IoT Challenge #2

Energy Analysis

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March 2025

Contents

1 EQ1 - Energy Consumption Evaluation

To compute the total energy consumed by the battery-powered devices (sensor and valve) over a period of 24 hours, we considered the most energy-efficient configurations for both CoAP and MQTT protocols:

- **CoAP:** we used the *observer pattern* with *Non-confirmable* messages and no QoS.
- **MQTT:** we used QoS level 0, which is the least energy-consuming configuration.

Assuming the following parameters:

- Transmission energy cost: $ETX = 50$ nJ/bit
- Reception energy cost: $ERX = 58$ nJ/bit
- Computation cost per average temperature: $E_c = 2.4$ mJ

The sensor transmits one message every 5 minutes: 288 transmissions per day. The valve receives 288 readings and performs 48 computations per day.

1.1 CoAP Configuration

Message sizes:

- PUT request (notify): 55 B
- GET response (observation): 55 B
- Registration GET request: 60 B

Energy calculations:

- Sensor: Notify Transmission Energy $= 55 \times 8 \times ETX = 0.022mJ$
  $RegistrationTransmissionEnergy = 60 \times 8 \times ETX = 0.024mJ$
  $TotalSensorEnergy = 0.024 + 288 \times 0.022 = \mathbf{6.36}mJ$
- Valve: Observation Reception Energy $= 55 \times 8 \times ERX = 0.02552mJ$
  $RegistrationTransmissionEnergy = 60 \times 8 \times ETX = 0.024mJ$
  $TotalValveEnergy = 0.024 + 288 \times 0.02552 + 48 \times 2.4 = \mathbf{122.57}mJ$

Total CoAP Energy: $128.93mJ$

1.2 MQTT Configuration

Message sizes:

- Connect/ConnAck: 54 B / 47 B
- Subscribe/SubAck: 68 B / 52 B
- Publish: 68 B

Energy calculations:

- Sensor: Connect + ConnAck Energy = $(54\ \times 8 \times ETX) + (47 \times 8 \times ERX) = 0.0216 + 0.0218 mJ$
  $PublishEnergyperreading = 68 \times 8 \times ETX = 0.0272 mJ$
  $TotalSensorEnergy = 0.0434 + 288 \times 0.0272 = \mathbf{7.87} mJ$
- Valve: Connect + ConnAck Energy = 0.0434 mJ
  Subscribe + SubAck Energy = $(68\ \times 8 \times ERX) + (52 \times 8 \times ETX) = 0.0316 + 0.0208 mJ$
  $ReceptionofPublish = 68 \times 8 \times ERX = 0.0316 mJ$
  $TotalValveEnergy = 0.0434{+}0.0316{+}0.0208{+}288{\times}0.0316{+}48{\times}2.4 = \mathbf{124.38} mJ$

Total MQTT Energy: $132.26 mJ$

2 EQ2 - Energy Consumption Optimization

2.1 Changing Communication Protocol

To reduce the energy consumption of the battery-powered devices, we adopted an optimization strategy by switching from MQTT to **MQTT-SN** in order to minimize overhead in each message header.

2.1.1 Energy Calculation with MQTT-SN

Message sizes:

- Connect/ConnAck: 6 B / 3 B
- Subscribe/SubAck: 6 B / 5 B
- Publish: 15 B

Energy calculations:

- Sensor: Total Sensor Energy $= 6 \times 8 \times ETX + 3 \times 8 \times ERX + 288 \times (15 \times 8 \times ETX)$
$= 0.0048 + 0.0014 + 288 \times 0.006 = \mathbf{1.73mJ}$
- Valve: Total Valve Energy $= 6 \times 8 \times ETX + 3 \times 8 \times ERX + 6 \times 8 \times ERX + 5 \times 8 \times ETX$
$+ 288 \times (15 \times 8 \times ERX) + 48 \times 2.4$
$= 0.0048 + 0.0014 + 0.0035 + 0.004 + 288 \times 0.00696 + 115.2$
$= \mathbf{117.22mJ}$

Total Energy with MQTT-SN: $118.95mJ$

2.1.2 Estimated Energy Saving

Compared to the standard MQTT configuration:

$$EnergyConsumption(MQTT) = 132.26mJ,$$

$$EnergyConsumption(MQTT - SN) = 118.95mJ$$

This results in an approximate saving of:

$$13.31mJ \quad (\approx 10\% reduction)$$

This shows that using MQTT-SN can lead to significant energy savings in constrained IoT environments due to its compact and optimized packet structure.

