ECE6615: Sensor Networks
Spring 2018
Homework 1

Given: **January 20, 2018**
Due: **February 9, 2018 (Midnight) + 1 week for "off Campus" students**

Submission Instructions:
Submit your homework as a DOC or PDF file to infocom@ece.gatech.edu
Mention "**[ECE6615] Homework 1**" in the subject line.
No hardcopies will be accepted. Scanned pages are fine.

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Question 1 (Energy Consumption):

a) Suppose a rechargeable lithium ion battery with a nominal voltage of 3.6 V and a nominal charge capacity 2200 mAh.
   i) What is the total energy of this battery?
   ii) How long can such two batteries in series power a sensor node that has a demand of 1.5 W?

b) Given a sensor node that consumes 725 μA when the radio is not transmitting and 21.5 mA when the radio is transmitting. It is powered using two batteries in series, each with 3.6 V and 2200 mAh.
   i) How long do the batteries last, if the device is transmitting 10% of the total time?
   ii) Suppose the transmission rate of the node is 1.25 Mbps, what is the energy required for transmitting one byte of data?

c) Assume an office desk with an area of 1.2 m^2 has a sensor node that relies on solar energy harvesting to recharge the two batteries same as in Question 1 a). If we assume the time of recharging is 2 hours and the energy transfer efficiency is 100%, the sensor node consumes 750 μA when sleep and 20 mA when activated with a nominal voltage of 2 V.
   i) How long can the sensor node last after one time of recharging when it works 75% of total lifespan?
   ii) If in this office area (3600 m^2) there are in total 900 such sensor nodes with a broadcast radius of 5 m, determine the node density.

d) The relationship between the transmitted and the received power of a signal follows the inverse square law $P_r \propto \frac{P_t}{d^2}$, i.e. power density and distance have a quadratic relationship. This can be used to justify multi-hop communication, i.e. energy can be preserved by transmitting packets over multiple hops at lower transmission power. Assume that a packet P must be send from transmitter A to a receiving sensor node B. The energy necessary to directly transmit the packet can be expressed as the simplified formula $E_{AB} = d(A,B)^2 + c$, where $d(x,y)$ (or simply d in the remainder of this question) is the distance between two nodes x and y and c is a constant energy cost. Assume that you can turn this single-hop scenario into a multi-hop scenario by placing any number of equidistant relay nodes between A and B.

i) Derive a formula to compute the required energy as a function of d and n, where d is the distance between two nodes A and B and n is the number of relay nodes (for example, n = 0 as in the single-hop case)

ii) What is the optimal number of relay nodes to send packet P with the minimum amount of energy required and how much energy is consumed in this case for a distance $d(A,B) = 10$ and c = 10? You can refer to the following table to compute.

Number of Relays	0	1	2	3	4	5	6	7
Energy (c = 10)	110	70	63.3	65	70	76.6	84.3	92.5

Question 2 (Energy Modeling and Reliability):

Wireless sensor nodes consist of several functional modules: microprocessor, transceiver, sensor, and power supply modules. The processor module is the center for node control and data processing. In general, there are three operation states (sleep, idle, busy) and has five state transitions, but there are more operation modes in reality to consider. For this question, we look at a real-world wireless sensor specification to consider the energy consumption models for sensing, computation, and communication. You will need to use the Atmel AT86RF233 Transceiver datasheet:
http://ww1.microchip.com/downloads/en/DeviceDoc/Atmel-8351-MCU_Wireless-AT86RF233_Datasheet.pdf

Assume a network where each sensor should wake up once a second, measure a value, perform calculations and transmit it over the network. Consider the following:

- Assume sensing energy is negligible
- Calculations needed: 5K instructions (for measurement and preparation for sending)
- Time to send information: 50 bytes for sensor data, (another 250 bytes for forwarding external data)
- Energy needed to sleep for the rest of the time (sleep mode)
- Sleep mode and deep sleep mode can be generalized as sleep mode

Assume IRIS mote (Atmel processor + RF233 transceiver) with the following:

