WIRELESS COMMUNICATION SYSTEMS LABORATORY
LAB #9: MULTIPLE ACCESSING AND SCHEDULING

Objective

The objective of this experiment is to understand resource allocation among multiple users and comprehend managing resulting interference. The students will be familiar with the following items in PART-A:

- Time-division multiple access
- Code-division multiple access (DSSS and FHSS)
- Understand the effect of interference on communication systems

Applying multi-waveform and multi-numerology scheduling on a flexible frame is an important concept in 5G and beyond. There is an optimization necessity while scheduling users on a frame from the perspective of different application requirements. In PART-B, the students will try to make an optimal scheduling to meet the given requirements and learn to interpret the related performance indicators.

Pre-Lab

- Investigate the advantages and drawbacks of different multiple accessing methods in wireless communications systems. Make a comparison table considering these methods.
- Understand the multi-numerology OFDM concept in 5G NR by checking the below journal papers. Think about the trade-off cases for multi-waveform and multi-numerology frames.

1. A. B. Kihero, M. S. J. Solaija, H. Arslan, "Inter-Numerology Interference for Beyond 5G," IEEE Access, 7(1), 146512-146523, Oct. 2019.
2. A. Yazar, H. Arslan, "Flexible Multi-Numerology Systems for 5G New Radio," River Publishers Journal of Mobile Multimedia, 14(4), 367-394, Oct. 2018.
3. A. Yazar, H. Arslan, "A Flexibility Metric and Optimization Methods for Mixed Numerologies in 5G and Beyond," IEEE Access, 6(1), 3755-3764, Feb. 2018.

PART-A

In this part, students will use **recorded data** without running the GUI application.

I. TIME-DIVISION MULTIPLE ACCESS

- The transmitted signal is single carrier with root raised cosine filter.
- Filter coefficient is 0.3
- Modulation: BPSK
- OSR: 16 in the recording (TDMA125KHzSpan.mat)

The signal has replica of m-sequences (m=6) as training one in the front the other one at the end of the frame. And the user data is cascaded at end of each other. The frame structure can be summarized as in [m-seq, data0, data1, data2, data3, m-seq] and each data part has 91 symbols. Take last 2 digits of your ID#, modulo 3 it and the resulting number is your data (mod(XY,3) = d). Demodulate the d^{th} data frame and obtain the text message sent to you.

II. CODE-DIVISION MULTIPLE ACCESS (DSSS)

- The transmitted signal is a basic CDMA signal.
- Rectangular filter is used at Tx, no Rx filter needed.
- OSR is 1 in the recording CDMA12_5KHzSpan
- Modulation: BPSK

Similarly, to previous section this data also includes training signal with msequences (m=6). The frame structure can be given as in [m-seq, m-seq, CDMAdata, m-seq]. 91 symbols are coded in CDMA using 4-bit orthogonal codes (91x4 total bits). The codes are given in the following, $Code0 = [\ 1 \quad 1 \quad 1 \quad 1]$; $Code1 = [\ 1 \quad -1 \quad 1 \quad -1]$; $Code2 = [\ 1 \quad 1 \quad -1 \quad -1]$; $Code3 = [\ 1 \quad -1 \quad -1 \quad 1]$. Using the same d from previous section, assume your code is the d^{th} one, demodulate the text sent to you.

CDMA12_5KHzSpan2Active data is a recorded signal of a CDMA signal with 2 active codes. After a successful synchronization implementing code domain analysis find out which two codes are active in this signal.

III. FREQUENCY HOPPING DATA

- The transmitter implements basic frequency hoping
- Use data FreqHoping125KhzSpan

In this section, you do not need to implement synchronization. The transmitter implements one of the 4 possible hopping sequence (similar to CDMA time coding, this time signal parts are coded in frequency shifts). Using a proper analysis tool you have learnt so far find out the hopping sequence, frequency shifts and the duration that the signal stay at a frequency.

