ECE6615: Sensor Networks
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FINAL EXAM: MAY 5, 2011

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*** PUT A CODEWORD NEXT TO YOUR NAME!!!**
*** THIS IS AN OPEN BOOK EXAM (EVERYTHING ALLOWED EXCEPT LAPTOPS AND CELL PHONES)**
*** DURATION 3 HOURS**
*** ANSWER THE QUESTIONS RIGHT TO THE POINT;**
*** AVOID LONG EXPLANATIONS; COUPLE SENTENCES WILL BE ENOUGH AS LONG AS THEY ARE CORRECT!!**

QUESTION 1 (Error Control: FEC and ARQ)

Consider a sensor network in which all sensors have equivalent transmission range R = 10 m, transmission rate r = 140 kbits/s, and packet size L = 20 bits. Assume that the bit error rate (BER) is 10^{-3}. As shown in Figure 1, a particular sensor node i is located at a distance D = 50 m from the data sink, while another sensor j resides closer to the sink than sensor i. Consider the case where sensor i selects sensor j as the next hop to transmit packets to data sink.

a) At each hop, let the sensor node encode packets by using BCH code with BCH (7,4,1). Calculate the estimated end-to-end packet error rate and end-to-end delay from sensor i to the data sink. (note that propagation delay and queuing delay are negligible)
b) Now, at each hop, let the sensor node use ARQ for error control, where each sensor can retransmit a packet for at most 2 times if the packet is received with errors. Under this case, calculate the estimated end-to-end packet error rate and expected/mean end-to-end delay from sensor i to the data sink. (Note that propagation delay and queuing delay are negligible).

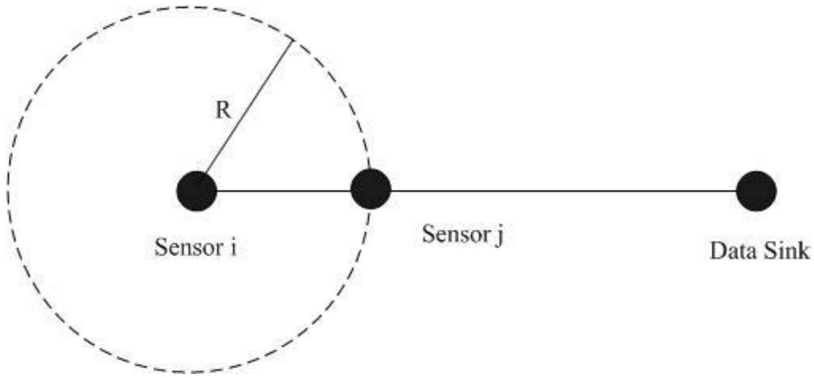

Figure 1

QUESTION 2 (Cross Layer Protocols)

XLP utilizes an initiative concept to determine the potential next hop nodes for communication. Consider a sensor network as shown in Fig. 2. When node *a* has packets to send, it broadcasts an RTS packet to its neighbor nodes. Five of its awake neighbor nodes (*b, c, d, e,* and *f*), which are closer to the sink, have received the RTS packet from node *a*. The required conditions to participate in communications are given in Table I, and the states of the five candidate nodes are given in Table II.

a) Based on the initiative concept, which of the five nodes (*b, c, d, e,* and *f*) will participate in the communication?

b) The nodes that decide to participate in the communication then perform receiver contention. After the receiver contention, which node is most likely to become the next hop for node *a*?

c) To extend the XLP protocol for real-time traffic, we add an extra delay condition to the initiative function: the average delay from node *a* to node *i* should not be larger than a threshold. This condition can be given by $\delta_{ai} \le w \cdot \delta^{Th}$, where δ_{ai} is the average delay from node *a* to node i, δ^{Th} is the required delay from node *a* to the sink, and *w* is the *advance coefficient* related to the locations of the nodes. The advance coefficient is given by $w = (D(a,S) - D(i,S))/D(a,S)$, where $D(a,S)$ is the distance between node *a* and the sink and $D(i,S)$ is the distance between node *i* and the sink. Suppose $D(a,S)$ equals to 100 meters and the required δ^{Th} is 0.5 second. Considering this extra delay condition, which of the five nodes will participate in the communication?

