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Internet of Things Exercise

Part 2 – Exercise Questions

Some data and assumptions are given for the whole exercise:

- For both the sensor and valve, the transmit and receive energy cost per bit are:
  - E_{TX} = 50nJ/bit and E_{RX} = 58nJ/bit.
- The processing cost on the valve to compute the average temperature every 30 minutes is E_C = 2.4mJ.
- The Wi-Fi network is ideal, so we assume no losses.
- The sensor and valve start in power-off state.

We can also simply calculate number of transmissions and computations are necessary each day:

- The temperature sensor transmits data every 5 minutes: $\frac{24\times 60}{5} = 288$ transmissions per day.
- The valve computes the average temperature every 30 minutes: $\frac{24\times 60}{30} = 48$ computations per day.

EQ1a – CoAP

The following sequence of CoAP messages and events occur when using CoAP in its most efficient configuration energy-wise for the communication between the sensor and valve:

1. **Valve → Sensor (GET request)**: The valve sends non-confirmable GET request with observe, such that it receives a new GET response every 5 minutes, without having to send new GET requests. The message size for a GET request is given as 60 bytes = 480 bits. Energy used for each of these transmissions are:

$$E_{\text{TX, Valve}} = 480 \times 50 = 24.0\mu J$$

$$E_{\text{RX, Sensor}} = 480 \times 58 = 27.8\mu J$$

2. **Sensor → Valve (GET response)**: Sensor The valve sends a GET response back every 5 minutes. The message size for a GET response is given as 55 bytes = 440 bits. Energy used for each of these transmissions are:

$$E_{\text{TX, Sensor}} = 464 \times 50 = 22.0\mu J$$

$$E_{\text{RX, Valve}} = 464 \times 58 = 25.5\mu J$$

3. **Valve (computation)**: Valve computes the average temperature every 30 minutes. Energy use for this is:

$$E_{\mathrm{C}} = 2.4mJ$$

Total transmission energy consumption per day (288 transmissions) by both sensor and valve:

$$\mathrm{E}_{\text{Transmission, Day}} = 24.0 + 27.8 + (22.0 + 25.5) \times 288 = 13.73\mathrm{mJ}$$

Total valve processing energy consumption per day:

$$\mathrm{E}_{\text{C, Day}} = 2.4 \times 48 = 115.2\mathrm{mJ}$$

Which means the total energy consumption of the two battery-powered devices over a period of 24 hours when using CoAP for message communication is:

$$E_{\mathrm{Day}} = 13.73 + 115.2 = 128.93mJ$$

using its most efficient configuration energy-wise, and assuming ideal Wi-Fi network with no losses and that the sensor and valve start in power-off state.

Answer EQ1a: 128.93mJ

EQ1b – MQTT

When using MQTT as the communication protocol, we assume that the keep-alive field is 0, such that neither the sensor nor broker need to send “Ping Req” or “Ping Res” to the broker to maintain the MQTT connection, to save battery. The following sequence of MQTT messages and events occur when using MQTT in its most efficient configuration energy-wise for the communication between the sensor and valve:

1. **Valve + Sensor → Broker (MQTT Connect)**: Both the valve and sensor must send an MQTT Connect message to the broker to initiate the MQTT connection. The message size for MQTT Connect is given as 54 bytes = 432 bits. Energy consumption used by each valve and sensor for transmitting the MQTT Connect Ack is:

$$E_{\text{TX, Connect}} = 432 \times 50 = 21.6\mu J$$

2. **Broker → Valve + Sensor (MQTT Connect Ack)**: The broker must send an MQTT Connect Acknowledgement back to both the valve and sensor, which is mandatory in MQTT. The message size for MQTT Connect Ack is given as 47 bytes = 376 bits Energy consumption used by each valve and sensor for receiving the MQTT Connect Ack is:

