Problem 1.1 – Cell Search

For the sake of simplicity, in exam tasks, we are using 3^{rd} order M-sequences. In the following figure, a Primary Synchronization Signal (PSS) generating scheme is given:

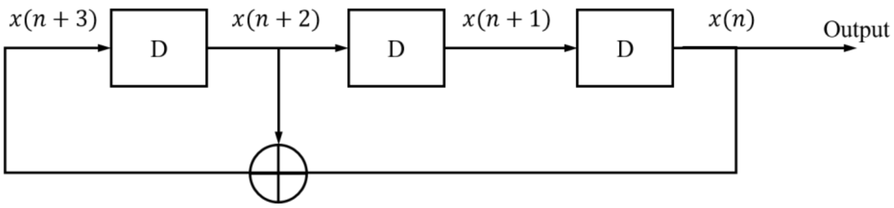


Figure 1. Generation of basic M-sequence: $x(k) = x(k-1) \oplus x(k-3)$.

Initial sequences for the scheme are determined as follows:

- PSS = 0 has initial sequence $[x(2), x(1), x(0)]$ = [0 1 1];
- PSS = 1 has initial sequence $[x(2), x(1), x(0)]$ = [0 1 0];
- PSS = 2 has initial sequence $[x(2), x(1), x(0)]$ = [1 0 0].

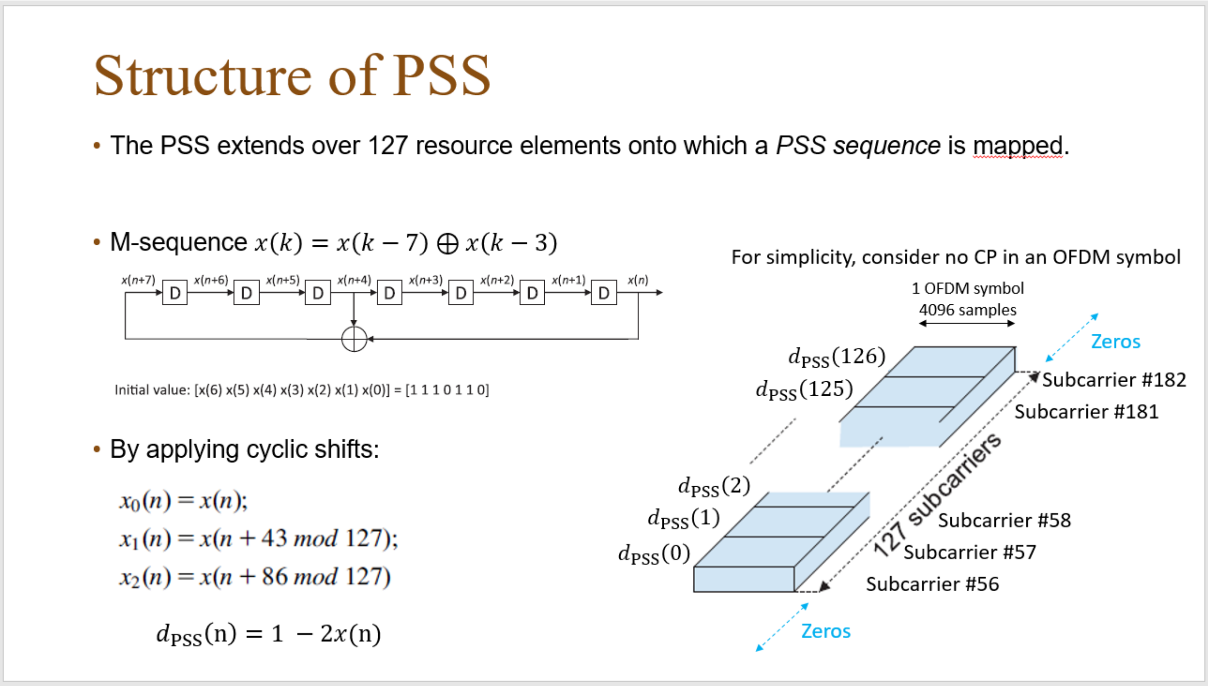
After a UE is switched on, it starts the procedure of cell search. During the synchronization phase it detects a PSS sequence $[p(6), p(5), p(4), p(3), p(2), p(1), p(0)] = [1\ \ 0\ \ 0\ \ 1\ \ 0\ \ 1\ \ 0]$. Assume that one value of the received sequence is detected incorrectly (either 0 or 1) due to the channel influence. **Note**, keep in mind that the ordering must be correct.

