COM 405: Mobile Networks – Fall 2025
Homework 2
EPFL

Due Friday November 14 at 8:00pm

Instructions

- Homework is due Friday November 14 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

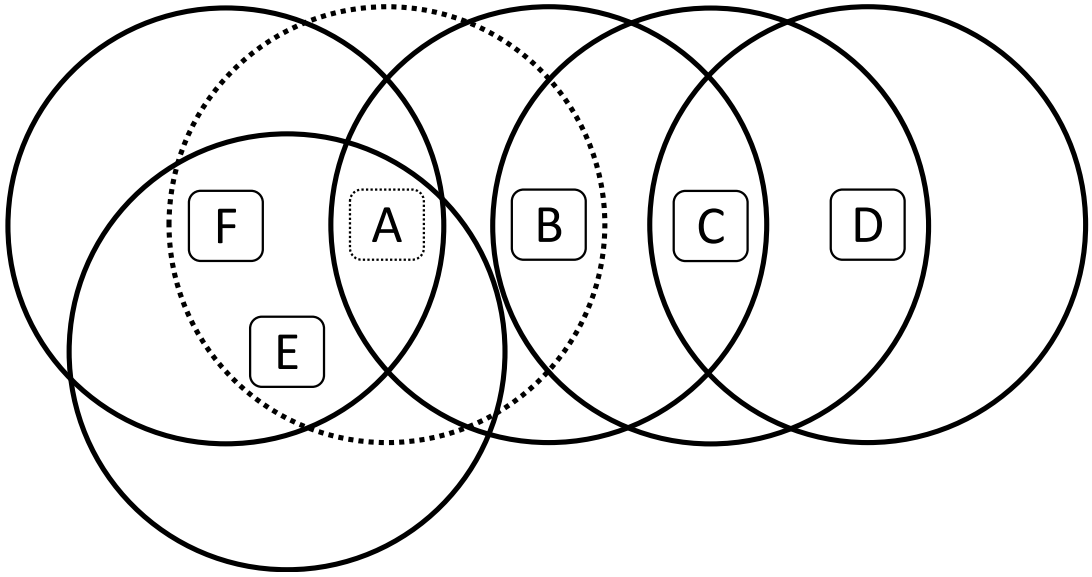
  24 – 48 hrs late: -20 points

  48 – 72 hrs late: -40 points

  $>$ 72 hrs late: -100 points

1 Interference 22 points

In the diagram below, each wireless node is shown along with its transmission radius. E.g., A's transmission radius is the circle with the dashed line.



1. List all the hidden terminals in the above wireless network?
2. The network uses CSMA/CA. When B wants to transmit to A it sends an RTS and A replies with a CTS to reserve the channel. Is this guaranteed to avoid collisions, explain why or why not?
3. In 802.11, after node A receives the data packet successfully, it sends an ACK message. Why is it necessary to send an ACK message?
4. Suppose the nodes F, A, B, C, D are equally spaced by a distance of d. Assume all nodes are identical and transmit at same power level on the same frequency. Also assume the signal attenuates based on free space pathloss equation presented in class.

   F is transmitting to A while C is transmitting to D. Compute the SINR of C's signal at D in the following cases?

   (a) The noise power at D is zero.

   (b) The noise power at D is not zero and in the absence of any interference, the SNR of C's signal at D is 10.

2 WiFi MAC Fairness 10 points

Consider an 802.11 network with 2 clients connected to an AP. One client has a good channel to the AP that can sustain a bit rate of 54 Mb/s, while the second client has a bad channel to the AP that sustains

only a bit rate of 2 Mb/s. Assume the MAC is perfectly fair and efficient, and has no overhead. Also, assume that bitrate adaptation is perfect and has converged to the optimal rates mentioned above.

1. What is the throughput that each client achieves to the AP when operating individually i.e. only one of the clients is present?

2. What is the throughput that each client achieves to the AP when the two clients operate jointly i.e. both clients contend and get to transmit the same number of packets on the channel?

3 CDMA Codes & GPS **26 points**

As mentioned in class, the most popular use cases of CDMA codes are 3G and GPS. Since 3G is being phased out, we will focus on GPS. GPS uses a CDMA code of length 1023 that is transmitted with 1.023 MHz bandwidth at a center frequency of 1.57542 GHz. The GPS receiver correlates with the codes of known satellites to lock on to each satellite i.e., decode the data bits and determine the relative delay between satellites.

1. Calculate the data rate of the data bits transmitted by the GPS satellite given the fact that each bit is repeated 20 times before encoding it using the CDMA code? Show your calculation.

