University of Illinois at Urbana Champaign
Department of Electrical and Computer Engineering

ECE 598HH Fall 2017 **Homework 2** Due: April 30, 2018

Instructions: The homework has 5 questions. It is due on April 30, 2018 at 11:59 PM.

Please submit an electronic copy via Compass (`http://compass2g.illinois.edu`). If you plan to submit a hand-written copy, you must upload a **legible** scanned copy on compass. Contact the TA if you face technical difficulties in submitting the assignment.

You may discuss ideas with others in the class, but your solutions and presentation must be your own. Do not look at anyone elses solutions or copy them from anywhere.

1 WiTrack (10 pts)

This problem refers to the WiTrack system discussed in class. For this problem, the following assumptions hold:

- There is no multipath.
- We operate with an ideal FMCW with no noise.
- The world is one-dimensional, so the localization problem is a ranging problem along 1 dimension (we care about finding a single distance to an object).
- The FMCW system has a single receive antenna, co-located with the transmit antenna.

1. Alissa wants to operate the system within the ISM band. This means that the total bandwidth allowed for the FMCW frequency sweep is 80 MHz. Can you tell Alissa the FMCW distance resolution that she would get based on this bandwidth, i.e., the minimum distance between 2 objects so that they may be located separably?
2. After reading the WiTrack paper and learning about FMCW, Alissa is convinced that given that there is no multi-path, and for the scenario where there is a single object in the scene, she can localize that object with much higher accuracy than the minimum distance resolution computed in the previous question. Either provide a high-level description of how you could do that, or explain why this is not possible.

2 Distance-based Localization (15 pts)

Ben wants to build an RF-based localization system, where he attaches a transmitter to the object of interest and tries to localize it based on the received signal. Assume for this question that the localized object is far enough from the receiver such that the waves are planer. Ben is considering the following options for his system.

1. Assume that Ben is localizing a transmitter in an open field with no multipath. Further, Ben knows that the transmitter is between 100+epsilon meters in front of his receiver. He knows that epsilon is about +/-2 meters. Assume the noise is Gaussian, the transmitter does not move, and the environment does not change. Ben claims that by making the transmitter transmit at low frequency like 27 MHz, he can find the value of epsilon to an accuracy of one millimeter using a single receiver with only two antennas. Is Ben right? Explain your answer.

2. It turned out that it is very difficult to use low frequency due to FCC regulations. So Ben decided to operate his transmitter and receiver at 2.4 GHz, and use antenna arrays to obtain a good measure of direction. However, since it is very hard to build a very large antenna array, Ben decided to use SAR with a single moving antenna and one fixed antenna. Does Ben's scheme work? Explain.

3. Ben changed his mind and became interested in locating people without requiring them to hold or carry any wireless device. Ben built a WiTrack device as described in the Witrack paper. However since he is operating in a planer domain (i.e., 2D localization) and he has no multipath effects in his setting, he removed the third RX antenna and operated using 2 RX antennas. Ben however failed to locate two people with his design. Can you explain to Ben why his device will not locate 2 people? Recall that the environment has no multipath.

3 Inaudible Sounds (20 pts)

An ultrasound speaker sends four tones at 40 kHz, 50 kHz, 52 kHz, and 70 kHz. Leia uses her smartphone's microphone to record the signal.

1. Leia uses a spectrogram App to detect what frequencies she recorded. She does not see any of the fours tones on her spectrogram. Why?

2. Instead, Leia notices some other frequency tones in her spectrogram. What are these frequencies? Where do they come from?

3. Dave records the same signal using an Amazon Echo device. What frequency tones does Dave see?

4. Dave proposes to design a new microphone. He proposes to place a filter before the amplifier to filter out all ultrasound tones. Leia thinks this is a bad idea. Who is right? Why or why not?

4 Wireless Charging (30 pts)

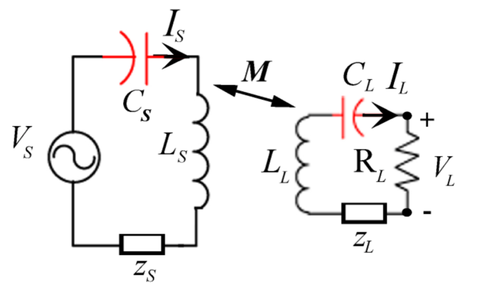

Figure 1: Magnetic Resonance Charging

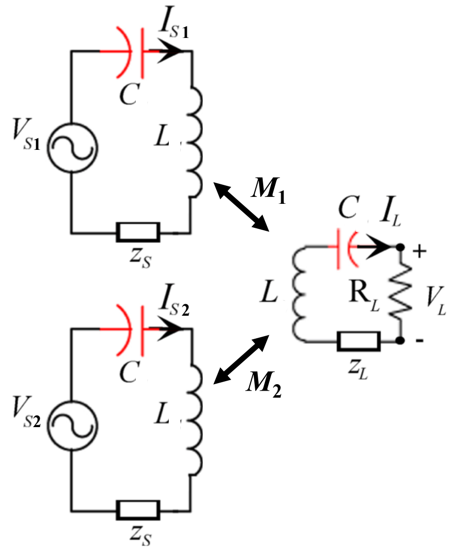

Figure 2: Magnetic MIMO

Consider the single source coil wireless charging system shown in figure 1.

