Massachusetts Institute of Technology

6.808/MAS.453 Spring 2022 **Problem Set 1 Solutions** February 7, 2022

This problem set has 6 questions, each with several parts. Answer them as clearly and concisely as possible. You may discuss ideas with others in the class, but your solutions and presentation must be your own. Do not look at anyone else's solutions or copy them from anywhere.

Turn in your solutions on **Wednesday, Feb 28, 2022 before 11:59pm** by uploading it online to Gradescope using code: 5VERBY to join the class.

1 GPS Localization

Explain why GPS needs distance estimates from four satellites, rather than just three.

We need the 4th satellite to get the time offset for GPS clock synchronization.

2 Cricket

1. Eager B. Eaver is deploying beacons from the Cricket location system in the room shown below. He would like to use the system to distinguish between the two halves of the room, "FRONT" and "BACK". The part of the room near the large TV is the "FRONT", while the part of the room with the couch and plants is the "back". Where should he place beacons to accomplish this task using the design described in the Cricket paper? Mark your placement of beacons clearly in the picture below, aiming to place as few beacons as possible. Each beacon's range is the entire room. Briefly (in one sentence) explain your answer.

Cricket uses TDoA, so we need two beacons to find the difference in arrival times. The two beacons need to be roughly equidistant from the center line.

2. Eager sets the radio bit rate to 20 kbit/s and the size of the radio message sent from each beacon to 75 bytes (600 bits). He must now configure the ultrasonic transmitter and receiver to ensure that the maximum distance traversed by an ultrasonic signal before it is undetectable at a listener is no more than D meters. Calculate D, assuming that the speed of sound is 330 meters per second. Show your work.

$\Delta t = \frac{600bits}{20kbits/s} = 30ms$
$D = C_{sound}\Delta t = 330m/s * 30ms = 9.9m$

3 Device-Free Localization

In the WiTrack lecture, we discussed that it is possible to locate both static and moving users by using different subtraction windows. We perform background subtraction using two different windows: 3second and 30ms windows. After background subtraction, assume we are able to eliminate all multipath reflections and are only left with reflections off humans in the environment.

In Figure 3, we show the 2D output (representing a 2D plane) from each of the two subtraction windows. The "X" correspond to the location of peaks in the 2D output (i.e., user locations).

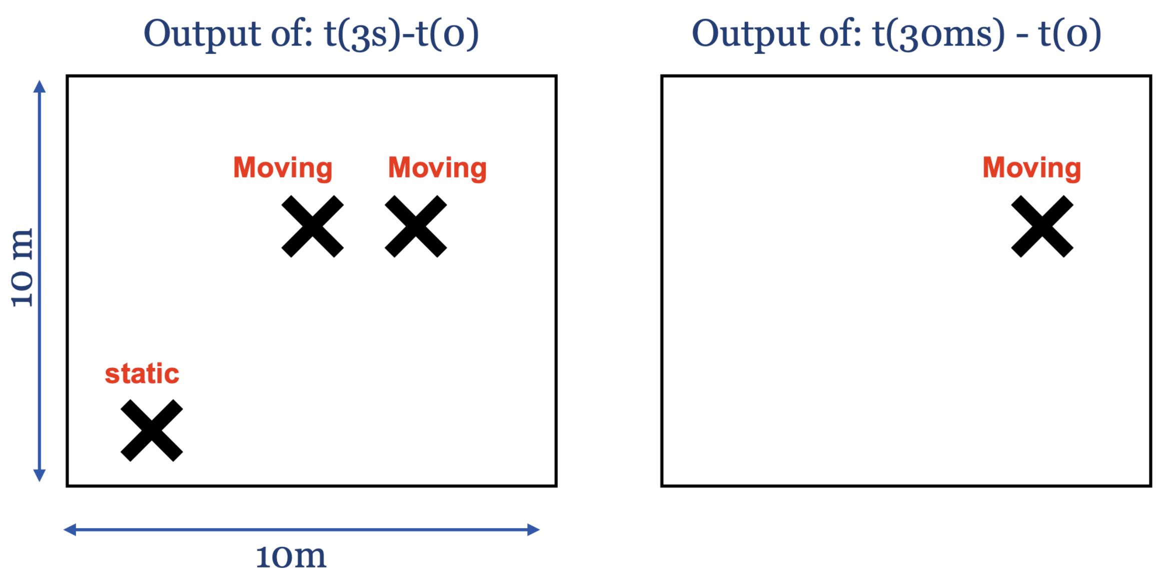


Figure 1: Two Subtraction Windows

1. Based on the above outputs, what is the minimum possible number of users in the environment? Briefly explain your reasoning.