2. For BPSK, the BER $< 10^{-3}$ for SNR above 7 dB. The noise floor of the GPS receiver is -110 dBm.

   (a) At what power in (dBm) should the GPS signal be received to ensure that the BPSK coded bits are decoded with a BER less than 10^{-3}? (Hint: GPS signals are typically received below the noise floor and correlating with the CDMA code brings the signal above the noise floor.)

   (b) Assuming a GPS satellite is right above the receiver at a distance of 20200 km. Assume that the signal loss mainly comes from free space propagation pathloss. The GPS satellite uses an antenna with a gain of 12 dB and the GPS receivers uses an antenna with a gain of 4 dB. An additional 5 dB loss is incurred due to atmospheric absorption. What is the minimum transmit power in Watts of the GPS satellite that ensures the BPSK bits are decoded with BER less than 10^{-3}?

   (c) GPS satellites typically transmit at 44.8 Watts. Does this match the answer computed in the previous questions? Explain why or why not.

3. The motion of the satellites creates a Doppler shift that can corrupt the correlation between the CDMA code and the received signal.

   (a) Mathematically explain why the Doppler shift prevents us from finding the peak of the correlation.

   (b) Assuming no CFO (carrier frequency offset) and satellites travel at a speed of 14000 km/hr, what is the maximum Doppler shift that the receiver sees.

   (c) To deal with Doppler shift, GPS receivers typically do a search over Doppler shift. The receiver tries to correct for the Doppler shift and then does the correlation. The receiver tries 41 Doppler shifts between -10 kHz and +10 kHz. What is the resolution at which the Doppler shift is corrected for?

   (d) Give one advantage and one disadvantage of using higher resolution in correcting for the Doppler shit.

4 Scheduling 18 points

In a downlink single-cell cellular network (using TDD), all clients experience free space line-of-sight channels to the base station. In each time slot, only one client can be scheduled and the client will send a packet across the whole system bandwidth $B = 100$ MHz. The SNR gap is $\theta = 1.2$. The transmission power of the base station P_{TX} is 1 Watt. The noise floor N_0 is -192.5 dBm/Hz. Five clients are located at 10, 50, 100, 150, and 250 meters aways from the base station. The base station and clients are operating at a carrier frequency $f_c = 2$ GHz.

Recall that the expected data rate of a terminal can be computed as:

$$S = B \times \log_2\left(1 + \frac{\Gamma}{\theta}\right)$$

where Γ is the SNR and can be calculated as:

$$\Gamma = \frac{P_{RX}}{N}$$

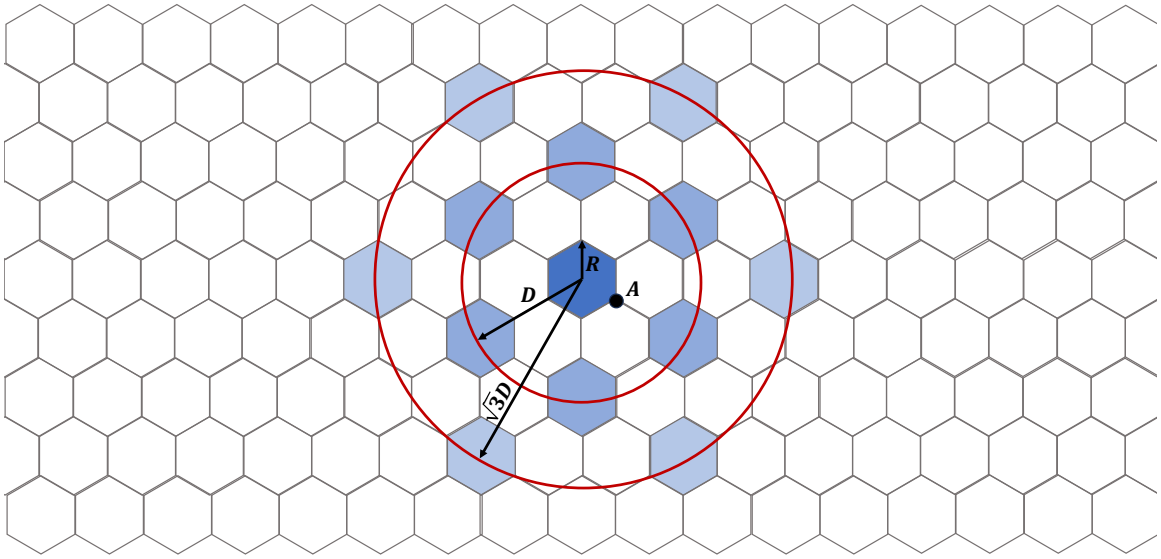
We have:

