COM 405: Mobile Networks – Fall 2025
Homework 1
EPFL

Due Friday October 17 at 8:00pm

Instructions

- Homework is due Friday October 17 at 8:00pm on Moodle.
- Homework can be done in groups of two or individually.
- Homework can be submitted handwritten or typed. If handwritten, please make sure to have good handwriting. Anything we do not understand, we do not correct. Scan handwritten homework and Submit as pdf.
- You must justify your answer or show your calculations to all questions even if it is not explicitly stated in the question. Simply giving the final answer without showing any work will not get you any credit.
- If you find any typos, please do not hesitate to let us know.
- Recall, you do not need to ask us to submit the HW late. You can simply take advantage of the following late submission policy:

  0 – 24 hrs late: −0 points

  24 – 48 hrs late: −20 points

  48 – 72 hrs late: −40 points

  > 72 hrs late: −100 points

1 Wireless Channel 20 points

Julie is standing in a large open agricultural field 1 km away from a cellular base station on a near by hill operating at 3 GHz. The direct line-of-sight path dominates that channel impulse response such that we can ignore multipath and assume it is a single path channel.

1. Julie sees an SNR of 21 dB on her phone. Her phone connection will not work below an SNR of 7 dB as the bit error rate will be too high. How much farther from the base station can Julie go before her phone connection will stop working?

   Julie is still 1 km away from the base station. A large tractor came and parked next to Julie creating a second strong path between Julie and the base station. Now the wireless channel consists of two paths, the direct line-of-sight path and the reflected path. Due to reflection, the reflected path is received with 9× lower power and has a distance of 1.00135 km. Assuming that Julie uses a narrowband channel that can be approximated with a single complex value, compute the new SNR that Julie sees in dB. Assume signals travel at the speed of light $c = 3 \times 10^8 m/s$

2. Did the SNR increase or decrease? What is this phenomenon called?

3. Julie decides to switch to a different frequency to maximize her SNR. Find the set of possible frequencies that maximize the SNR and compute the maximium SNR?

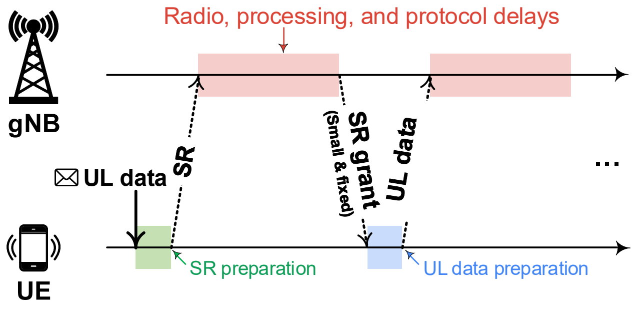
    - For simplicity, assume that the frequency does not affect the attenuation of the channel $|h|$ but only affects the phase $\angle h$.
    - Hint: Channel Phase for single path $\angle h = \phi = 2\pi d/\lambda \mod 2\pi = 2\pi df/c + 2k\pi$ for $k \in \mathbb{Z}$ where d is the distance, λ is the wavelength, f is the frequency, and c is the speed of light.

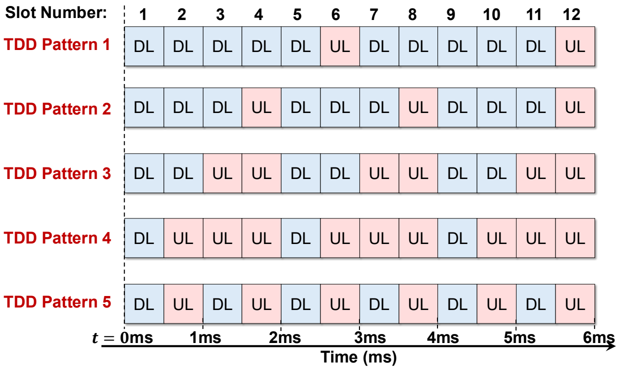
4. Julie's hardware only supports frequencies in the range 2.9 GHz - 3.2 GHz. Which frequency should Julie use to maximize SNR?

2 5G Uplink Scheduling 30 points

Consider a 5G network that uses TDD (Time Division Duplexing) with numerology 1 where the time slot length 0.5 ms. The base station can use one of the below TDD patterns where UL stands for uplink slot, and DL stands for downlink slot.

Recall that for uplink transmission, the UE needs to send a scheduling request (SR) and once the basestation sends the UE an SR grant, the UE can start transmitting uplink data as shown in the figure below. For simplicity, assume that the amount of uplink data that the UE needs to send is small and fits in the initial resources that the base station allocates to the UE in the SR grant. Also assume that the SR can be sent in any uplink time slot, i.e., ignore the SR period.





