University of Illinois at Urbana-Champaign
Computer Science

CS 598 WSI, Fall 2024 **Homework 2** Due: Dec 10, 2024

In this homework, we will try and understand the principles underlying wireless localization, i.e. finding the position of a device based on wireless signals that it sends out.

The homework contains an accompanying dataset. The dataset contains one .mat file for each part of this homework. .mat files can be loaded in Matlab using the load command. You do not need to do the homework in Matlab. You can load mat files in other languages like python.

You need to submit your code as well as a document containing the answers to questions below.

You can do this homework in teams of two. To submit the homework, please use gradescope: `https://www.gradescope.com/courses/877302` (Code: 4JYE4D). You should be able to upload zip files containing your code and the document.

1 Wireless Channels

Consider, a transmitter, tx, that transmits symbol x to the receiver, rx. As the signal goes over the medium, it suffers attenuation and a phase rotation, denoted in class by the channel h. Recall that h is a complex number, with its magnitude representing the attenuation. The receiver receives signal y, where $y = hx$. If the channel, h, is just an effect of the propagation delay, it can be modelled as $h \propto \frac{1}{d} e^{\frac{-j2\pi d}{\lambda}}$, where λ is the signal wavelength. However, the channel is corrupted by several other offsets due to hardware differences, as we have discussed in class.

For this problem, we took a single antenna transmitter and a two-antenna receiver and ran a simple measurement for you (1). The transmitter transmits 100 WiFi packets and the receiver measures the channels for each of the packets. As you may recall, WiFi uses OFDM and thus, transmits data on multiple sub-carriers, each with slightly different frequency. However, we handled that for you and for this question, we will consider channel measurements on a narrowband on frequency 5.5 GHz. The channel measurements are in the file, *h_static.mat*. This file contains a 100×2 matrix, h, representing the channel measurement on the two antennas (first column is antenna 1) and a 100×1 matrix, t, containing the timestamps of the measured channels in milliseconds.

i Plot the phase of the channel measured on antenna 1 with respect to time. Include the plot in your solution. Hint: Use the matlab function `angle()` (or `numpy.angle` in python)to get the phase of a complex number.

ii You will observe that the channel phase does not remain constant. Why do the channel measurements change even though the receiver and the transmitter are static?

iii Plot the phase of the ratio of the channel measured on antenna 1 to the channel measured on antenna 2 for each packet, with time on the x-axis. Include the plot in your solution.

iv Does the phase remain constant (almost) for the ratio of the channels? If yes, why? If no, why not?

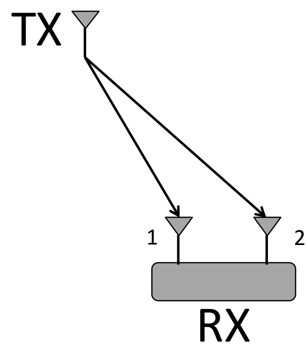

Figure 1: This figure demonstrates the setup for section 1

2 Let's move the antenna!

For this part, we decided to spice things up a bit. We put the transmitter on a Roomba robot and moved the Roomba at a constant speed, v, from left to right and right to left. The setup for this experiment is shown in figure 2

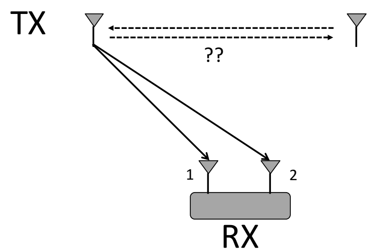

Figure 2: This figure demonstrates the setup for section 2

As we moved the Roomba, the transmitter was transmitting packets at regular intervals and we measured the channels at the receiver. The channel measurements are in the file *h_move.mat*. The file contains two 200×2 matrices, $h1$ and $h2$, representing the channel measurements and two 200×1 matrices, $t1$ and $t2$, representing the timestamps (in ms) for the respective channel measurements.

Use your understanding of the channel phase to figure out the direction of the motion of the roomba based on the channel measurements (left to right or right to left). Describe your approach in the solution. (Hint: You might find the unwrap() function in Matlab or numpy useful.)

3 Antenna Arrays

ArrayTrack introduced you to linear antenna arrays. In this section, we will introduce the circular antenna arrays.

Consider the circular antenna array shown in Figure 3. Each of the antennas receive a signal from a far-off transmitter (located at distance D) and measure the channel. The goal is to find the direction of the transmitter, θ, with respect to the line joining the centre and antenna 0. The power of the

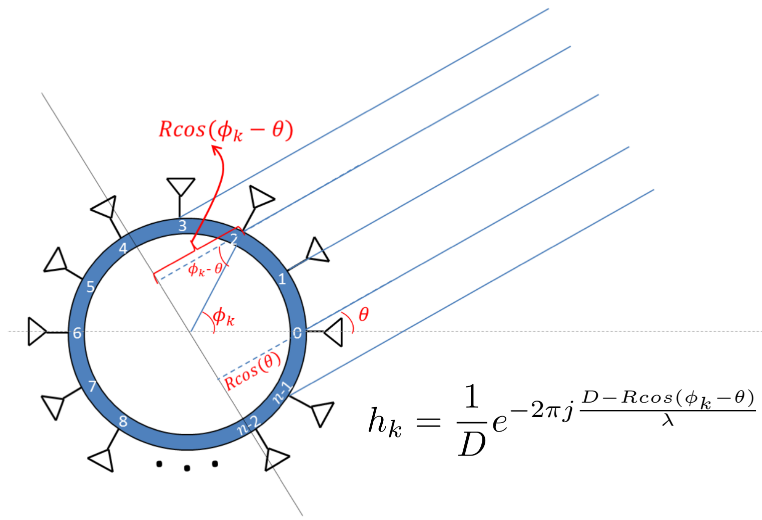

Figure 3: Circular antenna array.

signal, P, coming from the direction θ' can be given by the following formula:

$$P(\theta') = |\sum_{k=0}^{n-1} h_k e^{-j2\pi \frac{R\cos(\phi_k - \theta')}{\lambda}}|^2 \tag{1}$$

Here, R is the radius of the antenna array and ϕ_k is the angular position of the k^{th} antenna. Intuitively, this formula just compensates for the additional phase accumulated by channel measurements as the signal travels to different antennas. Again, this is very similar to the linear antenna array discussed in ArrayTrack. The value of P is high for values of θ' which correspond to the signal from the transmitter or signal reflections due to the environment.

In practice, building such antenna arrays is a tough job. You need to calibrate for hardware offsets in each antenna receive chain, which can be very painful. In order to avoid this, people use rotations of a single antenna system to emulate a rotating antenna array. We did this for you. We strapped the two antenna receiver from figure 1 to a Roomba and rotated it at one rotation per 12.25 seconds. The channel measurements, h, as well as the time stamps, t, for each of the channels are given in file *circular.mat*. R is 20.8 cm for this experiment. The frequency of the signal is 5.5 GHz.

Your goal is to obtain the multipath profile (P at different values of θ' varying from -180 degrees to 180 degrees at intervals of 1 degree) for the signal from the transmitter. Plot the multipath profile and add it to your solution. You should keep the following in mind:

- To compensate for hardware offsets between the transmitter and the receiver, you should apply equation 1 to the ratio of channel measured on antenna 2 divided by the channel measured on antenna 1.
- The antenna sampling is not necessarily uniform. So, you should calculate ϕ by using the time stamps and the angular velocity.
- You can check the correctness of your solution by plotting the values of P in the file *MultipathProfile.mat*. In this file, the value of P is obtained at $\theta' = -180, -177, -174, \ldots, 180°$.