# ECE6615: Sensor Networks

## Spring 2015

## Homework 3

**Given:** **March 19, 2015**
**Due:** **April 19, 2015 (MIDNIGHT 11:59pm)**

**Submission Instructions:**

1. Please put **"[ECE6615] HOMEWORK 3"** in the subject line.
2. Submit your homework as on-line files (such as a DOC or a PDF file) to **infocom@ece.gatech.edu**.
   No hard copy will be accepted!!

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**QUESTION 1 (Routing)**

Consider the topology in Figure 1 and also in the given PPT, which shows the first step of flooding.

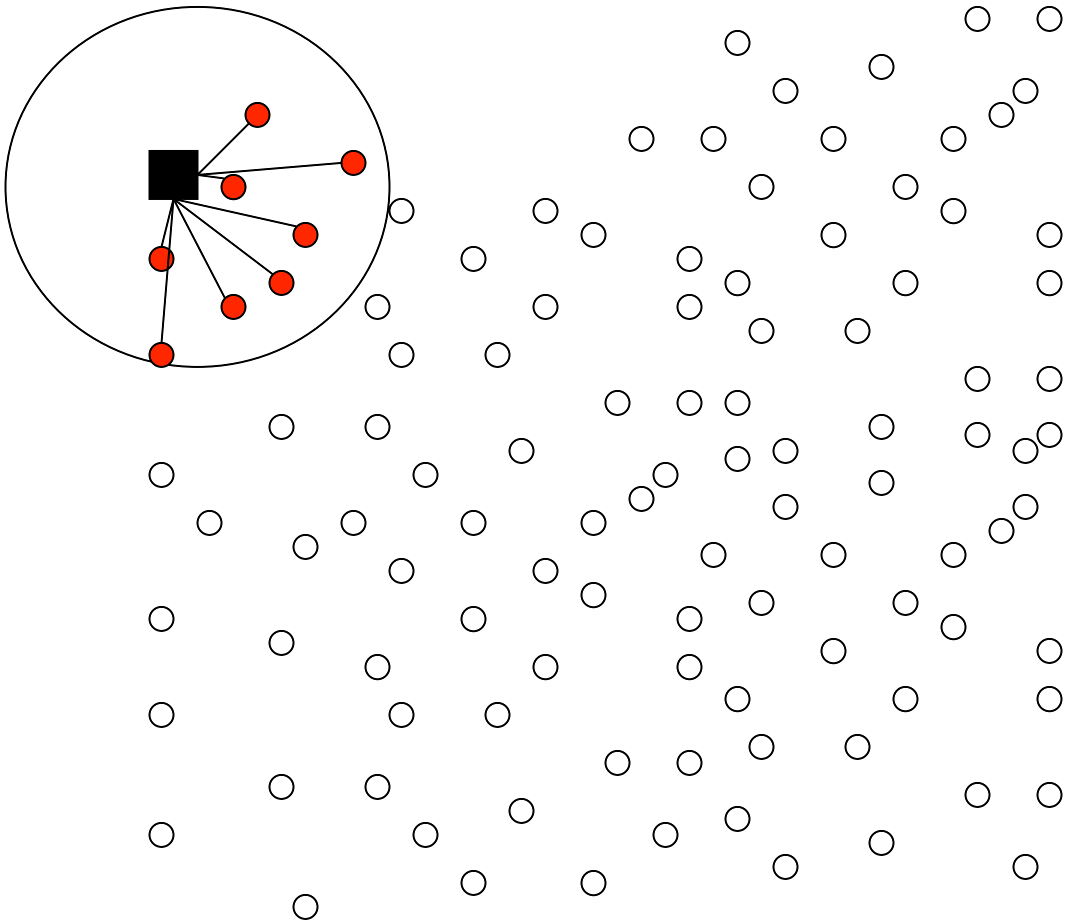


Figure 1

Using the topology and the transmission range circle in the figure, show the evolution of flooding in terms of time steps. For each step, draw the state of the network until all nodes receive the flooding packets. Draw the resulting flooding tree at each step and then copy the slide for the next step to prevent confusions.

Assume the following for the question:

1. Perfect channel condition inside the transmission circle. (All nodes inside the circle can receive the flooding packet successfully)
2. All the red nodes receive the flooding packet in the first step.
3. Only one node inside a transmission circle can transmit a packet at a step (denote these nodes as black nodes in each step).
4. At each step, start with randomly selecting one of the red nodes as a transmitter and draw its transmission range. The other red nodes that fall into this transmission range will be blue nodes. Repeat this until all red nodes are processed for that step.
5. Transmission of a packet takes one step.

