EITP30: Laboratory session
LTE Toolbox

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I. OBJECTIVE

Throughout this series of exercises the student will learn some of the most important procedures at the LTE physical layer, which can be seen as a useful tool to understand many of the concepts covered during the course lectures.

II. FIRST STEPS

1) Run MATLAB
2) Open the script provided *EITP30_lab.m*.

III. INTRODUCTION

The student will be provided with a MATLAB script, which is described in the following link. The script covers the steps an UE should follow in order to access the network, assuming a carrier has been already found:

1) Input samples: From real measurement (capture file) or generated from LTE model (ideal).
2) Filtering: Input signal is filtered to 6 central resource blocks (RBs) and resampled accordingly. The resulting spectrum is shown.
3) Cell Search, Cyclic Prefix Length and Duplex Mode Detection: Algorithm to find CellId, Duplex Mode (FDD or TDD), Cyclic Prefix and timing offset.
4) Frequency estimation and compensation.
5) PBCH Demodulation, BCH Decoding, MIB parsing.
6) OFDM Demodulation on Full Bandwidth: signal resampling, frequency offset estimation and correction, timing synchronization and OFDM demodulation.
7) SIB1 Decoding: PCFICH demodulation, CFI decoding, PDCCH decoding, Blind PDCCH search, SIB bits recovery and Buffering and resetting of the DL-SCH HARQ state.

IV. QUESTIONS

The questions are divided into sections, covering different areas of the course. I know some concepts are yet to be given in lectures. Don't panic! Start with sections you already know, or which are easy to figure out, and work on the rest step by step. You can use lectures, exercises, books, or online resources. Understanding the whole script takes time but provides really good practical knowledge, as it covers and connects many important topics. Don't hesitate to contact me in case of help.

A. *Input IQ signal analysis*

Let's start with an ideal signal generated by the LTE Toolbox. For that, make sure loadFromFile = 0. The input signal is sampled at 15.36MHz. Set a breakpoint in line 100 and run the script.

Execute:
>> figure, plot(real(eNodeBOutput)), grid on
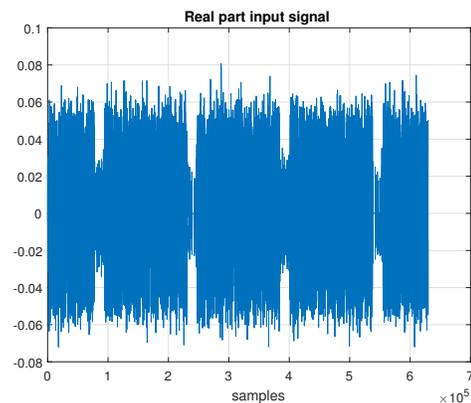
You should now see a figure like Fig. 1.

Fig. 1. Real part input signal.

1) How many frames, subframes and OFDM symbols do you see in the figure? Hint: pay attention to the signal sampling rate.

2) Is the signal level always constant or does it change?

3) Why do you think the signal has gaps?

Now, let's have a look at the histogram of the signal. Execute:
>> figure, hist(real(eNodeBOutput),100)

You should see a figure like Fig. 2.
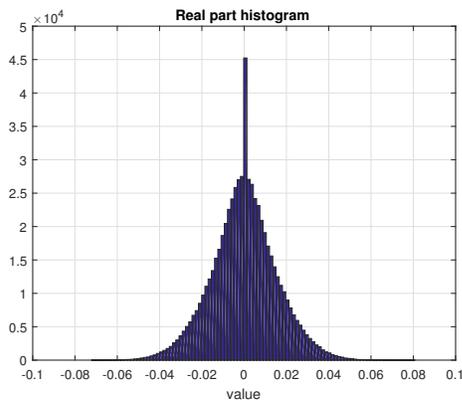
4) What information can you extract from the plot?

Fig. 2. Real part histogram.

Let's have a look at the imaginary part. Execute:
$>>$ figure, hist(imag(eNodeBOutput),100)

5) Is there any difference compared to the real part?

