Exercise

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1 Question 1

Compute the total energy consumed by the two battery-powered devices over a period of 24 hours in both cases when using COAP (a) and MQTT (b), using each in its most efficient configuration energy-wise.

1.1 Question 1: Case A CoAP

For minimizing energy consumption, CoAP is more efficient when using Observe mode, which allows the temperature sensor to send updates without requiring frequent GET requests from the valve.

Initially, the valve sends a GET Request with the Observe option to the sensor, in order to register to the topic, and the sensor responds with the current temperature and confirms the observation.

For the initial setup we have:

- Size of GET Request from the valve to the sensor: $L_{GETReq} = 60B$
- Size of GET Response from the sensor to the valve: $L_{GETRes} = 55B$

Then, the sensor sends new GET Response every 5 minutes to the valve with the updated temperature. The periodic temperature updates are GET Response (Observe Notification) with size $L_{GETRes} = 55B$.
Since the sensor sends an update to the valve every 5 minutes, we have in total 12 updates per 1 hour. Thus, for 24 hours we have $N_{sensor} = 24\ hours \cdot 12\ updates = 288\ updates\ per\ day$.
Since the valve computes the average temperature every 30 minutes, we have 2 measures in 1 hour. Thus, for 24 hours we have $N_{valve} = 24\ hours \cdot 2\ measures = 48\ measures\ per\ day$.

The total energy consumption per day for each battery-powered device is:

- **Sensor Energy Consumption**:

$$E_{sensor} = E_{RX} \cdot L_{GETReq} \cdot 8 \text{ bit} + N_{sensor} \cdot L_{GETRes} \cdot 8 \text{ bit} \cdot E_{TX}$$

- **Valve Energy Consumption**:

$$E_{valve} = E_{TX} \cdot L_{GETReq} \cdot 8 \text{ bit} + N_{sensor} \cdot L_{GETRes} \cdot 8 \text{ bit} \cdot E_{RX} + N_{valve} \cdot E_c$$

Where E_{TX}, E_{RX}, E_c are the energy for transmission, energy for reception and energy for computation, respectively, given by the requirements.
The results are:

$$E_{sensor} = 58 \text{ nJ/bit} \cdot 60 \cdot 8 \text{ bit} + 288 \cdot 55 \cdot 8 \text{ bit} \cdot 50 \text{ nJ/bit} = 6.364 \text{ mJ}$$

$$E_{valve} = 50 \text{ nJ/bit} \cdot 60 \cdot 8 \text{ bit} + 288 \cdot 55 \cdot 8 \text{ bit} \cdot 58 \text{ nJ/bit} + 48 \cdot 2.4 \text{ mJ} = 122.574 \text{ mJ}$$

The total energy consumption by sensor and valve together is:

$$E_{tot,CoAP} = E_{sensor} + E_{valve} = 6.364 \text{ mJ} + 122.574 \text{ mJ} = 128.94 \text{ mJ}$$

1.2 Question 1: Case B MQTT

MQTT requires a Publish-Subscribe mechanism, so both the sensor and the valve must communicate through the Raspberry Pi (the broker).

Initially, both the valve and the sensor need to connect to the Raspberry Pi, indeed both exchange CONNECT and CONNACK messages with the broker. The valve needs to subscribe to the topic, thus it exchanges SUBSCRIBE and SUBACK messages with the broker. It receives every 5 minutes PUBLISH messages from the sensor through the broker, and then calculates the average temperature.
The sensor every 5 minutes sends a PUBLISH message to the broker with QoS "At most once", i.e. 0, because the requirements state to find the most efficient energy configuration.

The total energy consumption per day for each battery-powered device is:

- **Sensor Energy Consumption**:

$$\begin{aligned} E_{\text{sensor}} = {} & L_{\text{Connect}} \cdot 8 \text{ bit} \cdot E_{\text{TX}} + L_{\text{ConnAck}} \cdot 8 \text{ bit} \cdot E_{\text{RX}} \\ & + N_{\text{sensor}} \cdot L_{\text{Publish}} \cdot 8 \text{ bit} \cdot E_{\text{TX}} \end{aligned}$$

- **Valve Energy Consumption**:

$$\begin{aligned} E_{\text{valve}} = {} & L_{\text{Connect}} \cdot 8 \text{ bit} \cdot E_{\text{TX}} + L_{\text{ConnAck}} \cdot 8 \text{ bit} \cdot E_{\text{RX}} \\ & + L_{\text{Subscribe}} \cdot 8 \text{ bit} \cdot E_{\text{TX}} + L_{\text{SubAck}} \cdot 8 \text{ bit} \cdot E_{\text{RX}} \\ & + N_{\text{sensor}} \cdot L_{\text{Publish}} \cdot 8 \text{ bit} \cdot E_{\text{RX}} + N_{\text{valve}} \cdot E_c \end{aligned}$$