2.2 Alternative Optimization Strategy

Another effective way to reduce energy consumption is by adjusting the sampling frequency of the temperature sensor and the computation frequency of the valve. For example, if the sensor transmits data less frequently (e.g., every 10 or 30 minutes), the total number of transmitted and received messages is reduced, leading to lower energy consumption. Similarly, reducing the computation rate of the valve lowers the number of high-cost processing operations.

The following plots illustrate how energy consumption varies with these frequencies:

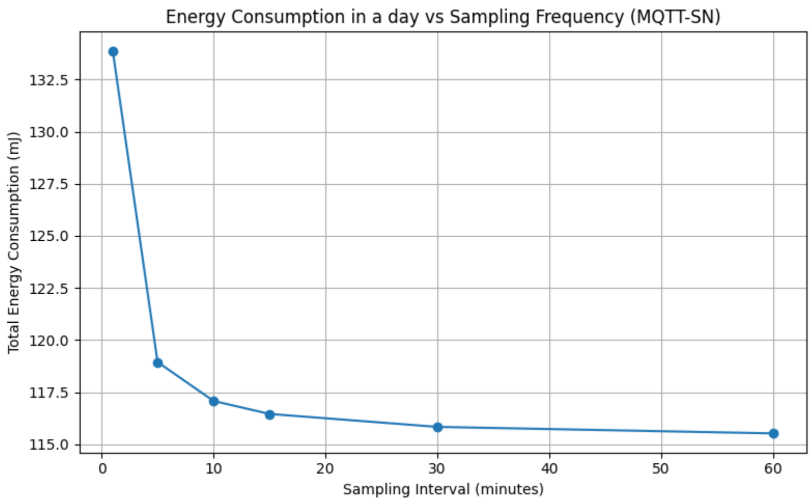

Figure 1: Total energy consumed per day with varying sensor sampling intervals (MQTT-SN).

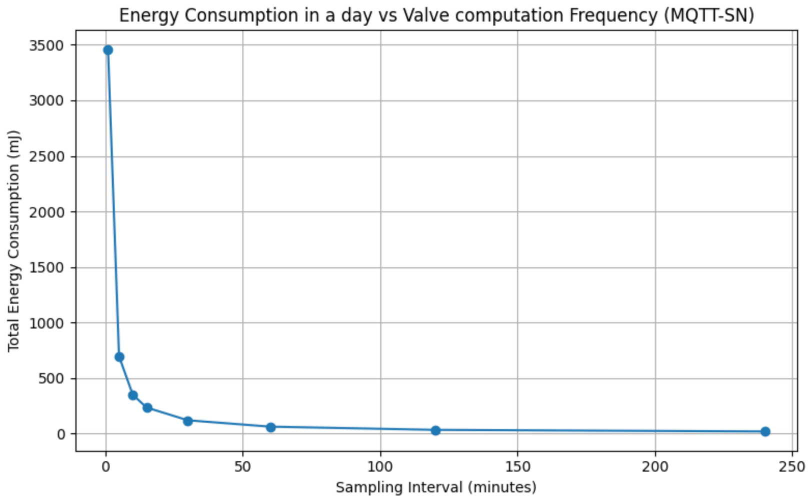

Figure 2: Total energy consumed per day with varying valve computation intervals (MQTT-SN).

E.g. in our consideration, for optimality, we took a sampling frequency of 15 minutes, with a total consumption of **116.15 mJ**. For the computational frequency we took 60 minutes with a total consumption of **61 mJ**

As shown, increasing the interval (i.e., reducing frequency) leads to a noticeable decrease in total energy consumption. These trade-offs must be evaluated based on the specific requirements for data freshness and system responsiveness.