Now, we can plot the complex signal. Execute:
$>>$ figure, plot(eNodeBOutput), grid on

6) How is it related to the histograms seen before?

B. Filtering

Set a breakpoint at line 154 and continue running the script. Look at the Received Signal Spectrum figure.

1) What is the signal BW? How many RB are used? Hint: You can use the vertical markers to measure

2) Is the system bandwidth needed in order to acquire synchronization?

3) Why is filtering needed?

4) How many RBs correspond to the filter bandwidth? Why?

5) Why is downsampling recommended after filtering?

C. Cell Search, Cyclic Prefix Length and Duplex Mode Detection

1) What is the purpose of the two nested for loops between lines 188 and 202?

2) Why do we need to iterate through all duplex modes and all cyclic prefix possibilities?

3) How are the right values obtained?

4) What does the "offset" variable contain? Why is it important?

Now you can run until line 250.

5) What are the values obtained by the algorithm?
   - Duplex Mode (FDD, TDD):
   - Cyclic Prefix (Normal, Extended):
   - CellID:
   - offset:

6) What is the purpose of line 234?

Please, see the figure with title "PSS/SSS correlation". Observe the output of the correlator.

7) What are the peaks representing in the figure?

D. Frequency estimation and compensation

Run until line 261.

1) Why is frequency compensation needed?

2) What is the frequency offset value? Is it expected?

E. OFDM Demodulation and Channel Estimation

In line 298 we demodulate the downsampled OFDM signal.

1) What is OFDM demodulation and why is it needed?

2) What is Channel Estimation and why is it needed?

3) How do we know the number of OFDM symbols per subframe?

Note: the number of OFDM symbols per subframe is obtained in line 296.

Breakpoint in line 299. In line 298, the variable *rxgrid* contains a grid with the demodulated symbols. Let's plot all OFDM symbols together:

$>>$ figure, plot(rxgrid, '+'), grid on

4) What do you see? Was it expected?

Plot OFDM symbols individually to better understand this figure. Try this for the n-th symbol: plot(rxgrid(:,n). '+'). Plot n=1, 10, 100, 200, 300. Compare with Fig. 3.

5) What effect do you see in the constellation?

6) What is the estimated frequency offset? Is it expected? Hint: the estimated frequency offset is represented by $delta\_f$ in line 259.
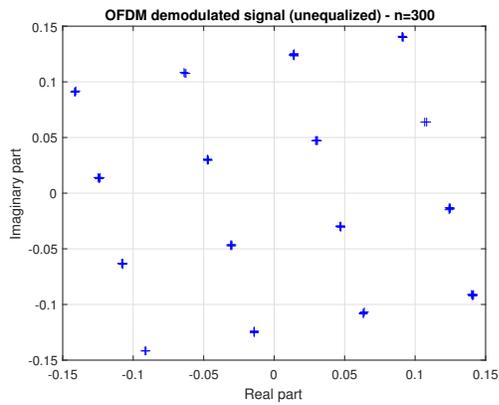
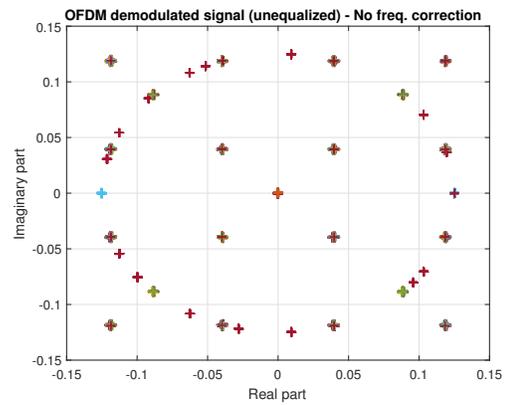Fig. 3. OFDM demodulated signal (unequalized). n=300.

Fig. 4. OFDM demodulated signal (unequalized). No frequency correction.