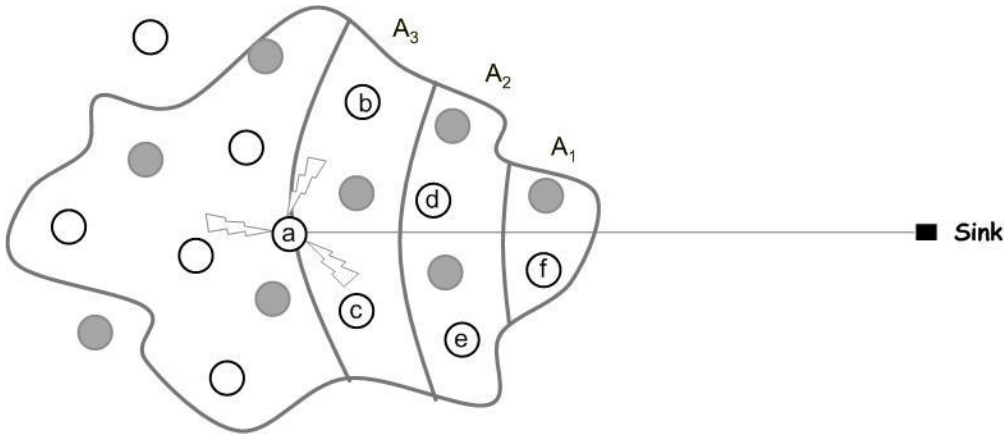

Figure 2. XLP

Table I. Required conditions

ξ_{Th} (dB)	λ_{relay}^{Th} (pkts/s)	$\beta^{\max}$	$E_{rem}^{\min}$ (J)
5	4	0.6	10

Table II. Parameters of the neighbor nodes

Nodes	ξ_{RTS} (dB)	λ_{relay} (pkts/s)	β	E_{rem} (J)	Distance to the sink $D(i,S)$ (meter)	Average Delay δ_{ai} (second)
b	10	2	0.45	12	90	0.1
c	7	4	0.7	8	90	0.25
d	6	5.25	0.65	15	75	0.2
e	7	3	0.4	20	75	0.1
f	6	2	0.3	15	60	0.15

QUESTION 3 (Localization: Range-based and Range-free)

a) Assume that the distance between two nodes cannot be estimated but is guessed according to which nodes a particular node hears. In figure 3, nodes A and B do not know their positions but they can hear each other. Node A knows its neighbors C and F. Moreover, node B can hear its neighbors D and E. The circular radio range of all nodes has a radius of 1.5 units. Calculate which positions in the following are valid for A and B and explain why.

a. A (2,5); B(3,3.5). b. A (2,3); B(3.5,3). c. A (1.5,4.5); B(4,2). d. A (2,4); B(3,3)

b) Consider another sensor network where the anchor node can estimate the distances between itself and a sensor using Received Signal Strength (RSSI). The RSS is modeled by the following simplified equation:

$$P_r = P_t - 20\lg d\ ,$$

where P_r is the received signal strength; P_t = 0 dBm, which is the transmitting power and is the same for all sensors; d is the distance between the two sensors. Assuming that the minimum received signal strength for correct receiving is -50 dBm. Four anchors are deployed at the positions shown in figure 4. Not that the unit of the length in figure 4 is 10^2 m. Using 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 can hear each other.

