ENGR 5720G Pervasive & Mobile Computing: Assignment 1 - Group 6

Group Members: David Abiola - 100974509, Chao Meng - 100997810, Suhas Sunder - 100548159

Q1 – Paper Objective (15 pts)

The objective of this paper is to analyze and explore the design of wireless sensor networks (WSN) intended to monitor temperature fluctuations in vineyards, with a strong emphasis on strategies for energy management (EM) and minimizing energy consumption [1].

- The authors explore EM strategies at both the hardware/OS level and, more significantly, at the application layer to extend the network's operational lifetime [1].
- Present findings based on testing and validation of new strategies for energy management using WSN [1].
- They also investigate and explain the potential reasoning behind discrepancies between the predicted and actual lifespans of sensor nodes when deployed in a networked environment [1].
- Additionally, the paper aims to provide insights on the potential pitfalls of this new design, as well as ideas for future improvements in terms of energy management [1].

Q2 – Interpretation of Table 1 (Energy Budget) (15 pts)

Table 1 showcases a breakdown of the duty cycles and current consumption metrics with respect to crucial components of an IRIS wireless sensor mote. It establishes a baseline for evaluating energy strategies, highlighting how low-duty-cycle designs drastically extend node lifespan via strategically lowered energy consumption. The average energy consumption is quantified in milliamp-hours (mA-hr), with the assumption that the system will be active for only 1% of the duty cycle, and in sleep mode for the remaining 99% [1].

- The microcontroller consumes approximately 6 mA during the active phase, but shifts to sleep mode when no tasks are scheduled, reducing energy consumption to a conservative 8 μA [1].
- The radio transceiver is the most power-hungry component, typically listening for 3 seconds and transmitting for 1. It draws 8 mA when listening, 12 mA when transmitting, and just 2 μA in sleep mode [1].

- The logger and sensor board have similar on/off gaps (4–15 mA vs 2–5 μA).
- Without duty cycling, the system would continuously draw about 24 mA, rapidly depleting battery reserves in under four days.
- With a 1% duty cycle, average current consumption falls to 0.217 mA-hr, extending battery life to 384 days compared to 3.47 days without power management [1].

Q3 – Why Current Still Flows in MCU Sleep Mode (15 pts)

There are several reasons why current is drawn even when the MCU is in sleep mode, which is not a complete power-off state but designed for minimal power usage while preserving essential functions [1]. Minimal power is required to retain data in memory, internal state, and scheduled events, including:

1. *Wake-up timers and clocks:* stay active to enable timed operations [1].
2. *Sensors and peripherals:* remain partially powered for readiness or polling. For example, watchdog and brown-out detectors need to remain on at all times for active monitoring [1].
3. *RAM and registers:* such as SRAM require a small leakage current to retain memory and preserve program state [1].
4. *Custom sensor interfaces and voltage boosters:* introduce additional leakage paths, drawing micro-amp level current [1].
5. *Low Power Listening (LPL) mechanism:* periodically wakes the radio transceiver even during sleep intervals, contributing to current consumption.
6. The cumulative effect of these factors is that, even in sleep, the mote draws a measurable current (e.g., 8 μA for the microcontroller and 2 μA for the radio) as shown in Table 1 [1].
7. This design ensures the node can quickly resume normal operation without full reinitialization, balancing low energy use with responsiveness [1].

Q4 – What is Low-Power Listening (LPL)? Compare with Sleep Mode (20 pts)

Medium Access Control (MAC) is a protocol layer that supports Low Power Listening (LPL), a technique designed to minimize energy consumption by carefully managing the duration that sensor nodes spend actively listening for transmissions in wireless sensor networks [2][3].

LPL is a MAC-layer technique where a node sleeps most of the time but periodically wakes to check for activity on the channel. Senders prepend a preamble message long enough to overlap a receiver's wake slot, guaranteeing delivery without time-sync. This approach eliminates the need for global clock synchronization among nodes, simplifying implementation compared to Time Division Multiple Access (TDMA) [1][2][3].

Thus, LPL offers a trade-off: modest extra idle power (0.102 mA-h per 5 min per Table 3) buys us asynchronous connectivity, whereas pure sleep would break multihop routing [1][2][3].

LPL has certain pitfalls such as vulnerability to false wakeups caused by environmental noise misinterpretation, causing unwanted energy consumption due to an increase in the node's duty cycle. Additionally, long preamble messages are likely to result in increased energy consumption due to the longer transmission time [3].