2 – see below

2. Assuming all users are either sitting or walking. Label each "X" in the above output as a static or a moving user. Explain your reasoning for each label.

Static user appears only in 3s due to breathing (slow motion)
Moving user appears as ghost (initial + final position) in 3s

3. How fast is/are the moving user(s) walking? Briefly explain your reasoning.
Distance between two movement locations divided by 3 seconds = 2/3 m/s

4. Using the same data from the above experiment, we used a 5second instead of a 3second subtraction window. This time, we only got 2 peaks (i.e., two X's in the 2D output of the long subtraction window instead of 3 peaks).

We have already ruled out all the following potential reasons:

- All users are still within the 10m x 10m space.
- The moving user(s) final position is different from their initial position.
- All users remain at least 2m away from each other throughout the experiment.

In 1-2 sentences, explain what might've caused this.

Breathing cycle is periodic and chest returned (close) to original position after full cycle of 5s

4 BLE Energy Consumption

Alyssa P. Hacker has developed a BLE-equipped sensor node to use on a bicycle. It advertises data when the bicycle is moving, consuming on average 0.25 milliAmp in the advertisement state; at all other times, the node is on standby consuming 0.5 microAmp. She estimates that the average use of her bicycle (i.e., advertisement state) is 1 hour per day. Ignore the energy consumed in switching between standby and advertisement states. The node uses a coin-cell battery with capacity 500 milliAmp-hours. For how long will the node function before running out of energy?

Average Consumption: $\frac{0.25mA*1+0.5\mu A*23}{24hrs} = 0.0108mA$ on average.
$\frac{500mAH}{0.011mA} = 45889$ hours = 1912 days = 5.23 years

5 Networking

1. Consider the wireless network shown below in Figure 2. The delivery probabilities shown are the combined delivery probabilities (i.e., the product of the forward and reverse link delivery probabilities). If no delivery probability is specified, the nodes are out of range. Node S is sending packets to D using a shortest path routing protocol based on the ETX metric. What is the path S will choose? What is the ETX metric of this path?

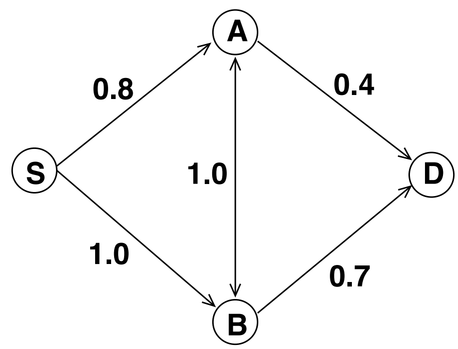


Figure 2: Simple wireless topology. The labels on the links are the delivery probabilities.

S - B - D

ETX $= 1 + 1/0.7 = 2.428$

2. Consider the chain of 5 equally spaced nodes shown in Figure 3. The radio range is slightly larger than the inter-node distance, i.e., each node can sense his left and right neighbors only. Each link is perfect, i.e., the delivery probability is always 1.0 for any link. Node S is sending packets to D.

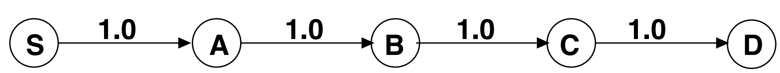


Figure 3: Simple wireless topology. The labels on the links are the delivery probabilities.

3. What is the ETX metric of the 4-hop path in Figure 3?

4

4. Assume that the capacity of the wireless medium is 1 packet/second and there is a protocol which schedules transmissions optimally. What is the maximum throughput of the flow from S to D in Figure 3? Briefly explain your answer.

S&C can transmit at the same time without interfering

Throughput $= 1/3$

5. Why can't the ETX metric accurately predict the throughput of the path in Figure 3 whereas it correctly predicts the throughput of the path in Figure 2?

ETX doesn't account for spatial re-use.

6 RFID

1. Which of the following statements are true below about the MIT ID card, as discussed in the RFID lecture. (There may be more than one correct answer. Specify all the correct ones. No need to explain your answer.)