Tasks:

1. Calculate basic M-sequences based on the initial sequences (you should obtain 3 M-sequences).
2. By defining which sequence has been received by the UE, specify the value of the considered PSS, and calculate the Physical Cell Identity (PCI) based on the given **SSS = 269**.
   Hint! Scalar product between the detected PSS sequence and the basic M-sequences can be helpful.

Problem 1.2 – 5G/NR Cell Search in Matlab

In 5G/NR, PSS sequence consists of ones and zeros. To map the values of PSS to subcarriers, it is converted to $\{-1,1\}$ alphabet. Use the following enhanced slide from the lectures (Lecture 10)



Slide 1: Structure of PSS in 5G/NR

Assume that your mobile device has been listening to the channel during four OFDM symbols and performing PSS synchronization. You have the received signal – 4 OFDM symbols as a Matlab *.mat file = `received_4_OFDM_symbols_V5.mat`

Tasks:

1. Create a Matlab script to generate M-sequences based on the slide above (you should obtain 3 M-sequences). Map M-sequences correctly in the frequency domain and transfer from the frequency domain to the time domain.
2. By using the received signal file (`received_4_OFDM_symbols_V5.mat`), define the value of the received PSS using a "sliding window" algorithm, and calculate the Physical Cell Identity (PCI) based on the given **SSS = 269**.
3. Define the starting sample of the received PSS.
4. Define your carrier frequency, numerology, and number of resource blocks (RBs) from Table 1.

PCI	fc in GHz	μ (Numerology)	N_RB (Number of RBs)
144	24.2	4	206
145	24.2	2	84
146	24.2	3	135
159	2.4	0	74
160	2.4	1	36
161	2.4	2	29
333	3.7	2	76
334	3.7	0	59
335	3.7	1	70
426	27	3	120
427	27	2	204
428	27	4	62
489	4.4	2	32
490	4.4	1	55
491	4.4	0	39
798	29	2	255
799	29	3	162
800	29	4	96
807	4.8	0	18
808	4.8	1	92
809	4.8	2	57
921	28	2	126
922	28	3	38
923	28	4	238
966	37	4	130
967	37	3	148
968	37	2	266
978	3.5	1	84
979	3.5	0	83
980	3.5	2	76

Table 1: Carrier frequency, numerology, and number of resource blocks for different PCI

Problem 2 – Throughput Calculation and Channel Modeling

You are given with a 2D environment schematically depicted below:

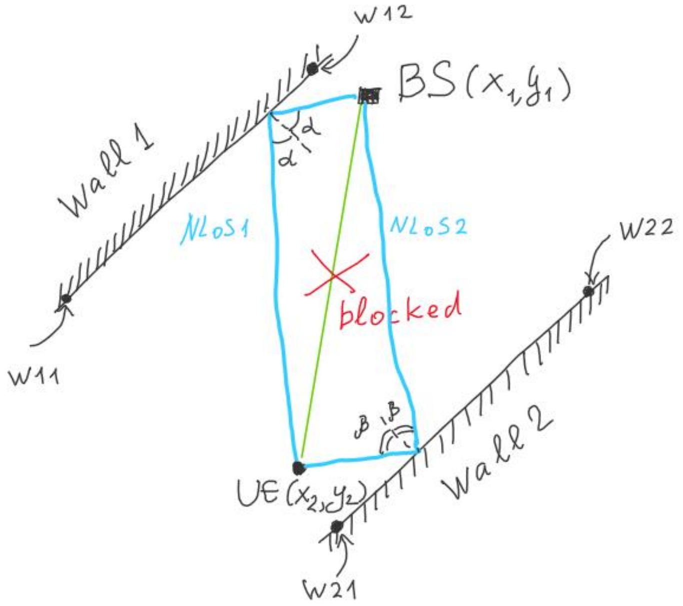


Figure 2: Propagation environment

Signals propagate from the BS to the UE. The walls are ideally reflecting surfaces defined by two points (W11, W12) and (W21, W22) each (small black dots on the walls surfaces).

