COM 405: Mobile Networks – Fall 2024
Homework 1
EPFL

Due Friday October 18 at 8:00pm

Instructions

- Homework is due Friday October 18 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.
- 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

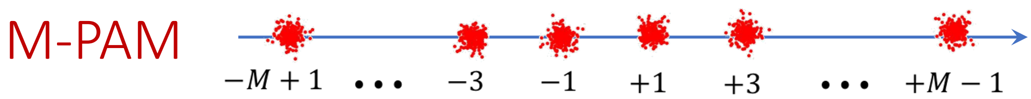
1 Wireless Channel — 30 points

Consider a wireless channel where the signal traveles along two paths $d_1 = 3\ m$ and $d_2 = 3.075\ m$. The frequency of operation is $f_c = 1$ GHz and the speed of light is $c = 3 \times 10^8 m/s$. You can assume that the attenuation factor (channel magnitude) on the first path d_1 is 0.01 and on the second path d_2 is 0.008.

1. Write the exact equation of the complex channel impulse response $h(t)$.
2. Assuming the transmitter and receiver use a narrowband channel, what is the narrowband channel approximation of the channel impulse response.
3. Assume the transmitter transmittes at 0.1 mW. The receiver's noise floor is −80dBm. What is the SNR of the received signal in dB?
4. Compute the SNR if we switch to a frequency of operation $f_c = 2$ GHz, the transmitter is still using a narrow band channel and transmit power of 0.1 mW, and the attenuation factor is 0.005 on the first path and 0.0048 on the second path.
5. What is the wireless channel phenomenon called?

2 Constellations **(30 pts)**

1. Consider the M-PAM constellation shown above.



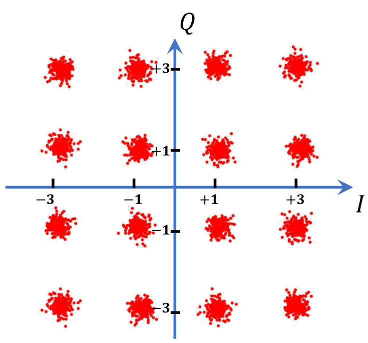
   (a) Derive the normalization factor that ensures the total transmitted energy is E_s. Hint, you can use the following formulas:

$$\sum_{k=1}^{n} k = \frac{n(n+1)}{2} \qquad\qquad \sum_{k=1}^{n} k^2 = \frac{n(n+1)(2n+1)}{6}$$

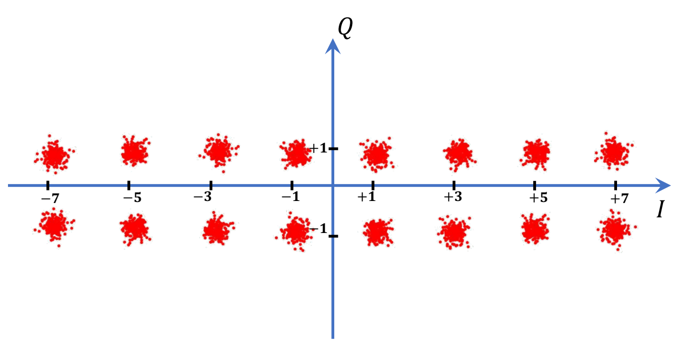
   (b) What is the average number of nearest neighbor in the above constellation?

   (c) What is the BER vs E_s/N_0 of the M-PAM constellation using the nearest neighbor approximation?

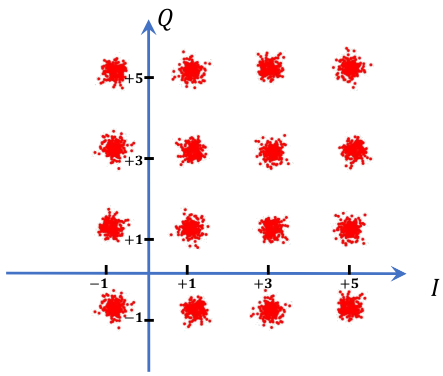
2. Consider the below 16-QAM constellations: (i) Regular 4×4 Grid. (ii) 16-QAM on a rectangular 2×8 Grid (iii) 4×4 Grid shifted so the constellation has mean of $2 + 2j$ i.e., $\mathrm{E}[x(t)] = 2 + 2j$. (iv) 4×4 Grid rotated around $(0, 0)$ by $\pi/2$.