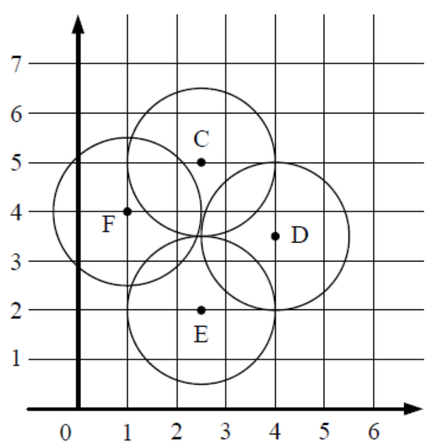

Figure 3

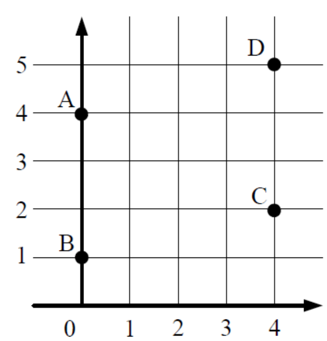

Figure 4

QUESTION 4 (Wireless Multimedia Sensor Networks - Correlation-Based Communication)

As shown in Figure 5, three camera sensors are deployed to observe an area of interest in a WMSN. The area of interest is in the center of the coordinate system, and the locations and sensing directions of the cameras are given as shown in the figure. Suppose each camera has observed one image ($X_i (i = 1,2,3)$) and the entropies of the individual images are the same ($H(X_i) = H(\cdot)(i = 1,2,3)$). Consider the case that we need to select two cameras to report to the sink.

a) Which two cameras should be selected to maximize the amount of information gained at the sink?

b) If we perform joint coding on the selected two cameras, which two cameras should be selected to minimize the joint coding rate?

(Suppose d = 2 in the figure.)

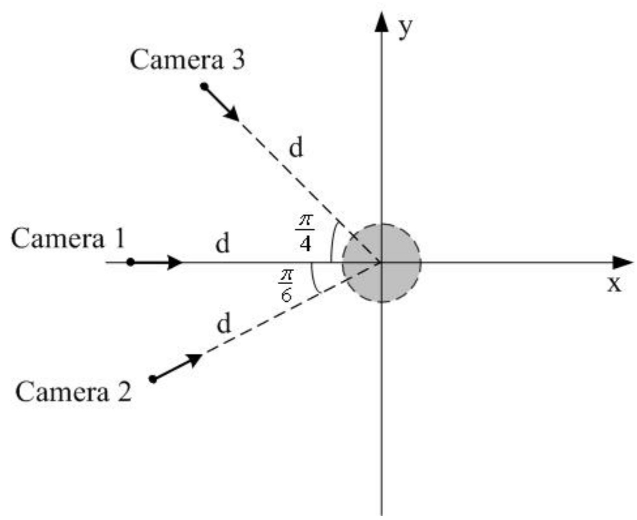

Figure 5. Cameras deployed in a WMSN

QUESTION 5 (Underground Sensor Networks)

In an EM wave-based wireless underground sensor network in soil medium, the system and environmental parameters are given as:

- The two underground sensors are buried in the same depth, which is 0.5 m below the ground surface.
- Volumetric water content in soil is 5%.
- The transmitting power of each sensor is 10 mW.
- The operating frequency is 300 MHz.
- The minimum received power for correct demodulation is -90 dBm.
- The antenna gains Gt=Gr=10 dB.

a) Using the soil medium path loss given in Fig.6 and Fig.7 to determine the transmission range between two underground sensors.

