# ECE6615: Sensor Networks
## Spring 2014
## Final Exam: April 30, 2014

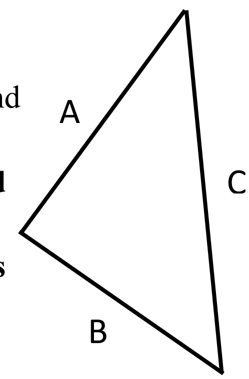
**Dr. Ian F. Akyildiz**
Ken Byers Chair Professor in Telecommunications
Broadband Wireless Networking Laboratory
School of Electrical and Computer Engineering
Georgia Institute of Technology, Atlanta, GA 30332
Tel.: 404-894-5141; Fax: 404-894-7883;
E-Mail: infocom@ece.gatech.edu

**Instructions**

- Put your **CODEWORD** next to your name in **EACH PAGE**!!!
- Open book exam (everything allowed except laptops and cell phones).
- Duration: 170 minutes.
- Each question has 20 points.
- Answer the questions **RIGHT TO THE POINT**.
- Avoid long explanations; couple sentences will be enough as long as they are correct!!

**Question 1 (Localization)**

Consider a room whose walls form a triangular shape. The room walls, labeled as A, B, and C, have the following properties




1. Wall A is metallic (**completely reflects electromagnetic waves**) and acoustic echoing (**reflects sound waves**)
2. Wall B is metallic but acoustic anechoic (**completely absorbs sound waves**)
3. Wall C is radio-frequency anechoic (**completely absorbs electromagnetic waves**) but acoustic echoing

Imagine a sensor mote placed inside the triangular room is equipped with both radio and ultrasound transceivers, and it tries to find its location within the room. The sensor mote, after the **emission of an electromagnetic pulse and a sound pulse**, receives the following:

- An electromagnetic pulse with RSS (Received Signal Strength) equal to $P_{r1}$ = -31.13 dBm
- An electromagnetic pulse with RSS equal to $P_{r2}$ = -36.12 dBm
- A sound pulse 17.5 ms after the transmission

Assuming that the electromagnetic pulse is transmitted with a power $P_t$ = 0 dBm, the electromagnetic attenuation constant is equal to 4dB/m, and the multipath/shadowing effects are negligible. Identify the location of the sensor mote within the room, relative to the three walls. (The speed of sound is 343.2 m/s)

**Hint**: the sensor mote can differentiate two received pulses only if the arrival times of the two pulses are different.

**Question 2 (Wireless Underwater Sensor Networks)**

Consider the scenario given by Figure 1, in which two underwater sensors are exchanging information by means of acoustic communication.

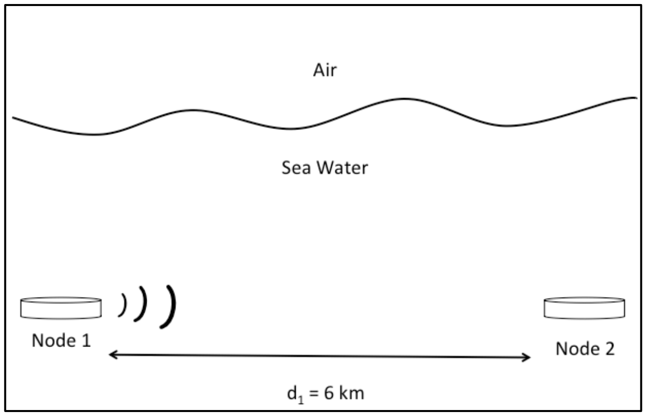



**Figure 1**

a) Compute the acoustic transmission power in Watts for the transmitter, Node 1, which is necessary to guarantee a Signal to Noise Ratio (SNR) of 20 dB at the receiver, Node 2. The distance between Node 1 and Node 2 is $d_1$=6 km, the system operates at a frequency $f$=20 kH*z*, and the ambient noise is 70dBreμPa. For the path-loss, utilize the Urick Propagation Model with spreading factor $k$=2, medium absorption coefficient $\alpha$=0.0006 dB/m, and transmission anomaly $A$=5 dB (consider H=1m).

b) Consider that the packet size is 100 bytes and that the transmission data rate is 1 kbps. Which is the energy consumption per packet in Joules? What is the total time (transmission time plus propagation time) needed for the packet to be received at Node 2? Consider that the speed of sound in water is 1500 m/s.

In order to reduce the energy consumption, two buoys are included in the network (see Figure 2). Each buoy has an acoustic transducer at the bottom and an electromagnetic transceiver on the top. Under this scenario, Node 1 transmits its information to Buoy 1 by means of acoustic communication. The buoys communicate over the air at 900 MHz. Buoy 2 relays the information to Node 2 acoustically.

