Services Orchestration at the Edge and in the Cloud on Energy-Aware Precision Beekeeping Systems

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The context of this research – Fighting against Colony Collapse Disorder

- Pesticides
- Varroa destructor mite
- Genetic constraints
- Habitat destruction
- Asian hornet
- Viruses

Domesticated Western honeybee, Bumblebee, Wasp, European hornet, Asian hornet
Goals of this research

• Design a cheap, open source smart beehive

• Provide services to bees and beekeepers

• Collecting and sharing on site data

• Explore autonomous behavior in terms of energy consumption and energy efficient design

• Being frugal at every level (data, energy, ...).
Designing a smart beehive system

• Designed to keep intrusivity low
• Our system base: a Raspberry Pi
• Sensors: temperature, humidity, gas, sound and image
• Energy source: solar panels
• Network: data sent to Cloud servers through Wi-Fi or 4G
• Embedded intelligence on the Edge and on the Cloud: AI models
• Open system, low cost
Designing a smart beehive system
On site deployment

• Focus on urban honeybee beehives

• Deployment of 5 smart beehives
  • 3 in Lyon (France)
  • 2 in Paris (France)

• Open to students projects

• Our system is able of collecting at all time the energy production and consumption data and of collecting apiary data at regular intervals.
Our roadmap

Initially: deploy as much as possible services on the smart beehives (edge)
   -> continuous measurements and data collect
   -> reactivity
   -> autonomous system..etc...

First illustrative focus: AI services -> queen detection

In reality:
   -> energy production is limited, energy budget is limited
   -> battery issues

Data collection cannot work permanently -> On/Off

Must balance between Edge and Cloud servers
Deployment of various services

As an example, use sound data to detect the presence of the queen thanks to energy-managed sound classification algorithms.

Log-spectrogram of a 15-second in-hive audio sample & Dominant sound frequencies of a 15-second in-hive audio sample
AI Models


• Sound classification model using a deep convolutional neural network (ResNet34) to **determine the presence/absence of the queen bee**.
Energy of CNN model execution and its accuracy on the test set as a function of training set’s images’ size

For a 100x100 spectrogram image:
- Energy for CNN scenario: 94.8 Joules
- Accuracy for CNN model: 99%
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Solar production

Progress of solar production over the course of one day
Environmental and energy collected data on one day/week....

Summer 2022

Spring 2022

Ligh gray = night
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Energy measurements of queen detection service

- Raspberry Pi deployment

- Collection of the energy, step by step:
  1. Audio recording
  2. Conversion into spectrogram
  3. Loading AI model
  4. Prediction

Time elapsed: 99.34s
Average power: 536.42mA
Energy consumed: 530.35J
Std Dev. Energy consumed: 185.80mA
Energy differences

![Bar chart showing energy consumption over time](chart.png)

- **Average consumption (W)**: The y-axis represents the average consumption in watts, ranging from 0.0 to 1.2 watts.
- **Minutes between Pi3 wake up**: The x-axis represents the time in minutes between the wake-up of Pi3, with intervals of 5 minutes from 5 to 120 minutes.
Energy costs of AI on Edge

<table>
<thead>
<tr>
<th>Edge Task</th>
<th>Energy of Edge (joules)</th>
<th>Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scenario: Edge (SVM)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep</td>
<td>111.6</td>
<td>178.5</td>
</tr>
<tr>
<td>Wake up &amp; Data collection</td>
<td>131.8</td>
<td>64.0</td>
</tr>
<tr>
<td>Queen detection model (SVM)</td>
<td>98.9</td>
<td>46.1</td>
</tr>
<tr>
<td>Send results</td>
<td>3.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Shutdown</td>
<td>21.0</td>
<td>9.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>366.3 joules</strong></td>
<td><strong>300 seconds</strong></td>
</tr>
</tbody>
</table>

| **Scenario: Edge (CNN)**               |                         |                |
| Sleep                                  | 116.9                   | 187.0          |
| Wake up & Data collection              | 131.8                   | 64.0           |
| Queen detection model (CNN)            | 94.8                    | 37.6           |
| Send results                           | 3.0                     | 1.5            |
| Shutdown                               | 21.0                    | 9.9            |
| **Total**                              | **367.5 joules**        | **300 seconds**|