Where E_{TX}, E_{RX}, E_c are the energy for transmission, energy for reception and energy for computation, respectively, given by the requirements, and N_{sensor}, N_{valve} are the previous computed results.
The obtained results are:

$$\begin{aligned} E_{\text{sensor}} & = 54 \cdot 8 \text{ bit} \cdot 50 \text{ nJ/bit} + 47 \cdot 8 \text{ bit} \cdot 58 \text{ nJ/bit} \\ & \quad + 288 \cdot 68 \cdot 8 \text{ bit} \cdot 50 \text{ nJ/bit} \\ & = 7.877 \text{ mJ} \end{aligned}$$

$$
\begin{aligned}
E_{\text{valve}} &= 54 \cdot 8 \text{ bit} \cdot 50 \text{ nJ/bit} + 47 \cdot 8 \text{ bit} \cdot 58 \text{ nJ/bit} \\
&\quad + 58 \cdot 8 \text{ bit} \cdot 50 \text{ nJ/bit} + 52 \cdot 8 \text{ bit} \cdot 58 \text{ nJ/bit} \\
&\quad + 288 \cdot 68 \cdot 8 \text{ bit} \cdot 58 \text{ nJ/bit} + 48 \cdot 2.4 \text{ mJ} \\
&= 124.378 \text{ mJ}
\end{aligned}
$$

The total energy consumption by sensor and valve together is:

$$E_{tot,MQTT} = E_{sensor} + E_{valve} = 7.877 \text{ mJ} + 124.378 \text{ mJ} = 132.25 \text{ mJ}$$

2 Question 2

2.1 First Solution

The first solution aims to reduce the number of PUBLISH messages sent from the broker to the valve. Since the valve computes the average temperature every 30 minutes, the broker can collect the 6 updates from the sensor (30 minutes/5 minutes) and then sends to the valve one PUBLISH message with the aggregated updates. Then, the valve recieves the "batch" of 6 temperature updates and compute the average. This eliminates the need for the broker to forward each individual PUBLISH message, reducing communication overhead.

The energy consumption of the sensor remains the same as before:

$$E_{\text{sensor}} = 7.877 \text{ mJ}$$

While the energy consumption of the valve would change since the broker only forwards 48 messages (one per 30 minutes) to the valve instead of 288, reducing the valve's receiving workload significantly:

$$
\begin{aligned}
E_{\text{valve}} &= 54 \cdot 8 \text{ bit} \cdot 50 \text{ nJ/bit} + 47 \cdot 8 \text{ bit} \cdot 58 \text{ nJ/bit} \\
&\quad + 58 \cdot 8 \text{ bit} \cdot 50 \text{ nJ/bit} + 52 \cdot 8 \text{ bit} \cdot 58 \text{ nJ/bit} \\
&\quad + \mathbf{48} \cdot 68 \cdot 8 \text{ bit} \cdot 58 \text{ nJ/bit} + 48 \cdot 2.4 \text{ mJ} \\
&= 86.77 \text{ mJ}
\end{aligned}
$$

The total energy consumption of the two devices would be:

$$E_{tot,1} = E_{sensor} + E_{valve} = 7.877 \text{ mJ} + 86.77 \text{ mJ} = 94.647 \text{ mJ}$$

For this proposed solution, we would have about 28.4% energy saving compared to the case of Question 1 using MQTT.

2.2 Second Solution

The second solution is simpler and it is about sending the sensor updates with a lower frequency by incrementing the time between each update. For example, we can send the temperature updates every 15 minutes instead of 5 minutes, this would reduce the number of messages sent and received, thus the total

energy consumption. In this case, by considering that in 1 hour we would have 4 updates, in 24 hours we would have 96 updates (compared to the previous 288 updates).
In the previous formulas we would replace N_{sensor} with 96.
The total energy consumption per day for each battery-powered device would be:

$$\begin{aligned} E_{\text{sensor}} &= 54 \cdot 8 \text{ bit} \cdot 50 \text{ nJ/bit} + 47 \cdot 8 \text{ bit} \cdot 58 \text{ nJ/bit} \\ &\quad + \mathbf{96} \cdot 68 \cdot 8 \text{ bit} \cdot 50 \text{ nJ/bit} \\ &= 7.137 \text{ mJ} \end{aligned}$$

$$\begin{aligned} E_{\text{valve}} &= 54 \cdot 8 \text{ bit} \cdot 50 \text{ nJ/bit} + 47 \cdot 8 \text{ bit} \cdot 58 \text{ nJ/bit} \\ &\quad + 58 \cdot 8 \text{ bit} \cdot 50 \text{ nJ/bit} + 52 \cdot 8 \text{ bit} \cdot 58 \text{ nJ/bit} \\ &\quad + \mathbf{96} \cdot 68 \cdot 8 \text{ bit} \cdot 58 \text{ nJ/bit} + 48 \cdot 2.4 \text{ mJ} \\ &= 109.63 \text{ mJ} \end{aligned}$$

The total energy consumption of the two devices would be:

$$E_{tot,2} = E_{sensor} + E_{valve} = 7.137 \text{ mJ} + 109.63 \text{ mJ} = 116.767 \text{ mJ}$$

For this proposed solution, we would have a reduction of about 11.7% of the energy consumption compared to the second case of Question 1 using MQTT.