1. Compute the efficiency of power transfer between the source and the load in terms of $M, C_S, C_L, L_S, L_L, z_S, z_L, R_L$ and the operating frequency ω. You can assume the load resistance R_L is constant. Recall, that power is voltage times current.
2. Assume $C_S L_S = C_L L_L = CL$. For what frequency ω is the power transfer efficiency maximized? Explain why and provide a new equation of th efficiency.
3. For perfectly aligned coils, assume $M \propto d^{-3}$ where d is the distance between the coils. How much does the efficiency of power transfer decrease when the distance increases from 1mm to 1cm?

Now consider the two source coil wireless charging system shown in figure 2.

4. Express $I_L = m_1 I_{S1} + m_2 I_{S2}$. What is m_1 and m_2?
5. What are the values of I_{S1} and I_{S2} that maximize the received power?
6. What is the new efficiency of power transfer? Why is it better than the single source coil system?

5 Network Coding with Full Duplex Radios (25 pts)

The following assumptions hold for this problem:

- There are no per packet acknowledgements.
- The destination sends 1 acknowledgement only after the whole file is received correctly.
- The radios are full duplex and hence the router can receive and transmit on the next link simultaneously.
- Acknowledgements are never lost.
- Packet losses are independent.
- Assume the links have negligible propagation delays. Assume all delays are due to limited link capacity i.e. transmission delay and the time it takes a bit to travel from the begining of a link to its end is zero.

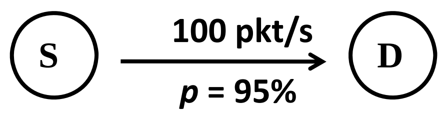

Figure 3: A single hop link between source S and destination D. The link operates at 100 pkt/s and is lossy with a delivery probability of 0.95.

Consider the network shown in Figure 3. The source S wants to deliver a file containing 100 packets $P_1, P_2, ..., P_{100}$ to the destination D. The transfer occurs over a wireless link which operates at a speed of 100 pkt/s and has a delivery probability of 0.95 per packet. There are no per packet acknowledgements; the destination will acknowledge the file once it has correctly received all 100 packets $P_1, P_2, ..., P_{100}$. Assume this acknowlegdement is delivered with 100% probability. The source has to keep transmitting until the destination acks the file i.e. if the source doesn't receive an acknowledgement after transmitting the first batch of 100 packets, it starts all over again and trasmits P_1 and then P_2 etc.,

1. What is the average time it takes for the file to be correctly received at the destination D? Assume the source does not code the packets (i.e., the source doesn't perform any additional coding beyond the PHY FEC which already results in a delivery probability of 95%).
   Circle the closest answer:
   (a) About 1.05s
   (b) About 1.1s
   (c) About 2.1s
   (d) About 3s
   (e) About 4s
   (f) About 6s

2. Consider the same scenario as above except that now the source S transmits a random linear combination of the 100 packets every time it transmits a packet. What is the average time it takes now for the entire file to be correctly received at the destination. **Circle the closest answer:**

   (a) About 1.05s
   (b) About 1.1s
   (c) About 2.1s
   (d) About 3s
   (e) About 4s
   (f) About 6s

For the rest of the problem assume the topology in Figure 4, where there is a router between the source and the destination which can transmit and receive simultaneously. All other assumptions are the same.

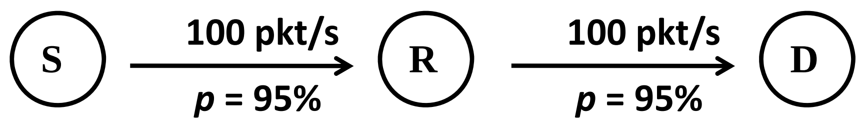

Figure 4: A network containing a source S, a full duplex router R and destination D. Both links operate at 100 pkt/s and are lossy with a delievery probablity of 0.95

3. Assume that the source and the router forward the packets without coding (i.e., S and R do not perform any additional coding beyond the PHY FEC which already results in a delivery probability of 95%). What is the expected time for the entire file to be received at D?
   Circle the closest answer:

   (a) About 1.05s
   (b) About 1.1s
   (c) About 2.1s
   (d) About 3s
   (e) About 4s
   (f) About 6s

4. In Fig. 4, assume now that the source performs random linear coding on each packet it transmits (i.e., each packet is a linear combination of the 100 packets in the file). The router however doesn't do an coding; it simply forwards the packets received from the source. What is the expected time for the file transfer?
   Circle the closest answer:

   (a) About 1.05s
   (b) About 1.1s
   (c) About 2.1s
   (d) About 3s
   (e) About 4s
   (f) About 6s

5. For the network in Figure 4, assume now that both the source and the router perform randomized linear coding of the packets they transmit. What is the expected time for the file transfer?
   Circle the closest answer:

   (a) About 1.05s
   (b) About 1.1s
   (c) About 2.1s
   (d) About 3s
   (e) About 4s
   (f) About 6s