Assume:

- the line-of-sight path is blocked,
- only first-order reflection is considered (single-bounce),
- the polarization of the antennas is not taken into account,
- the attenuation caused by reflection can be represented via coefficient $C = 0.5$,

Input data:

- The transmitter's power is 20 mW within the given bandwidth,
- At the receiver side, the power density of noise is -174 dBm/Hz.
- The coordinates of the BS and UE are the following:
  - BS = [211.50, -133.66]; UE = [-133.30, -130.88];
- The coordinates of the walls' defining points are the following:
  - Wall #1: W11 = [-86.60, 50]; W12 = [259.80, -150];
  - Wall #2: W21 = [-186.60, -123.20]; W22 = [159.80, -323.20];

Tasks:

1. Determine possible non-line-of-sight paths: calculate lengths of the paths, find reflection points on the walls.
   a. What numerologies can be used in the given scenario to avoid ISI?
   b. What is the maximum theoretical transmit bandwidth the system can achieve in the proposed numerologies? *Note: Assume all subcarriers are used.*
   c. How much the baseband sampling rates (Fs) differ in the proposed numerologies?

2. By considering the determined carrier frequency f_c, numerology μ, and number of RBs N_RB from Problem 1.2, Task 4, calculate the channel observed by the receiver. Plot the channel on the dB scale in the y-axis. Refer to the generic channel modeling script `Multipath_Channel.m` where you need to incorporate your input data.

   You should obtain a result similar to the following picture:

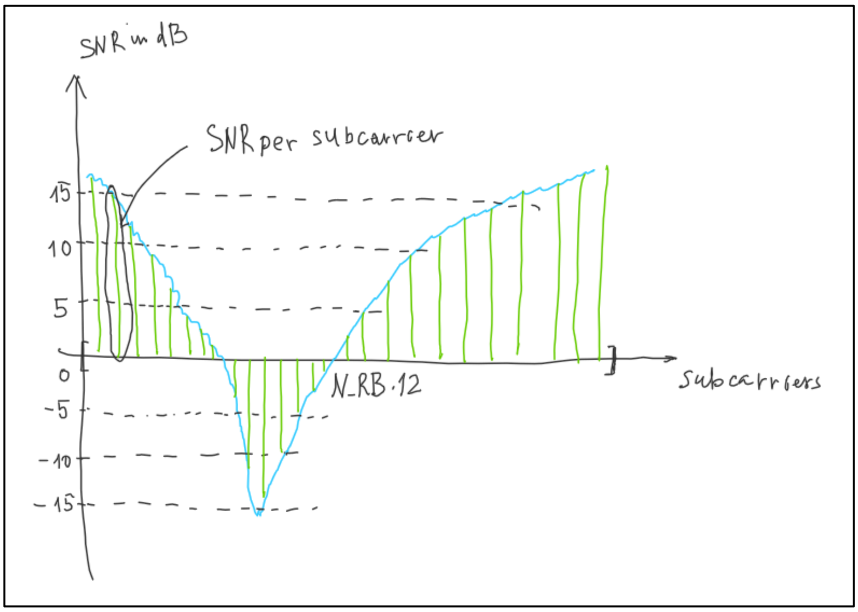


Figure 3: Example of SNR per subcarrier vs frequency in the receiver.

3. For each subcarrier propose a proper MCS option from Table 2. For simplicity purposes, use different MCS values for each subcarrier with a granularity of 5 dB, i.e. [-15, -10, -5, 0, 5, 10, 15] dBs. (No need to choose MCSx for 5 dB and MCSy for 8 dB; use the same MCSx for both 5 dB and 8 dB).

   Note! If your SNR is too low (for example SNR < -5 dB), adjust the coding rate in Table 2 and make it lower than the minimum presented in the table, i.e. rc=30/1024 < 120/1024.

   The Shannon capacity formula for a channel subject to AWGN is given by: C = B log2(1+SNR) [bps], where B is the system bandwidth (in Hz), and SNR is the Signal-to-Noise Ratio.

4. Calculate the total throughput of the system under the considered conditions.

The MCS table is taken from document “3GPP TS 38.214 version 15.3.0 Release 15”.

MCS Index I_{MCS}	**Modulation Order** Q_m	**Target code Rate** R **x [1024]**
0	2	120
1	2	193
2	2	308
3	2	449
4	2	602
5	4	378
6	4	434
7	4	490
8	4	553
9	4	616
10	4	658
11	6	466
12	6	517
13	6	567
14	6	616
15	6	666
16	6	719
17	6	772
18	6	822
19	6	873
20	8	682.5
21	8	711
22	8	754
23	8	797
24	8	841
25	8	885
26	8	916.5
27	8	948

Table 2: MCS table from 3GPP TS 38.214 version 15.3.0 Release 15