IV. OFDMA

- Waveform: CP-OFDM
- Modulation: BPSK
- Subcarrier Spacing: 15 kHz.
- Number of Active Subcarriers: 48
- FFT Size: 64
- CP Length: 8
- Starting from 2nd data carrier every 3rd data carrier has pilot symbols goes as, [1,-1,1,-1…] on the data carriers of [2,5,8,…]

As you have noticed, the OFDM structure is same as Lab #9. Differently, each user is cascaded to each other on the active carriers as in [user0, user1, user2, user3]. Therefore, each user has 9 data carriers and 3 pilot carriers while total active carriers are 48. The frame has 10 OFDM symbols and same structure as Lab #9. Again, using the d as your reference demodulate the d^{th} user's text. The time frame structure is given as in [m-seq, m-seq, OFDMA-data, m-seq]. The recorded data is provided in OFDMA.mat with OSR of 1. Hint: the data does not require an RX filter.

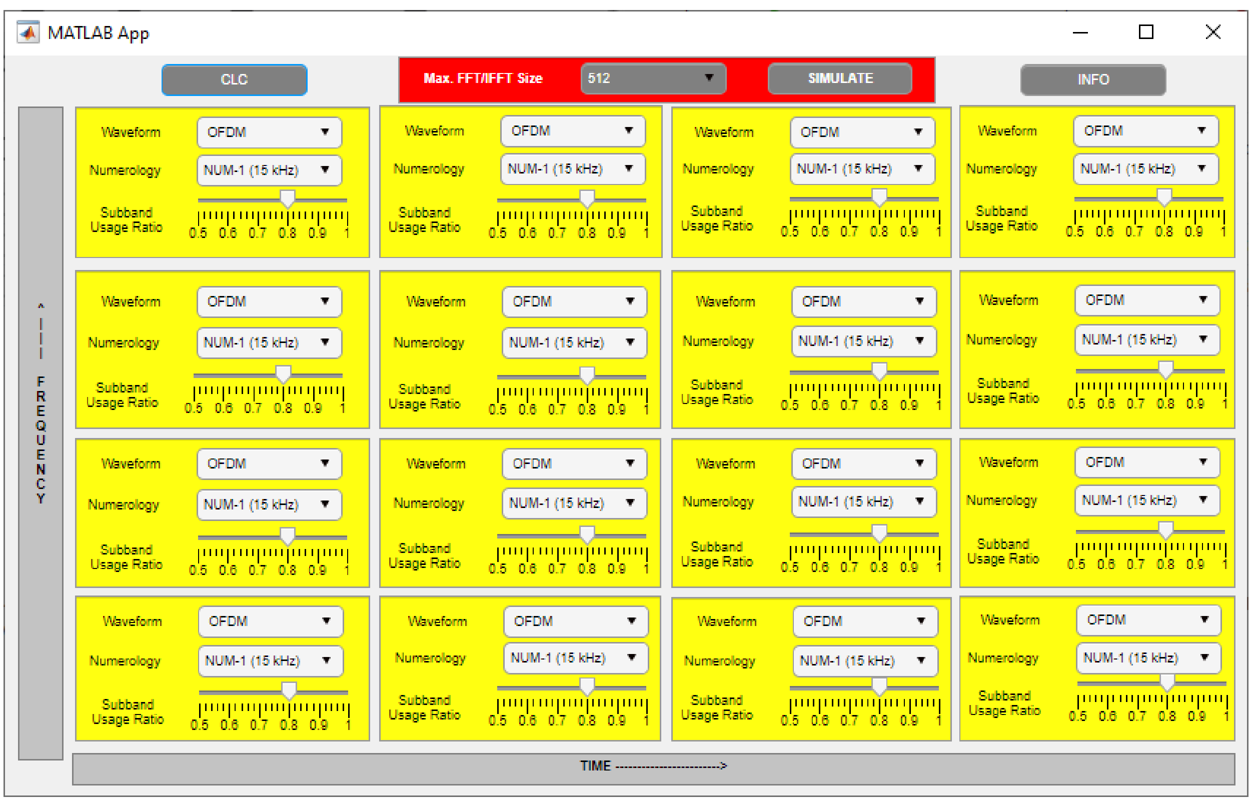
PART-B

In this part, students will use the GUI application (**Lab10-GUI**) without any recorded data. To install the GUI, open the installation file (**Lab10-GUI.mlappinstall**) in MATLAB. After that click on the Lab10-GUI icon from the APPS tab. This icon can be found under MY APPS section.