6. If a node receives the flooding packet in two consecutive steps (a red node receives a packet in the next step), it does not continue flooding and drops all of its packets (denote these nodes as blue nodes in each step)

**QUESTION 2 (Error Control)**

Given a sensor network in which all sensors have equivalent transmission range R = 20 m, transmission rate r = 250 kbit/s, and packet size L = 55 bits. Consider a particular sensor node i, which is located at a distance D = 100 m from the sink. Assume that within the transmission range of i, there exits only one sensor j and sensor j is closer to the sink than sensor i. The described network scenario is shown in Figure 2, and all nodes are distributed as shown.

a) Calculate the estimated number of hops from sensor i to the sink.
Hint: the actual advance distance from i to j is the projection of dij onto the line connecting sensor i and the sink.

b) Assume the bit error rate (BER) or bit error probability $P_b = 10^{-3}$. Calculate the packet error rate (PER) of BCH code with BCH(15, 11, 1) and BCH(15, 5, 3), respectively.

c) Based on the results of a) and b), evaluate the estimated END-TO-END reliability (i.e., PER) between sensor i and the sink provided that BCH code is employed for data transmissions at each hop.

d) Assume that at each hop the sensor uses BCH code with BCH (15, 11, 1) and the energy consumption for encoding and receiving packets is negligible. Calculate the total estimated energy consumption of transmitting a packet from sensor i to the data sink. Consider the energy to run circuitry is: $E_{tx\_elec}$ = 50 nJ/bit and the energy for radio transmission is: $e_{amp}$ = 100pJ/bit/m$^2$.
Hint: to compute the energy consumption for decoding, the decoding latency is given as

$$T_{dec}^{BL}(n,k,t) = (2nt + 2t^2)(T_{add} + T_{mult})$$

$$T_{add} + T_{mult} = 3\left\lceil \frac{m}{8} \right\rceil t_{cycle} \quad \text{where } m = \lfloor \log_2 n + 1 \rfloor \text{ and } t_{cycle} = 250ns$$

e) Assume that the total delay at each hop only consists of transmission delay and decoding delay. Calculate the estimated END-TO-END delay of transmitting a packet from sensor i to the data sink provided that BCH (15, 5, 3) is employed.

f) Briefly comment the tradeoffs of end-to-end reliability, end-to-end delay, and total energy consumption under different BCH coding schemes.

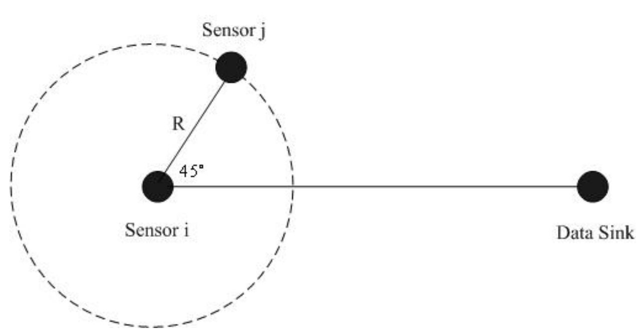



Figure 2

**QUESTION 3 (Transport Layer)**

Figure 3 shows a wireless sensor network used to measure the temperature inside an industrial refrigerated room. In this picture, red nodes represent sensors that have detected a sudden increase in the temperature (corresponding to the same event). These nodes need to report this information to the sink or command center. The radio range of each node is *r*.

**Qualitatively** explain how PSFQ and ESRT will perform in this situation and compare both protocols in terms of total number of packets transmitted. How does this affect the total energy consumption? Under which protocol is the network more likely to be congested?
Assumptions:

1. Consider that the network has been working for some time and that ESRT is working under no congestion and with high reliability. Assume that in this condition, only 50% of the nodes will report the event.
2. Consider that all packets are sent using the shortest path and that routes have already been pre-established.
3. Consider that a simple MAC protocol is used and that only 1 of every 4 packets is lost.

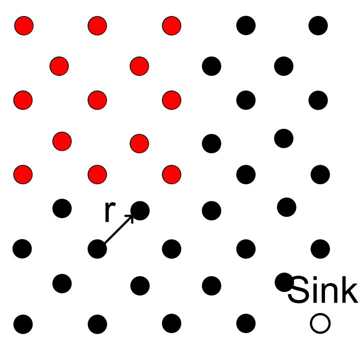



Figure 3

**QUESTION 4 (Localization: Range-based)**
Consider a sensor network where the anchor node can estimate the distances between itself and a sensor using the Received Signal Strength Indicator (RSSI). The RSSI is modeled by the following simplified equation:

$$P_r = P_t - 20\log(d) \ ,$$

where $P_r$ is the received signal strength, $P_t$ = 0 dBm, which is the transmitting power, and it is the same for all sensors, and $d$ is the distance between the two sensors. Assume that the minimum received signal strength for a correct reception is -50 dBm. Four anchors are deployed at the locations shown in Figure 4. Note that the unit of the length in Figure 4 is $10^2$ m. Use the following information to determine the position of node E and F.

- The RSS from E to A is -40 dBm.
- The RSS from E to B is -50 dBm.

- The RSS from F to C is -40 dBm.
- The RSS from F to D is -50 dBm.
- E and F cannot hear each other.