- It uses a passive RFID tag.
- It uses inductive coupling for power.
- The coils of the tag and the reader need to be aligned.
- The coils of the tag and the reader need to be orthogonal.

2. The medium access control (MAC) protocol for RFIDs discussed in class has which of the following properties: (There may be more than one correct answer. Specify all the correct ones. No need to explain your answer.)

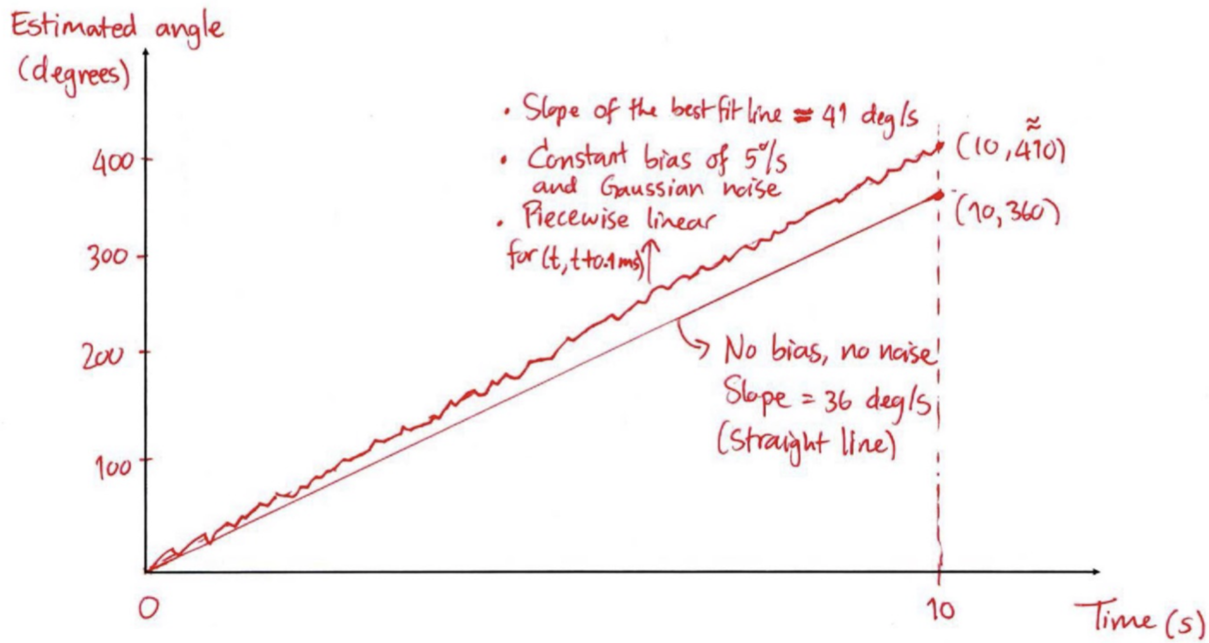
- It uses slotted Aloha.
- If the number of tags is known and fixed, its efficiency is higher than 90%.
- It reaches a deadlock if there is more than one RFID tag in the environment.
- An RFID tag transmits messages only when queried by an RFID reader.

7 Inertial sensing

1. A device rotates around its axis at a constant rate, completing 1 rotation in 10 seconds. If there is no noise and no bias, what angular velocity does the gyroscope on the device report? (You may assume any convenient units for the gyroscope, but state the units. Briefly explain your answer.)

$\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi}{10s} = \frac{\pi}{5}$ rad/s = 36 deg/s

2. Suppose the gyroscope has a constant bias of 5 degrees per second and also suffers from a small but non-zero amount of Gaussian noise. The gyroscope reports an angular velocity value every 100 ms. Sketch the **angle** estimated from these angular velocity values as a function of time between $t = 0$ and $t = 10$ seconds. You may assume the starting angle to be 0 at $t = 0$. On the same graph, also sketch the angle versus time if there were no bias and no noise. In addition, (1) label the axes, (2) mention the units on the axes, and (3) give the slopes of the best-fit lines for each of the two curves.



This plot assumes that the bias is in the same direction as the rotation of the device, i.e. $\omega = \omega_0 + b$. Otherwise, $\omega = (36 - 5)$ deg/s $= 31$ deg/s.