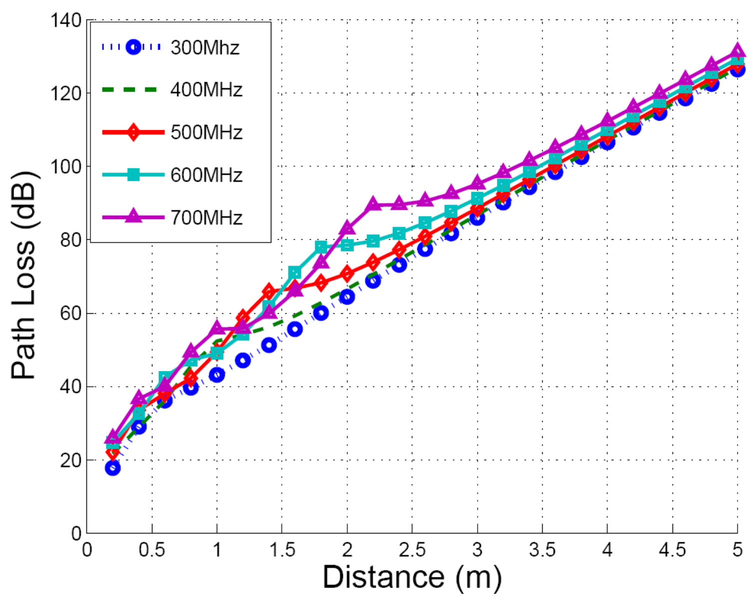

Fig. 6 Two-way path loss

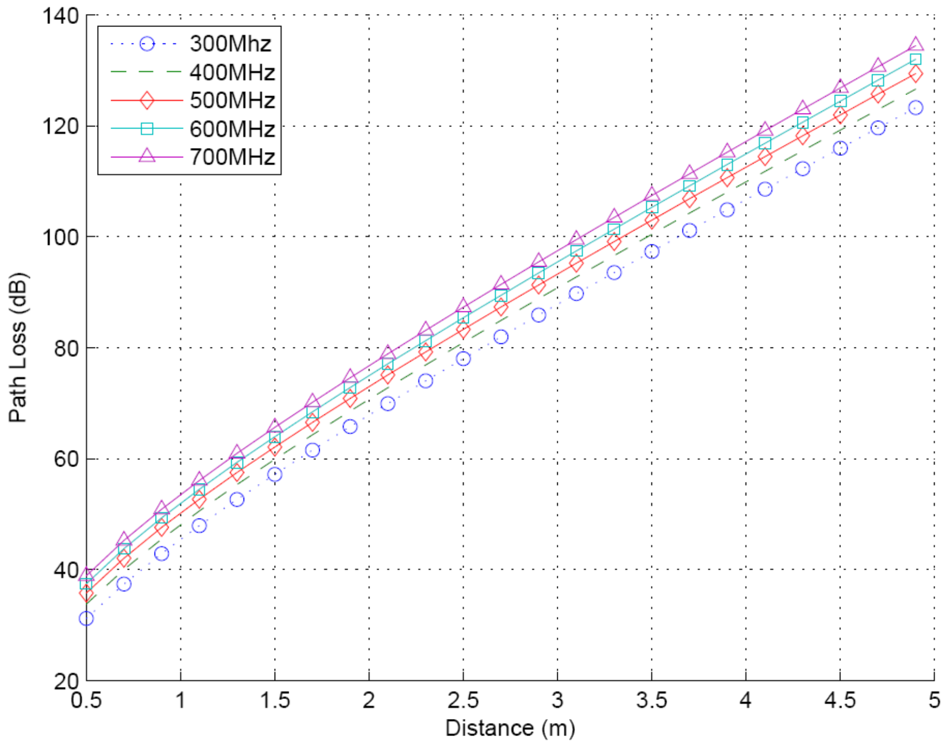

Fig.7 One-way path loss

b) If the underground sensors are randomly deployed according to a homogeneous Poisson point process in a region with 5000 m^2 area. Calculate the probability that there is no isolated sensor in this underground sensor network. Using the same parameters in a), determine which of the following sensor density λ (sensor per m^2) is the minimum to guarantee the probability that there is no isolated sensor can be larger than 95%.

A. $\lambda = 0.13$ B. $\lambda = 0.135$ C. $\lambda = 0.14$ D. $\lambda = 0.145$ E. $\lambda = 0.15$

c) What are the Pros and Cons of the EM wave-based communications in WUSNs? Why is the magnetic induction waveguide technique used in WUSNs?