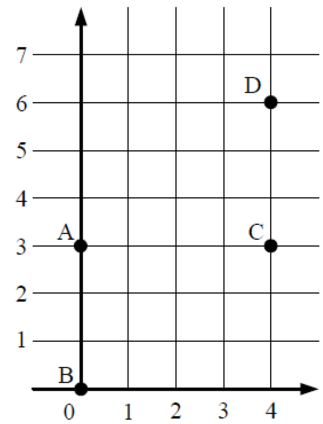



**Figure 4**

**QUESTION 5 (Cross Layer and Wireless Multimedia Sensor Networks)**

Consider the time hopping impulse radio ultra wide band system described in Section IV.B. (Physical Layer Model) of the paper:

*T. Melodia, I. F. Akyildiz, "Cross-layer QoS-Aware Communication for Ultra Wide Band Wireless Multimedia Sensor Networks," IEEE Journal of Selected Areas in Communications, Vol. 28, no. 5, pp. 653-663, June 2010.*

a) Two users are concurrently transmitting a sequence of three bits over three frame periods. User 1 is transmitting the sequence "111", and User 2 is transmitting the sequence "000". Using MATLAB, plot for each of the following cases the signals concurrently transmitted by User 1 and User 2 during the time interval $[0,4T_f]$

   i. Case 1: $c^{(1)} = [0\ 0\ 0]$ and $c^{(2)} = [4\ 4\ 4]$
   ii. Case 2: $c^{(1)} = [3\ 1\ 6]$ and $c^{(2)} = [4\ 2\ 7]$

   Use a single pulse to represent each bit, and the SNR level of your choice. The parameters of the system are listed in Table 1.

**Table 1**

| Parameter | Value |
|---|---|
| $T_f[ns]$ | 1.6 |
| $T_c[ns]$ | 0.2 |
| $\tau_p[ns]$ | 0.1 |

| | |
|---|---|
| $\delta[ns]$ | 0.1 |
| $N_h$ | 8 |
| $N_s$ | 1 |

b) What is the motivation behind using Time-Hopping Impulse Radio Ultra Wide Band for wireless multimedia sensor networks?
c) How are collisions prevented in TH-IR-UWB?
d) Cross layer module aims to provide high reliability with low energy consumption. However, cross layer module is not tailored for real-time data applications since end-to-end reliability and latency bounds are not guaranteed. Can the routing algorithm be changed for real-time traffic?

**QUESTION 6 (Wireless Underwater Sensor Networks)**

a) Using MATLAB, plot the Transmission Loss (TL) based on the deterministic Urick formula, $TL_{Urick}(f_0, d)$, using three different spreading factors ($k = 1, 1.5, 2$) when the carrier frequency $f_0$ is set to $20$ KHz and the distance d ranges in $1 - 5$ km. Consider α(f)=0.0006; A=7.5 dB.

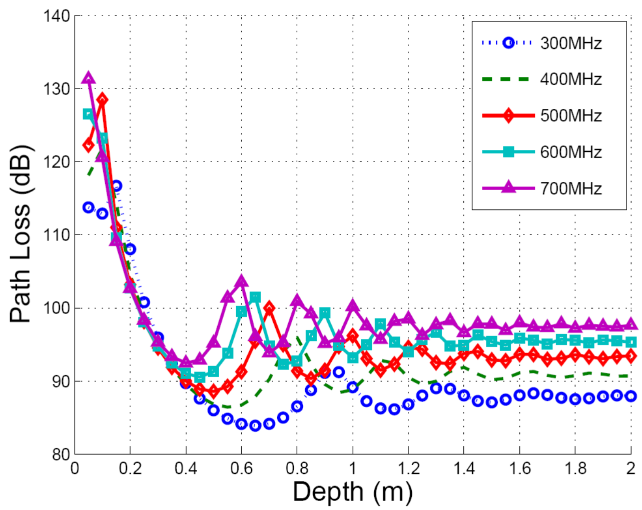
b) If a transmitter's battery had a residual energy of 1 kJ, what would be the residual lifetime of the node if it periodically transmitted packets of 10 Bytes every 10 minutes to a receiver at 5 km of distance (assume that TL=$TL_{Urick}$ and that the target SNR is $20$ dB and the ambient noise N is $70$ dBre1μPa)? Assume k=2, H=1m, and a data rate equal to 1 kbit/s.

**Question 7 (Underground Sensor Networks)**

Two EM wave-based wireless sensors are buried underground at the same depth. The following parameters are given:

- The distance between the two sensors is 4m
- The volumetric water content is 20% ($\alpha$ = 3[$m^{-1}$], $\beta$ = 77[rad $m^{-1}$])
- The operating frequency is 500 MHz
- The antenna gains Gt=10 dB, Gr=5 dB.
- The transmitted power is 5 mW
- The received power is $1.426*10^{-5}$ mW

a) Using the curves in the following figure, compute the minimum possible depth at which the sensors are buried.




**Two-way Path loss**

b) How would the received power be if, instead of EM waves, we use MI (Magnetic Induction) as a communication medium?