Students run the GUI to change input parameters of the simulation. SIMULATE button is used to start the simulation with the entered inputs. The related results are shown on **Command Window**. All results will be written to Excel file (**Lab10-GUI-Results**) by students for this part. In the report, only inferences are included.

There are 16 subblocks in the whole downlink frame that includes 4 subframes (in time) and 4 subbands (in frequency). Total channel bandwidth (BW) and frame duration are fixed. Subblocks are aligned with the neigbour subblocks. Frame, subblock, subframe and subband definitions should be used correctly in the lab reports.

Three waveform types and three OFDM numerologies can be selected on the GUI. Numerologies are only valid for OFDM waveform. Subband usage ratio is not considered in SC-CDM waveform.



I. MULTI-NUMEROLOGY SCHEDULING

In this section, students will try to make an optimal scheduling for on the flexible multi-numerology OFDM waveform frame with 16 subblocks. Inter-numerology interference (INI) effects will be investigated. The main performance indicators are flexibility, spectral efficiency, SINR and BER.

Note: Flexibility is estimated using the number of subblocks with different waveforms and numerologies. This metric is prepared **just for this experiment**. It takes values between 1 and 70. For example, if waveform types of subblocks are selected almost equally (6-5-5) and OFDM numerologies are preferred as similarly (2-2-2), flexibility metric is calculated as 70 (maximum). If there is only single-waveform and single-numerology, the metric is calculated as 1 (minimum).

a. Single-Numerology OFDM

- Simulate the single-numerology OFDM for whole frame as a benchmark result.
- Make selections for subband usage ratio less than 0.9 for the subblocks.
- Make a selection for max. FFT/IFFT size and use the same selection during this section.
- Note your results to the Excel sheet (PART-B-I-a).

b. Multi-Numerology OFDM w/o Guard Bands

- Simulate the multi-numerology OFDM with selecting different numerologies.
- Make selections for subband usage ratio as 1.0 for the subblocks.
- Note your results to the Excel sheet (PART-B-I-b).
- Compare your results with the benchmark result and comment on performance indicators.
- Which numerologies are more incompatible with the each other?

c. Multi-Numerology OFDM w/ Guard Bands

- This time, make selections for subband usage ratio less than 0.8 for the subblocks. It will make guard bands available between the consecutive subbands against INI.
- Note your results to the Excel sheet (PART-B-I-c).
- Compare your results with the previous ones and comment on performance indicators.

II. MULTI-WAVEFORM SCHEDULING

In this section, students will try to make an optimal scheduling for on the flexible multi-waveform and multi-numerology waveform frame with 16 subblocks. Inter-waveform interference (IWI) effects will be investigated along with the INI effects.

a. Maximize Flexibility

- Try to maximize flexibility metric considering that application diversity is very high.
- Note your results to the Excel sheet (PART-B-II-a).
- Discuss on the differences with the previous section and interpret them.

b. Maximize Spectral Efficiency

- Try to maximize spectral efficiency while using minimum two different waveforms.
- Note your results to the Excel sheet (PART-B-II-b).
- Compare your results with the previous ones and comment on performance indicators.

c. Maximize Reliability

- Try to maximize reliability metrics while using minimum two different waveforms.
- Note your results to the Excel sheet (PART-B-II-c).
- Compare your results with the previous ones and comment on performance indicators.

d. Jointly Maximize Spectral Efficiency and Reliability

- Try to maximize spectral efficiency and reliability together while using minimum two different waveform selections.
- Note your results to the Excel sheet (PART-B-II-d).
- Compare your results with the previous ones and comment on performance indicators.

e. Comments on the Multi-Waveform Frame Designs

Discuss on the necessity of multi-waveform frames for 6G with specific scenarios and use cases.