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Predicting Energy Consumption by Extending the Palladio Component Model
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Felix Willnecker\textsuperscript{1}, Andreas Brunnert\textsuperscript{1}, Helmut Krcmar\textsuperscript{2}
\textsuperscript{1}fortiss GmbH, \textsuperscript{2}Technische Universität München

fortiss GmbH
An-Institut Technische Universität München
Agenda

• Motivation

• Power Consumption Model
  – Calculation
  – Meta-Model Extension
  – Power Consumption Model Generation

• Evaluation
  – SPECjEnterprise 2010
  – Runtastic for Android

• Conclusion
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Motivation

• Energy Consumption of Information and Communication Technology is growing (Stobbe et al. 2009, Willnecker et al. 2014)
• Optimization on hardware and operating system level cannot compensate rising demand (Gottschalk et al. 2012)
• Investigating the energy efficiency on application level becomes a growing software engineering challenge (Brunnert et al. 2014)
• Main challenges and goals:
  – Reduce operation costs in data centers
  – Increase battery life time of portable devices
  – Ease carbon footprint
Motivation

- Performance metrics and energy consumption rely on the same underlying parameters of resource demand and hardware capabilities.
- Performance simulation and prediction techniques can be used to predict the energy consumption of applications.
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Power Consumption Model

Calculation

\[ P_{pred} = P_{idle,0} + \sum_{1 \leq i \leq n} P_{idle,i} \times u_i \]

- This function is calculated for each resource container or linking resource based on the utilization of the components in this resource container.
- \( P_{pred} \) is the Predicted Power Consumption of a resource container.
- \( P_{idle,0} \) is the Power Consumption function of the resource container in idle state.
- \( P_{idle,i} \) is the Power Consumption factor function of a component in this resource container.
- \( u_i \) is the utilization factor of the component (e.g., CPU utilization, GPS on/off state, throughput).
Power Consumption Model
Meta-Model Extension

![Class diagram for Power Consumption Model]

- **Resource Environment**: Represents the environmental conditions affecting the power consumption.
- **Resource Container**: Centralizes the relationship between resource environments and linked resources.
- **Processing Resource Specification**: Specifies the processing capabilities and their relationship to resource environments.
- **Linking Resource**: Connects resource containers to resource environments, allowing for dynamic linking.
- **Communication Link**: Facilitates communication between resource containers and linked power consumption model components.
- **Linking Power Consumption Component**: Specifies power consumption related to linked resources, including offset and battery capacity.
- **Power Consumption Model Component**: Extends the model with additional factors affecting power consumption.
Power Consumption Model
Meta-Model Extension
Power Consumption Model

Meta-Model Extension
### Power Consumption Model of a server

#### Server in PCM with Power Consumption Model (Brunnert et al. 2014b)

- **P**\(_{\text{pred}}\) = 200 + 300 \(\times\) \(u_{\text{CPU}}\) + 50 \(\times\) \(u_{\text{HDD}}\)
- The energy consumption \(E\) of the system is the integral over \(P_{\text{pred}}\) over the simulation time \(T\):

\[
E = \int_{0}^{T} P(t) \, dt
\]
Power Consumption Model of a mobile device

- **Battery capacity** specified to calculate discharging
- **Stochastic functions** for varying power consumptions
- Added two resource types: **GPS** and **DISPLAY**
- Linking resource power consumption model to calculate energy demand of network traffic based on throughput
Power Consumption Model

Power Consumption Model Generation

• Manually creation based on specifications and estimations
  – Resource Specifications from manufacturer
  – Android Vendor Profiles

• Calibration by stressing resources independently
  – Intelligent Plattform Management Interface
  – Android Calibration App
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Evaluation
SPECjEnterprise 2010

System Under Test (Brunnert et al. 2014b)
Evaluation
SPECjEnterprise 2010

Measured and simulated results for the AMD-based server (Brunnert et al. 2014b)

<table>
<thead>
<tr>
<th>Clients</th>
<th>MMPC(^1)</th>
<th>SMPC(^2)</th>
<th>PCPE(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1300</td>
<td>367.55 W</td>
<td>320.26 W</td>
<td>12.87 %</td>
</tr>
<tr>
<td>2300</td>
<td>403.87 W</td>
<td>352.22 W</td>
<td>12.79 %</td>
</tr>
<tr>
<td>3300</td>
<td>433.76 W</td>
<td>384.52 W</td>
<td>11.35 %</td>
</tr>
<tr>
<td>3500</td>
<td>436.47 W</td>
<td>390.95 W</td>
<td>10.43 %</td>
</tr>
</tbody>
</table>

Measured and simulated results for the Intel-based server (Brunnert et al. 2014b)

<table>
<thead>
<tr>
<th>Clients</th>
<th>MMPC(^1)</th>
<th>SMPC(^2)</th>
<th>PCPE(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1300</td>
<td>197.05 W</td>
<td>175.94 W</td>
<td>10.71 %</td>
</tr>
<tr>
<td>2300</td>
<td>220.47 W</td>
<td>194.93 W</td>
<td>11.58 %</td>
</tr>
<tr>
<td>3300</td>
<td>241.67 W</td>
<td>213.91 W</td>
<td>11.49 %</td>
</tr>
<tr>
<td>4300</td>
<td>264.29 W</td>
<td>232.69 W</td>
<td>11.96 %</td>
</tr>
</tbody>
</table>

\(^1\) Measured Mean Power Consumption
\(^2\) Simulated Mean Power Consumption
\(^3\) Power Consumption Prediction Error
Evaluation
Runtastic for Android

- Nexus 5 running Android 4.4
- Galaxy Tab running Android 4.3
- Runtastic running on both devices 30 mins run

Measured and simulated results for the mobile devices (Leimhofer 2014)

<table>
<thead>
<tr>
<th></th>
<th>Nexus 5</th>
<th>Galaxy Tab</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMPC(^1)</td>
<td>0.883 W</td>
<td>1.251 W</td>
</tr>
<tr>
<td>SMPC(^2)</td>
<td>0.732 W</td>
<td>1.084 W</td>
</tr>
<tr>
<td>PCPE(^3)</td>
<td>17.12 %</td>
<td>13.35 %</td>
</tr>
<tr>
<td>BLPE(^4)</td>
<td>0.67 %</td>
<td>1.01 %</td>
</tr>
</tbody>
</table>

\(^1\) Measured Mean Power Consumption
\(^2\) Simulated Mean Power Consumption
\(^3\) Power Consumption Prediction Error
\(^4\) Battery Level Prediction Error
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Energy consumption can be predicted using the Palladio Component Model with an error of mostly below 13% for server systems and 17.2% for mobile devices.

- Multi-Processor Environments for mobile hard to calibrate
- Extension for other device types (Windows, iOS, etc.)
- Additional resource types (e.g., accelerometer) are necessary for mobile device evaluations
- Power Consumption Model Repository for different devices from different vendors.
- Automatic Performance Model Generation for mobile devices.
Bibliography


Felix Willnecker, Andreas Brunnert
performancegroup@fortiss.org
pmw.fortiss.org