frequency</td>
<td>2.8 GHz</td>
</tr>
<tr>
<td>Turbo Frequency</td>
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Power consumption and energy efficiency of SERT’s CPU worklets on different systems

- Varying operating systems, hardware components, architectures...

Some lessons learned:

- Power consumption varies for different CPU worklets and is affected differently by hardware/software changes
- Operating System has significant impact on power consumption per load level
- Load level for maximum energy efficiency depends on hardware and software configuration (usually between 70% - 100%)
- Java Virtual Machine affects power consumption via secondary attributes
Power management must account for varying load levels for optimal energy efficiency.

Power models must account for:
- different workload types utilizing the same resource
- Operating System effects

Need to explore drops in power consumption over rising utilization.
Thanks for listening!

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