- $P_{RX} = \frac{\lambda^2}{(4\pi d)^2} P_{TX}$ where d is the distance between the client and the base station, P_{RX} is received power, and $\lambda = c/f_c$ with c being the speed of light at 3×10^8 m/s.
- $N = N_0 \times B$ where N is the total noise power, N_0 is the noise spectral desnity (noise floor), and B is the bandwith. Remember to convert dBm/Hz to mW/Hz when you preform your calculations.

1. What are the expected downlink data rates of the clients that are at 10, 50, 100, 150, and 250 meters away from the base station? Indicate the steps that you are taking to find the solution and mention the unit of the computed values.
2. Assuming the constant from lecture 4.1, $\tau = 4$ and the throughput S_i of all clients at $t = 0$ what is the average network data rate over 30 time slots if the scheduling algorithm is:
   (i) *Round Robin*
   (ii) *Max-Throughput*
3. A sixth client moves from another cell to this cell's center and stops for communications at 250 meters away from the base station. Answer the following questions for both *Round Robin* and *Max-Throughput* scheduling:
   (i) What is the (down-link) data rate of this client when it stops for communications?
   (ii) What is the new average network data rate at that moment?
4. The client that was at 150 meters away from the base station has now moved and is at 37 meters away from the base station. Answer the following questions for both *Round Robin* and *Max-Throughput* scheduling:
   (i) What effect does this move have on the other clients' data rates?
   (ii) How does the average network throughput change?

5 Cellular Networks — 24 points

Consider a cellular system where the cell plan used is a symmetric hexagonal plan. The system under consideration is illustrated in the figure below. Note here that not all cells are colored in the picture. The blue colored hexagons in the figure represent co-channel cells (i.e., the cells using the same set of frequencies). These cells cause so called co-channel interference to any blue hexagon. The distance between the centers of the nearest co-channel cells denoted with D, and the radius of a cell with R.



In a symmertic hexagonal cell plan, each cell has exactly 6 co-channel cells at distance D as shown in the figure above. In addition there are 6 co-channel cells at distance $\sqrt{3}D$, 6 at $\sqrt{4}D$, 6 at $\sqrt{7}D$, $\cdots$, $\sqrt{N}D$, and so forth, where $N = (i+j)^2 - ij$, $i, j = 0, 1, 2, 3, \cdots$. Recall that for the hexagonal cell plan, we have the following: $K = \frac{1}{3} \cdot (\frac{D}{R})^2$, where K is the number of cells that divide the available channels in unique and disjoint channel groups of approcimately the same size.

Assume that the propagation model is a power law distance dependence model, that is, $P_r = cP_t d^{-\alpha}$, where P_t is the transmitted power, P_r is the received power, d is the transmitter-receiver separation distance, α is the propagation loss exponent and c is a constant. Also assume that the network is of infinite size, and that all base stations transmit at the same power P.

1. Find an expression for the co-channel interference (SIR) on the downlink channel (from a base station to a user) that a user at point A in the above figure experiences. Express the SIR as a function of $\frac{D}{R}$ for the following two values of the propagation loss exponent $\alpha = 2$ and $\alpha = 4$. Assume that all interferers at the same interference tier are at the same distance from point A i.e., all the first tier interferers are at distance D from A, the second tier are at distance $\sqrt{3}D$, $\cdots$.

   Hint 1: Compute the SIR at A as the ratio between the received power at A from the center cell (i.e., the signal) and the total received power at A from the other cells (i.e., the interference).

   Hint 2: $1 + \frac{1}{3} + \frac{1}{4} + \frac{1}{7} + \cdots = \infty$

   Hint 3: $1 + \frac{1}{3^2} + \frac{1}{4^2} + \frac{1}{7^2} + \cdots = 1.233$

2. What is the problem with $\alpha = 2$? Why is this not a problem in practice?

3. Consider that this celluar system has $C = 500$ channels, and a minimum signal-to-interference raio (SIR) of 19 dB is required in order to provide acceptable signal quality at a receiver. The radio capacity η of a cellular system is defined as the number of users that can be supported in a single cell, that is, $\eta = \lfloor \frac{C}{K} \rfloor$ radio channels/cell (for fixed channel allocation). What is the radio capacity η of this cellular system, assuming $\alpha = 4$?