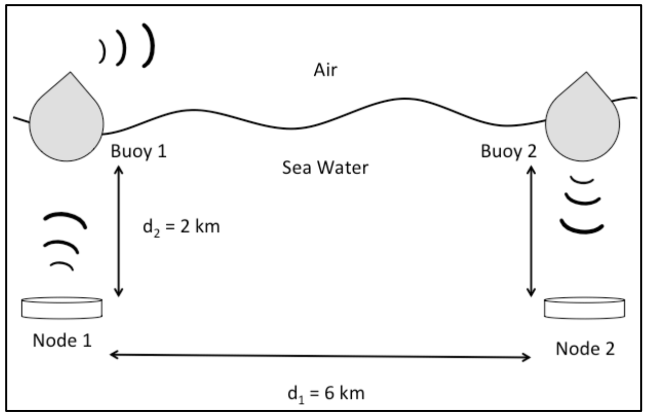



**Figure 2**

c) Compute 1) the acoustic transmission power, 2) the energy consumed per packet, and 3) the total time, in the vertical link between Node 1 and Buoy 1, for the same noise, SNR, packet size and data rate as before. For simplicity, consider the Urick Propagation Model with spreading factor $k$=1.15, medium absorption coefficient $\alpha$=0.0006 dB/m, and transmission anomaly $A$=10 dB (consider H=1m).

d) Compute 1) the transmission power, 2) the energy consumed per packet, and 3) the total time needed by Buoy 1 to guarantee a SNR of 20 dB at Buoy 2. Consider that the noise at the receiver is -120 dB, that the total path-loss between buoys is 114 dB, and that the data rate over the air link is 1 Mbps.

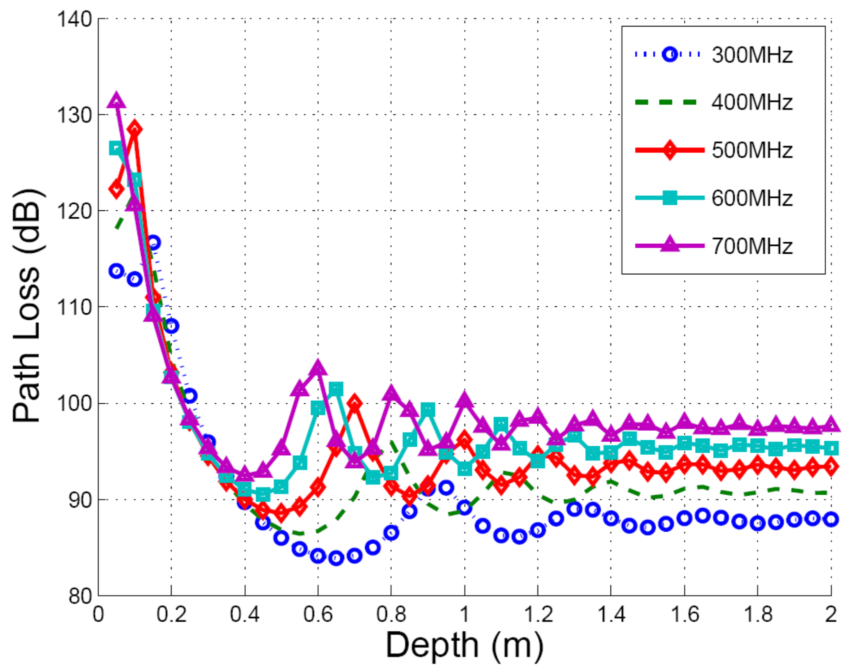
e) Compare the two routes (Node 1->Node 2 and Node 1->Buoy 1->Buoy 2->Node 2) in terms of total energy consumption and total end-to-end delay. Which is the best option? How would this solution change if the nodes were much deeper in the sea?

**Question 3 (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 4 m
- The volumetric water content is 20% ($\alpha = 3[m^{-1}]$, $\beta = 77[rad\ m^{-1}]$)
- The operating frequency is 500 MHz
- The antenna gains $G_t$=10 dB, $G_r$=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.
**Hint:** The total path loss is the contribution of the direct path and the two-way path (reflected path) path losses.




**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?

c) If the underground sensors are randomly deployed according to a homogeneous Poisson point process in a region with 15000 $m^2$ 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 $\lambda$ (sensor per $m^2$) is the minimum to guarantee the probability that there is no isolated sensor can be larger than 90%.

A. $\lambda = 0.14$ B. $\lambda = 0.145$ C. $\lambda = 0.15$ D. $\lambda = 0.155$ E. $\lambda = 0.16$

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