Modelling Energy-Aware Task Allocation in Mobile Workflows

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# Rise of the Smart-Devices (Battery Limited)

<table>
<thead>
<tr>
<th>Year</th>
<th>Model(s)</th>
<th>Frequency(s)</th>
<th>Battery Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>Nokia 8310, Ericsson T68</td>
<td></td>
<td>830mAh, 650mAh</td>
</tr>
<tr>
<td>2003</td>
<td>Sony Ericsson P900: 156MHz</td>
<td></td>
<td>1000mAh</td>
</tr>
<tr>
<td>2005</td>
<td>Nokia N91,</td>
<td>220 MHz</td>
<td>900mAh</td>
</tr>
<tr>
<td>2007</td>
<td>Blackberry 8800:</td>
<td>312MHz, 412MHz</td>
<td>1400mAh</td>
</tr>
<tr>
<td></td>
<td>iPhone 1:</td>
<td></td>
<td>1400mAh</td>
</tr>
<tr>
<td>2009</td>
<td>HTC Hero:</td>
<td>528MHz, 600MHz</td>
<td>1350mAh</td>
</tr>
<tr>
<td></td>
<td>Palm Pre:</td>
<td></td>
<td>1150mAh</td>
</tr>
<tr>
<td>2013</td>
<td>Sony Z1: Quad-Core 2.2GHz</td>
<td></td>
<td>3000mAh</td>
</tr>
<tr>
<td></td>
<td>iPhone 5S: Dual-Core 1.5GHz</td>
<td></td>
<td>1560mAh</td>
</tr>
<tr>
<td></td>
<td>(iPad Air)</td>
<td></td>
<td>8820mAh</td>
</tr>
</tbody>
</table>
Battery Management Tools

- **Hardware**
  - Fast Charging
  - Energy-Efficient Processors, Displays
  - New Chemical Compound?

- **Software**
  - Energy Profiling
    - PowerTop, Trepn Profiler, PowerTutor, AppScope, etc.
  - Workload Offload
    - Cuckoo, CloneCloud, MAUI, etc.
Mobile Workflow Example 1

calculate landing point

display

sense action

sense action

sense action
Mobile Workflow Example 2
Energy Model

Given an allocation scheme $\psi: T \rightarrow M$, we first derive the energy cost of computing $t_a, a \in \{1, \ldots n\}$ to be

$$\mathcal{E}_{a\psi(a)}^{cmp} = e_{\psi(a)}^{cmp} \times \frac{c_a}{s_{\psi(a)}} \quad (1)$$

where $\psi(a)$ is the device to which $t_a$ is assigned. Secondly, we have the energy cost of transferring $d_{ab}, (t_a, t_b) \in R$ as

$$\mathcal{E}_{ab\psi(a)\psi(b)}^{tran} = e_{\psi(a)}^{snd} \times \frac{d_{ab}}{b_{\psi(a)\psi(b)}} + e_{\psi(b)}^{rcv} \times \frac{d_{ab}}{b_{\psi(a)\psi(b)}} \quad (2)$$

sender’s cost

receiver’s cost
Formulation

To represent an allocation scheme \( \psi \), we first construct an \( n \times m \) binary matrix \( X = (x_{ai}) \), such that

\[
x_{ai} = \begin{cases} 
1 & \text{if } \psi(a) = i, \\
0 & \text{otherwise.}
\end{cases}
\]  

(3)

We call matrix \( X \) an assignment matrix and a valid assignment must satisfy the following constraints

\[
\sum_{i=1}^{m} x_{ai} = 1, \quad a = 1, 2, \ldots, n,
\]

(4)

\[
x_{ai} \in \{0, 1\}, \quad a = 1, 2, \ldots, n, \quad i = 1, 2, \ldots, m.
\]

(5)
Let coefficients $q_{aibj}$ be the entries of an $mn \times mn$ matrix $Q$, such that $q_{aibj}$ is on row $(i - 1)n + a$ and column $(j - 1)n + b$, and $x = \text{vec}(X) = (x_{11}, x_{12}, \ldots, x_{1n}, x_{21}, \ldots, x_{mn})^T$ be the vector formed from the columns of $X$. Equivalent formulations for the minimum workflow energy cost problem’s objective function are given by (8) and

$$\text{vec}(X)^T Q \text{ vec}(X)$$

(9)
Coefficient Matrix $Q$

$\begin{array}{c}
| \text{------- M Devices -------|} \\
\hline
\text{m}_1 & m_2 & m_3 \\
\hline
m_1 & & \\
\hline
m_2 & & \\
\hline
m_3 & & \\
\hline
\end{array}$

$\begin{array}{cccc}
\text{------- N Tasks -------|} \\
\hline
t_1 & t_2 & t_3 & t_4 \\
\hline
d_{2,3} & & \\
\hline
d_{3,2} & & \\
\hline
\end{array}$

$\begin{array}{cccc}
\text{------- N Tasks -------} \\
\hline
t_1 & t_2 & t_3 & t_4 \\
\hline
\end{array}$
Adjustment Algorithms

(IIAM) Max Utilisation (% battery) 

Guide Utilisation (% battery) 

(GAM) 

- Energy Cap 
- Device Utilisation 
- Over-Utilised 
- Under-Utilised 

M1 M2 M3 M4 M5 M6 

3 1 2 

10
Simulation Definition

Definition 3.
A typical mobile device has a battery capacity of 2000mAh, draws a current of 250-400mA during data transmission and 100-200mA when executing local computation tasks.

Definition 4.
A task has a unit workload if its execution takes 1 second to complete on a typical device.
Simulation Definition (cont.)
Simulation Results

(a) Lower group energy cost and higher run count.  

(b) Sorted run counts  

Fig. 3: Reduction in group energy cost and increase in workflow run count
Fig. 4: Effect of adjustments within the MP.
Summary

- Energy Cost Model
- Formulate Optimisation Problems
- Adjustment Algorithm
- Verified by Simulation
Thank you

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