Model-based Performance Evaluation of Large-Scale Smart Metering Architectures

4th International Workshop on Large-Scale Testing (LT) 2015

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Agenda

• Motivation & Vision
• Experiment Design
  – Use Cases
  – Architecture
  – Variant Table
• Simulation Results
• Related Work
• Conclusion & Future Work
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Motivation & Vision

• Smart meter devices supersede conventional energy meters (Zheng et al. 2013)

• Advanced Metering Infrastructures (AMI) and smart grid systems interlink smart meters (Zheng et al. 2014)

• Data analytics need to be performed by smart grid systems in near real-time in order to ensure power grid stability (Illic et al. 2013)

• Since the introduction of smart meters continuously grows, …
  – performance issues can raise quickly.
  – smart grids systems must be able to scale accordingly.
Motivation & Vision

- To support architectural decisions during smart grid system design by using performance models to:
  - evaluate software architectures for different use cases and workloads.
  - plan the required capacity.
  - evaluate scalability characteristics.
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Experiment Design

Use Cases

Read Smart Meters

- EM Operator
- Household
- Send measurement data

Local Optimization

- Service Provider
- EM Operator
- Household
- Send production forecasts
- Send consumption forecasts
- Send schedule

adapted from Irlbeck and Koutsoumpas (2013)
Experiment Design

Architecture

Resources demands
- CPU: Message size \* 0.002 CPU
- HDD: Message size

Algorithm 1

N = 1
- CPU Processing Rate: 1000 ms
- HDD Processing Rate: 146 MBytes/s

Algorithm 2

N = 4
- CPU Processing Rate: 1000 ms
- HDD Processing Rate: 146 MBytes/s
# Experiment Design

## Variant Table

<table>
<thead>
<tr>
<th>Use case</th>
<th>Workload</th>
<th>System architecture</th>
<th>Hardware environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read smart meters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100,000</td>
<td>Centralized</td>
<td></td>
</tr>
<tr>
<td></td>
<td>150,000</td>
<td>Centralized</td>
<td></td>
</tr>
<tr>
<td></td>
<td>200,000</td>
<td>Centralized</td>
<td></td>
</tr>
<tr>
<td></td>
<td>150,000</td>
<td>Decentralized</td>
<td></td>
</tr>
<tr>
<td></td>
<td>200,000</td>
<td>Decentralized</td>
<td></td>
</tr>
<tr>
<td>Local optimization</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>100,000</td>
<td>Centralized</td>
<td>Constant</td>
</tr>
<tr>
<td></td>
<td>150,000</td>
<td>Centralized</td>
<td></td>
</tr>
<tr>
<td></td>
<td>200,000</td>
<td>Centralized</td>
<td></td>
</tr>
<tr>
<td></td>
<td>200,000</td>
<td>Decentralized</td>
<td></td>
</tr>
</tbody>
</table>
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Simulation Results

Throughput for Use Case “Read Smart Meters”

Throughput per day (millions)

Households

Centralized
Decentralized
Simulation Results
Mean CPU utilization for Use Case “Read Smart Meters”

<table>
<thead>
<tr>
<th>Households</th>
<th>Centralized (EM operator)</th>
<th>Decentralized (Mean for each of the four aggregators)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100,000</td>
<td>21.10 %</td>
<td>3.82 %</td>
</tr>
<tr>
<td>150,000</td>
<td>28.73 %</td>
<td>5.37 %</td>
</tr>
<tr>
<td>200,000</td>
<td>34.91 %</td>
<td>6.86 %</td>
</tr>
</tbody>
</table>

- Less IT capacity is required in the decentralized architecture (Overall CPU utilization is lower)
  - Achievable with two-step processing on centralized architecture?
Simulation Results
Response Time Sending Consumption Forecasts for Use Case “Local Optimization”

<table>
<thead>
<tr>
<th>Households</th>
<th>Centralized (EM operator)</th>
<th>Decentralized (Mean for the four aggregators)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100,000</td>
<td>21.62 minutes</td>
<td>5.79 minutes</td>
</tr>
<tr>
<td>150,000</td>
<td>31.98 minutes</td>
<td>6.81 minutes</td>
</tr>
<tr>
<td>200,000</td>
<td>42.34 minutes</td>
<td>7.62 minutes</td>
</tr>
</tbody>
</table>

- Time for optimization (mapping demand and consumption) needs to be fast:
  - e.g., the European Energy Exchange (EEX) adapts prices in 15 minute intervals in the EPEXSPOT Intraday Auction
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Related Work

• Several solutions have been proposed to model AMI and smart grid systems

• Most approaches focus on modeling and evaluating the network e.g.,
  – Mora et al. (2009) modeled the network for smart grids
  – Lin et al. (2011) similarly focused on network communication
  – Wang et al. (2011) discuss several communication architectures and requirements

• A model-based performance evaluation for smart grid systems could not been found in our literature review
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• Conclusion
  – We showed how performance models can be used to model and evaluate scenarios in the smart grid area
  – We implemented two common use cases and simulated them for two different smart metering architectures and large-scale smart meter installations

• We plan to extend our performance models in several ways
  – Adding measured resource demands for analytical algorithms
  – Including reliability as additional aspect in our model-based evaluation
  – Adding additional actors such as the European Energy Exchange (EEX)
  – Simulating multiple use cases in parallel in order to evaluate system scalability and performance characteristics in a greater extent
Discussion

• Request for feedback
  – Are there other/better ways to plan the required capacity in smart grid systems (e.g., using measurement-based techniques)?

• A thought-provoking statement or discussion question about the area
  – Are existing performance modeling techniques scalable enough to evaluate such system-of-systems architectures?
    • We are targeting for simulations of several million households
Thank you for your attention!

Questions?
References


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