Q5 – Sensor-Node Steps during a Reading Cycle (non-root) (15 pts)

Step 1: Timer fires (every 5 min); task queued [1].

- Purpose: This is the trigger scheduled for data acquisition.

Step 2: Enable sensor excitation (turn on 5.8 V booster); wait 200 ms warm-up [1].

- Purpose: This process will power up LM135 sensors to ensure accurate temperature readings.

Step 3: Start ADC; sequentially sample four LM135 sensors via MDA300 HAL (avoids redundant warm-ups) [1].

- Purpose: Each reading is performed one after another because concurrent sampling isn't supported by the driver.

Step 4: Package readings into a CTP data packet with metadata (node ID, battery voltage) [1].

- Purpose: To ensure sensor readings are encapsulated in a format that can be reliably transmitted.

Step 5: Transmit to parent; radio also forwards any in-transit packets from children. This behavior is defined in the state diagram (Fig. 4) as the forwarding and routing process [1].

- Purpose: Deliver sensor data to the network and ensure reliable multi-hop communication by forwarding packets from child nodes.

Step 6: Disable excitation immediately; The MDA300 ADC is kept on for approximately 2s to cool, then turned off by the driver [1].

- Purpose: Ensure sensor stability and conserve energy by powering down excitation and delaying ADC shutdown for a safer cooldown.

Step 7: Return to idle/LPL; MCU sleeps until next timer or inbound packet. Low Power Listening keeps the radio periodically checking for incoming messages even when idle [1].

- Purpose: Conserving energy while remaining responsive by periodically sampling the channel for incoming packets via the radio while allowing the MCU to sleep.

Q6 – Highest-Power Operating Modes in Table 2 (10 pts)

There are four modes of operation that consume the most power listed in sequential order from highest power draw to lowest. These are the primary contributors to energy consumption.

1. *Radio reception (Mark A, A1):*
    a. Actual current draw is 15 to 17 mA and expected is 8 mA.
    b. This mode consumes the most current due to the energy requirements of decoding incoming packets.
2. *Sensor excitation (Mark D, D1):*
    a. Actual current draw is 13 mA and expected is 11 mA.
    b. This current draw is due to the power requirements of the 5.8V boosters responsible for activating sensors.
3. *Radio Transmission (Mark G1 - D1):*
    a. Actual current draw is 11 mA and expected is 12 mA.
    b. This mode draws power whenever data is sent to the parent node.
4. *Microprocessor active (Mark C):*
    a. Actual current draw is 7 mA and expected is 6 mA
    b. This mode draws power when the CPU is processing sensor data.

The remaining modes of operation consume significantly less power, with roughly 1 mA being the highest among them.

Q7 – Most Energy-Hungry Activity over a 5-min Interval (excluding Idle) (10 pts)

Based on Table 3, the following activities consume most power besides the idle mode over a 5-minute operation interval:

1. *Most energy hungry* activity*:* From Table 3 the energy consumption during idle state totals is 0.387 mA-h, accounting for the highest overall consumption during a one hour period. This is due to the node maintaining this state for extended periods between sensing cycles.

2. *Second most energy hungry activity:* Low Power Listening (LPL) consumes 0.102 mA-h due to polling, which is approximately 15% of the total hourly energy budget. Since the radio wakes up 300 times per hour to sample the channel for potential transmission, it results in a much higher energy consumption rate, though actual data may not be present.

3. *Third most energy hungry activity:* Sensor excitation with 0.086 mA-h draw.

4. *Fourth most energy hungry activity:* Radio transmission with 0.073 mA-h consumption.

5. *Fifth most energy hungry activity:* ADC enabled results in 0.013 mA-h.

Bibliography

[1] J. Zheng, C. Elliott, A. Dersingh, R. Liscano and M. Eklund, "Design of a Wireless Sensor Network from an Energy Management Perspective," 2010 8th Annual Communication Networks and Services Research Conference, Montreal, QC, Canada, 2010, pp. 80-86, doi: 10.1109/CNSR.2010.53.

[2] C. J. Merlin and W. B. Heinzelman, "Schedule Adaptation of Low-Power-Listening Protocols for Wireless Sensor Networks," in IEEE Transactions on Mobile Computing, vol. 9, no. 5, pp. 672-685, May 2010, doi: 10.1109/TMC.2009.153.

[3] M. Sha, G. Hackmann, and C. Lu, “Energy-Efficient low power listening for wireless sensor networks in noisy environments.” [Online]. Available: https://www.cse.wustl.edu/~lu/papers/ipsn13-aedp.pdf