$$E_{\text{RX, ConnectAck}} = 376 \times 58 = 21.8\mu J$$

3. **Valve → MQTT Broker (MQTT Subscribe)**: The valve subscribes to the broker on the topic, using MQTT Subscribe message. The message size for MQTT Subscribe is given as 58 bytes = 464 bits. Energy consumption used by the valve when transmitting an MQTT Subscribe message is:

$$E_{\text{TX, Valve}} = 464 \times 50 = 23.2\mu J$$

4. **Valve → MQTT Broker (MQTT Sub Ack)**: MQTT Subscribe Acknowledgement is mandatory. The message size for MQTT Sub Ack is given as 52 bytes = 416 bits. Energy consumption used by the valve when receiving an MQTT Sub Ack message is:

$$E_{\text{RX, Valve}} = 416 \times 58 = 24.1\mu J$$

5. **Sensor → MQTT Broker (MQTT Publish)**: The sensor publishes temperature data every 5 minutes on the given topic, using the MQTT Publish message with QoS=0 (at most once). Because we assume ideal Wi-Fi network with no losses this is fine. No acknowledgement messages (ACKs) when using QoS. The message size for MQTT Publish is given as 68 bytes = 544 bits. Energy consumption used by the sensor when transmitting an MQTT Publish message is:

$$E_{\text{TX, Sensor}} = 544 \times 50 = 27.2\mu J$$

6. **MQTT Broker → Valve (MQTT Publish)**: When the MQTT broker receives Publish messages, it sends it to the subscribers of the topic, which is the valve in our case. Energy consumption used by the valve when receiving an MQTT Publish message is:

$$E_{\text{RX, Valve}} = 544 \times 58 = 31.6\mu J$$

7. **Valve (computation)**: As in EQ1a, the valve computes the average temperature every 30 minutes, 48 times a day.

$$E_{\text{C}} = 2.4mJ$$

Total transmission energy consumption per day (288 transmissions) by both sensor and valve:

$$E_{\text{Transmission, Day}} = (21.6 + 21.8) \times 2 + 23.2 + 24.1 + (27.2 + 31.6) \times 288 = 17.07\text{mJ}$$

Total valve processing energy consumption per day is the same as in EQ1a:

$$E_{\text{C, Day}} = 2.4 \times 48 = 115.2mJ$$

Which means the total energy consumption of the two battery-powered devices over a period of 24 hours when using MQTT for message communication is:

$$E_{\text{Day}} = 17.07 + 115.2 = 132.27mJ$$

Answer EQ1b: 132.27mJ

EQ2

Ways to decrease the energy consumption:

1. **Calculate average at Broker (Raspberry Pi)**: A solution to decrease the energy consumption is to compute the average temperate on the power supplied Raspberry Pi working as MQTT broker, instead of computing the average at the battery-powered valve, as we have observed that the computation takes a big percentage of the energy consumption per day of the two battery-powered devices.
2. **Send 1 message with average temperature to valve every 30 min**: When the average temperature is calculated by the broker, it is possible to further optimize the system by sending only one message to the valve from the broker every 30 min containing the computed average temperature, instead of sending six messages (every 5 min).

Precomputation of the energy under our proposed configuration:

- Step 1-4 of task EQ1b remains the same, as MQTT Connect and Subscribe messages with Acks are still needed.
- Step 5 remains the same as the sensor still sends the temperature to the broker every 5 minutes.
- Step 6, sending the publish message from the broker to the valve, is now only performed every 30 minutes (48 times a day).
- Step 7, valve computation, is completely removed from the calculation.

Thus, we well be able to calculate the energy consumptions used in the transmissions by both the battery-powered devices, which is now also the **reduced total energy consumption over 24 hours**:

$$E_{\text{Day}} = (21.6 + 21.8) \times 2 + 23.2 + 24.1 + 27.2 \times 288 + 31.6 \times 48 = 9.48mJ$$

This is a 92.8% reduction from the calculations in EQ1b.

Answer EQ2: 9.48mJ