- Computation power (Pp) is 24mW for IRIS

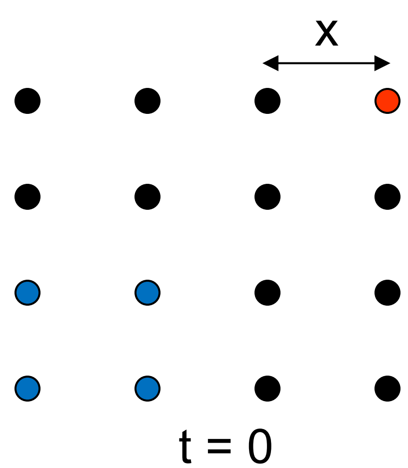
- 1 instruction takes an average of 3 cycles, where Atmel processor operates at 8MHz
- For start-up, assume PLO = 4.5mW, tst = 1.065ms
- For switch, assume PLO = 23.4mW, tsw = 25 us
- For receive energy, PLO + PRX = 46.5 mW
- For transmit energy, PLO + PTX = 49.5mW
- For sleep energy, PSL = 24 uW
- Assume transmission rate as 250kbps
- The sensor is supplied with 2 x 1.5V AA batteries, each of which has energy of 1150mAh

Answer the following questions:

a) Find the total energy consumption of a mote in one minute.
b) Assuming the batteries lose 12.5% energy/year, calculate the lifetime of a mote.
c) Start-up and switching are much more complicated that can be modeled by a single parameter PLO. Refer to Figure 7-1, Table 7-1, and Table 12-8 in the RF233 Transceiver datasheet and discuss the effects of the start-up and switching mechanism on the overall lifetime.
d) What are the consumed power and time for
    i) Start-up for transmit
    ii) Start-up for receive
    iii) Switching from receive to transmit and
    iv) Switching from transmit to receive?

QUESTION 3 (S-MAC)

Consider the grid topology in the Figure.



The blue nodes are the source nodes that need to send a packet to the sink (red node). Assume that all immediate horizontal and vertical neighbors of a node are accessible (sqrt(2)*x > R > x). The total time for transmitting a packet is 3 sec. Assume S-MAC with adaptive listening is the MAC protocol at each node. All the nodes are awake for 1 sec. and asleep for 4 sec. For example, all the nodes are awake from t=0 to t=1, go to sleep until t=5, and repeat.

1) Calculate the time at which the sink receives all the packets from all the blue nodes. (You can assume any route respecting the transmission range of nodes)
2) Show the state of the network in each time slot.

State clearly any assumption you make.
Hints:
1- Assume perfect carrier sensing. When a particular node transmits during time $[t_0, t_0+3]$, no other node in its neighborhood can transmit simultaneously.
2- Assume RTS/CTS exchanges are instantaneous and if a node starts transmitting, it will continue until the packet is transmitted

Question 3 (Physical Layer – Error Control) (Optional)

Consider a chain topology of 5 sensor nodes where inter-node distance is 15m. End-to-end packet error rate of 10^{-2} is required for an application. Answer the following questions.

i) Assuming independent and identical errors at each hop, what is the required packet error rate for each hop?
ii) For a packet size of 50bytes, and independent and identical bit errors, what is the required bit error rate at each hop?
iii) For a Mica2 mote that uses 2-FSK modulation, what is the required SNR in dB at the data rate of 250kbps?

Consult the datasheets when necessary and state any references to the datasheet and assumptions you make.

Question 4 (Query Processing):

Suppose you are invited to design an IoT network for Georgia Tech Student Center using the knowledge you learnt from this course. On the first floor, there will be a network with 120 sensor devices to collect data from ambient environment. There are temperature sensor devices uniformly distributed in the main dining area, the post office, two lounges and three administrative offices. You want to constitute a temperature map of the floor at various resolutions in order to adapt the AC/Heating system parameter values, the minimum resolution being the average temperature of the entire floor and the maximum resolution being the temperature of each sensor. You should also be able to adjust the temperature by areas independently, e.g., average temperatures at the dining area and the post office need to be different. The required resolution for the temperature map can change over time. Consider that sensor nodes are battery powered and that lifetime is a crucial property for this sensor network.

Describe a solution to this task. In particular, you should:

(a) Propose an adaptive aggregation scheme that accounts for the required resolution of the temperature map. You can assume that the network topology is fixed, but you want to distribute the energy consumption uniformly among all the nodes.

(b) Propose a communication protocol aimed at dynamically exploiting the spatial-temporal correlation of the measurements.

(c) Specify a SQTL-like query message that would efficiently provide support to this specific application. Briefly discuss pros and cons for your design choices and clearly state all the working assumptions made.

(d) Consider a TAG scheme with the query:

SELECT AVE (temperature), humidity/10%, FROM sensors, Group BY humidity/10%

According to the topology in the following figure, what is the information table that can be generated at A?