Slot Number:	1	2	3	4	5	6	7	8	9	10	11	12
TDD Pattern 1	DL	DL	DL	DL	DL	UL	DL	DL	DL	DL	DL	UL
TDD Pattern 2	DL	DL	DL	UL	DL	DL	DL	UL	DL	DL	DL	UL
TDD Pattern 3	DL	DL	UL	UL	DL	DL	UL	UL	DL	DL	UL	UL
TDD Pattern 4	DL	UL	UL	UL	DL	UL	UL	UL	DL	UL	UL	UL
TDD Pattern 5	DL	UL	DL	UL	DL	UL	DL	UL	DL	UL	DL	UL

1. Compute the length of the TDD period in ms for each of the 5 TDD patterns.

2. Assume all radio, processing, and protocol delays are zero at both the UE and the gNB unlike the figure above. Hence, once a data packet arrives from the application at the UE, the SR request is sent in the immediate next uplink slot. Similarly, once an SR request is granted, the UE sends the data in the immediate next uplink slot. Finally, once the SR request arrives at the gNB, the

SR grant is sent in the immediate next downlink slot. Note, however, if the data packet arrives at the UE in an uplink slot, it has to wait for the next uplink slot to send the SR and cannot send it in the current uplink slot.

Define the latency as the time between when the packet arrives at the UE and the time the UE starts transmitting it on the air. For each of the five TDD patterns, compute the latency in ms for transmitting an uplink packet assuming the packet arrives at the UE at the beginning of time slot 1, $t = 0$ ms in the figure above. Which pattern exhibits the lowest latency?

3. Now assume that the packet can arrive at any time t within the first TDD period of each of the patterns below. Derive a formula as a function of t for the latency in ms in each pattern.
4. Assume the packet is equally likely to arrive anytime during the first TDD period, i.e., uniform distribution of probability of arrival in the first TDD pattern. For each TDD patern, compute the max, min, and mean latency in ms.
5. Which pattern minimizes uplink latency distribution? What is a drawback of using such pattern in practice if any?
6. Now assume that the transmission, radio, processing, and protocol delays are 0.7 ms on the gNB and 0.9 ms on the UE. Recompute the latency in ms for each of the 5 patterns assuming the packet arrives at the UE at the beginning of time slot 1, $t = 0$ ms in the figure above. Note, that the gNB and the UE cannot transmit in the same slot when the delays due to radio, processing, and protocol are done as resources for this slot have already been allocated. They always need to wait for the next slot.
7. Which TDD pattern yields the lowest latency in question 6? Is it the same as the one in question 2? What does this tell us about which pattern is best?

3 OFDM 30 points

Consider a wireless system using OFDM with a bandwidth of 80 MHz, $N = 512$ and the subcarriers are used as follows:

- DC Bins: $-1, 0, +1$
- Guard Bins: -256 to -246 and $+245$ to $+255$
- Pilot Bins: $\pm 25, \pm 53, \pm 89, \pm 117, \pm 139, \pm 167, \pm 203, \pm 231$
- Data Bins: All other subcarriers.

The system uses 8 preamble symbols as shown in the figure below: 4 for packet detection, 2 for CFO estimation, and 2 for channel estimation. The cyclic prefix is set to 0.8 μs.

The transmitter can choose between 3 modulation and coding schemes:

- MCS 0: BPSK with coding rate 1/2
- MCS 1: 16 QAM with coding rate 3/4
- MCS 2: 64 QAM with coding rate 2/3
- MCS 3: 1024 QAM with coding rate 3/4

1. Identify an error in the above figure that will prevent decoding the OFDM packet properly? Explain why is it an error and how to fix it.
2. Compute the data rate as described in lecture 3 for MCS0, MCS1, MCS2, and MCS3.
3. Suppose each transmitted packet must contain 1500 bytes of data bits. How long does it take to transmit the entire packet including preambles for each of MCS0, MCS1, MCS2, and MCS3.
4. We can compute the data rate by dividing the number of data bits transmitted in the packet by the total time to transmit the packet. Compute the data rate using this method for each of MCS0, MCS1, MCS2, and MCS3.
5. Do the data rates computed in questions 2 and 4 match? If not, explain why and which one is more accurate?
6. Compute the relative error between the data rates computed in questions 2 and 4 for MCS0, MCS1, MCS2, and MCS3 (relative to the more accurate values)? How does the error vary with the MCS? Explain why the error varies this way.
7. The preamble is sent with BPSK modulation. Would it make sense to transmit the preamble at higher order modulation to reduce its overhead?
8. Propose one possible solution to reduce the overhead of the preamble.