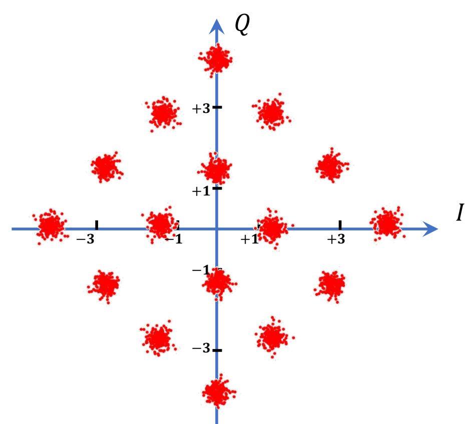
(i) 4×4 Grid



(ii) 2×8 Grid



(iii) 4×4 Grid shifted to mean $2 + 2j$



(iv) 4×4 Grid rotated by $\frac{\pi}{2}$

(a) Suppose $E_s = 1$, for each of the four constellations, compute the minimum distance d_{min} between any two constellation points. (Hint: make sure to first normalize the total transmitted energy to 1).

(b) For each of the rectangular, shifted, and rotated constellations, state whether their BER performance will be better, the same or worse than the regular 4×4 Grid. Justify your answer.

(c) If the BER performance is the same, is there another reason why we prefer to use the 4×4 Grid over the other constellations.

(d) **(Bonus)** Formally prove that any constellation where the mean of the constellation points $\mathrm{E}[x(t)] \neq 0$ is suboptimal in terms of its BER performance.

3 OFDM in WiFi 5 vs. WiFi 6 — 40 points

Consider 802.11ax (WiFi 6) and 802.11ac (WiFi 5) using OFDM with the parameters shown below:

WiFi	802.11ax	802.11ac
Bandwidth	80 MHz	80 MHz
N	1024	256
DC Bins	$-2, -1, 0, +1, +2$	$-1, 0, +1$
Guard Bins	-512 to -501 and $+501$ to $+511$	-128 to -123 and $+123$ to $+127$
Pilot Bins	$\pm24, \pm92, \pm158, \pm226, \pm266, \pm334, \pm400, \pm468$	$\pm11, \pm39, \pm75, \pm103$
Cyclic Prefix	$1.6\mu s$	$1.6\mu s$
Preamble	8 symbols: 4 for packet detection, 2 for CFO estimation, 2 for channel estimation.	

For both WiFi 5 and WiFi 6, the transmitter can choose between 3 modulation and coding schemes:

- MCS 0: BPSK with coding rate 1/2
- MCS 1: 4 QAM with coding rate 3/4
- MCS 2: 64 QAM with coding rate 5/6

1. Compute the data rate for each of the above modulation schemes for WiFi 5 and WiFi 6. (You should ignore the preamble in this part and you must show your detailed calculation to get the credit for this part.)
2. Which standard has higher data rates? WiFi 5 or WiFi 6? Given that the standards have the same bandwidth and support the same modulation and coding schemes, explain why one standard is able to provide higher data rates?

3. Suppose each transmitted packet must contain 1500 bytes of data bits. What is the overhead of the preamble in WiFi 5 and WiFi 6 for each of the 3 modulation and coding schemes? Only consider the overhead of the preamble.

4. Compute the actual data rate for each of the 3 modulation and coding schemes in WiFi 5 and WiFi 6 while accounting for the preamble overhead.

5. Which standard has higher actual data rates? WiFi 5 or WiFi 6? Explain why one standard performs better?

6. For each of WiFi 5 and WiFi 6, what is the maximum absolute value of the CFO that can be estimated given the above OFDM parameters i.e., a larger CFO would not be estimated correctly during the coarse CFO estimation? (Hint: Phase wraps around every 2π and CFO can be negative or positive.)

7. Name one advantage of using WiFi 5 to estimate CFO over WiFi 6 and one advantage of using WiFi 6 to estimate CFO over WiFi 5.