SVM : Support Vector Machine
CNN : Convolutional Neural Network
Our roadmap

Initially: deploy as much as possible services on the smart beehives (edge)
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  -> energy production is limited, energy budget is limited
  -> battery issues

Data collection cannot work permanently -> On/Off

Must balance between Edge and Cloud servers
Energy cycles with Edge+Cloud support
## Energy costs of AI on Edge + Cloud

<table>
<thead>
<tr>
<th>Edge Task</th>
<th>Energy of Edge (joules)</th>
<th>Cloud Server Task</th>
<th>Energy of Cloud Server (joules)</th>
<th>Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep</td>
<td>131.9</td>
<td>Idle</td>
<td>9415</td>
<td>211.1</td>
</tr>
<tr>
<td>Wake up &amp; Data collection</td>
<td>131.8</td>
<td>Idle</td>
<td>2854</td>
<td>64.0</td>
</tr>
<tr>
<td>Send audio</td>
<td>37.3</td>
<td>Receive audio</td>
<td>1032</td>
<td>15.0</td>
</tr>
<tr>
<td>Shutdown</td>
<td>0.2</td>
<td>Queen detection model (SVM)</td>
<td>6.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Shutdown</td>
<td>20.8</td>
<td>Idle</td>
<td>437</td>
<td>9.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>322.0 joules</strong></td>
<td></td>
<td><strong>13744.3 joules</strong></td>
<td>300 seconds</td>
</tr>
</tbody>
</table>

**Scenario: Edge+Cloud (SVM)**

| Sleep                      | 131.9                   | Idle                               | 9415                           | 211.1          |
| Wake up & Data collection  | 131.8                   | Idle                               | 2854                           | 64.0           |
| Send audio                 | 37.3                    | Receive audio                      | 1032                           | 15.0           |
| Shutdown                   | 2.1                     | Queen detection model (CNN)        | 108                            | 1.0            |
| Shutdown                   | 18.9                    | Idle                               | 397                            | 8.9            |
| **Total**                  | **322.0 joules**         |                                    | **13806 joules**                | 300 seconds    |
Results in ideal theoretical scenario

The server’s overall energy consumption per client converges towards 116 joules (energy when all server’s time slots are full).

The smart beehive case brings the overall best cost per beehive (shown in blue) to $116 + 322 = 438$ joules.

Edge wake-up frequency: 5 minutes - Number of clients allowed in parallel in time slots: 10
Benefits of cloud server? End2End energy costs

Number of clients allowed in parallel: 10 per time slot
Number of clients allowed in parallel: 35 per time slot

406 clients needed for edge+cloud scenario more energy-efficient
Maximum difference edge+cloud scenario is 12.5 joules at 630 clients
Above 803 clients, the edge+cloud scenario is more energy-efficient than the edge scenario.
Comparing loss of clients and cloud servers

Exploring scenario of loss: example of loss of clients at every wake-up time. A random Gaussian distribution (mean: 10% of the total number of clients; standard deviation: 2) is used to draw the number of lost clients.
End2End energy

Comparison of end-to-end energy per client for the two scenarios with different server settings and with loss. Number of clients allowed in parallel in time slots: 35.

Compared to ideal scenario, Cloud benefit is not always the case.
Conclusion & Future works

• When energy budget is so limited - hunting the joules is mandatory
• Cloud infrastructures become relevant when number of connected beehives increase (but not always) – hypothesis : same service
• Sharing data collection and datasets : https://zenodo.org/record/7880085#.ZGdeL9bP1Yg

• Yet to come:
  • Take into account of smart beehive + cloud servers full cycle and not only energy considerations
  • Large scale emulation of all beehives in France (around 2 Millions) -&gt; optimizing services to beekeepers and bees

• More to read
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Questions?