4 MIMO 20 points

For this problem, the following assumptions hold:

- All the participating nodes are in the radio range of each other
- The frequency offset between transmitter i and receiver j, Δf_{ij}, is known only at receiver j. The transmitters do not know the frequency offsets and each receiver knows only the frequency offsets between itself and the transmitters.
- The channel between any transmit-receive antenna pair is known to all transmitters, i.e., all h_{ij} are known to all transmitter nodes.
- assume the h_{ij}'s are all non-zero.

1. Consider Figure 1, where a 2-antenna AP transmits to two one-antenna clients A and B. The AP has two symbols p_1 and p_2, and wants to deliver p_1 to client A, and p_2 to client B.

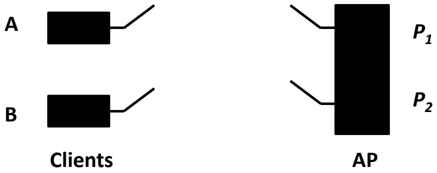


Figure 1: A 2-antenna AP transmitting to 2 clients, each with one antenna.

Assume there are no frequency offsets, i.e., $\Delta f_{ij} = 0$ for any i and j. Let n_i be the noise, then the symbols received at the clients y_A and y_B are given by:

$$\begin{bmatrix} y_A \\ y_B \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

If the transmitting AP does not zero-force by precoding the transmitted symbols p_1 and p_2, neither client can decode its symbol. Find a precoding matrix M such that if the AP multiplies the transmitted symbols by M before transmitting, i.e.:

$$\begin{bmatrix} M \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \end{bmatrix},$$

then each client receives its respective symbol without interference. If no such matrix exist, then explain why this is the case.

2. Again, consider the scenario in Figure 1, but assume now that there are **different and nonzero** frequency offsets Δf_{11} and Δf_{21} between the transmitting AP and the two receivers. The symbols at the receivers are now given by

$$\begin{bmatrix} y_A \\ y_B \end{bmatrix} = \begin{bmatrix} h_{11}e^{j2\pi\Delta f_{11}t} & h_{12}e^{j2\pi\Delta f_{11}t} \\ h_{21}e^{j2\pi\Delta f_{21}t} & h_{22}e^{j2\pi\Delta f_{21}t} \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

Can the AP still zero-force at the transmitter by precoding with a matrix M such that both clients can successfully decode their respective symbols without interference? If "yes", what is M and how do the clients decode, if "no", then why?

3. Let us now consider the scenario shown in Figure 2, where we have two single-antenna APs instead. AP1 has symbol p_1, which it wants to deliver to client A, and AP2 has symbol p_2, which it wants to deliver to client B.

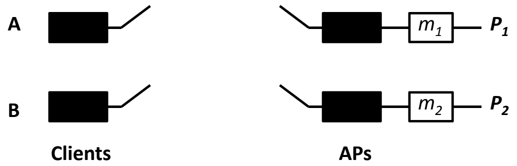


Figure 2: Two one-antenna APs transmitting to two one-antenna clients

Assume there is no frequency offset, i.e., $\Delta f_{ij} = 0$. Does there exist two multipliers m_1 and m_2 such that each transmitted symbol is received at its intended receiver without any interference? If so, what are these multipliers? If not, why not? (Note that both APs know all channels h_{ij} between all senders and receivers.)

4. Now let's assume that the APs are connected by a back-end Ethernet and can communicate the transmitted symbols to each other as shown in Figure 3. Hence, both of them now know p_1 and p_2. Still we need to deliver p_1 to client A and p_2 to client B.

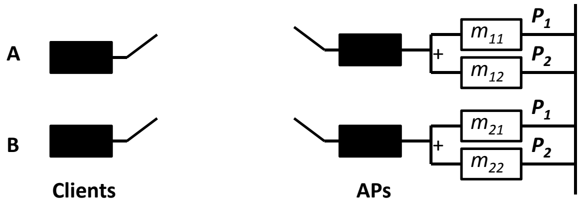


Figure 3: Two one-antenna APs transmitting to two one-antenna clients. The APs however can exchange symbols over a backend Ethernet

Does there exist multipliers m_{11}, m_{12}, m_{21} and m_{22} such that each client can receive the symbol intended for it without any interference? Assume that there is no frequency offsets (i.e., $\Delta f_{ij} = 0$ for all i and j).

5. Consider again the scenario shown in Figure 3. Let's now assume that there are non-zero frequency offests, i.e., $\Delta f_{11}, \Delta f_{12}, \Delta f_{21}$ and Δf_{22} are nonzero and different. Does there exist m_{11}, m_{12}, m_{21} and m_{22} such that client A will receive symbol p_1 without any interference, and client B will receive symbol p_2 without any interference?