As you can see in line 261, the estimated frequency off-set is compensated. In our case this leads to an undesired effect, which explains the plots in question 4. Taking into account that the k-th DFT point corresponding to the k-th subcarrier is given by

$$\mathbf{X}_k = \sum_{n=0}^{N-1} \mathbf{x}_n e^{-j\frac{2\pi}{N}kn} \tag{1}$$

where

$$\mathbf{x}_n = \frac{a}{N} e^{j\frac{2\pi}{N}kn} e^{-j\frac{2\pi\Delta_f}{F_s}n} \tag{2}$$

is the discrete time signal, a is the constellation complex value (i.e. 1+j), which depends on the modulation (QPSK, 16QAM,...), Δ_f the frequency offset to compensate and F_s the sampling rate (1.92MHz).

7) Can you explain the undesired effect observed in 4? Hint: Based on the previous expression, study what happens when $\Delta_f N \ll F_s$.

Now, set a breakpoint in line 299 and execute the 2 lines below, so we compensate for the frequency offset, canceling it completely:

$>>$ downsampled = lteFrequencyCorrect(enb, downsampled, -delta_f);
$>>$ rxgrid = lteOFDMDemodulate(enb, downsampled);
Plot **rxgrid** and compare with 4. See Fig. 4.

8) Is it expected?

9) What can be forming the ring?

10) Do all OFDM symbols have the same modulation?

Note: If you are interested about OFDM demodulation you can read the *lteOFDMDemodulate.m* function.

11) After the last result. Would it make sense to remove the frequency compensation?

12) How does the frequency offset affect the decoding of the constellation symbols? It is the same for first OFDM symbols than for others?

13) Is there any difference between using QPSK or 16QAM?

F. PBCH Demodulation, BCH Decoding, MIB parsing

PBCH carries part of the system information of the cell. By decoding it, the UE obtains information of the cell where it wants to register, which is a prior step before attempting to register.

Execute until line 351. Let's have a look at the PBCH constellation points. Execute:

$>>$ figure, plot(pbchRx, '+'), grid on

1) What type of modulation do you see? Is it expected?

The constellation points are then decoded to obtain the PBCH content. Go to line 333.

2) How many bits are obtained from the PBCH? From those, how many are allocated to the MIB?

3) Check the value of variable *enb* before and after parsing the MIB (line 333). What difference do you see? Why?

4) Why does the number of frames get updated in line 338?

After the MIB is parsed, please provide the following extracted values:
- Downlink Cell Bandwidth (Number of PRBs)
- Number of Frame
- PHICH Duration

G. OFDM Demodulation on Full Bandwidth

The original signal is now resampled according to system bandwidth. Frequency offset is estimated again and compensated. Also, the signal is aligned with the beginning of the frame. Then, OFDM is demodulated.

1) What is the estimated frequency offset now?

   Plot $rxgrid$ in line 390.

2) Is it the result expected?

H. SIB1 Decoding

Prior to SIB1 decoding, PCFICH is demodulated and CFI decoded.

1) What is the value of CFI? What is the meaning? tip: Check $lteCFIDecode.m$.

   Now that the UE knows CFI, then it looks for DCIs relevant to it and try to decode it. See $ltePDCCHSearch.m$ for more details.

   Go to line 505. We know the UE RNTI is 65535. This is a unique identifier for each UE. Let's imagine that another UE is on the same cell and try to decode the same DCI. Execute the following lines:
   $>>$ pdcch2 = pdcch;
   $>>$ pdcch2.RNTI = 65534;%RNTI of another UE
   $>>$ ltePDCCHSearch(enb, pdcch2, dciBits)

2) What is the result? Was it expected?

   Going back to our UE. In line 512, $ltePDCCHSearch$ function returns a non-empty structure, which indicates that there is a DCI intended for our UE.

3) Which is the DCI format?

   With the DCI information, the UE is able to decode the PDSCH. Go to line 533 and see the logs printed on screen.

4) What are the PDSCH settings?:
   - Number of Layers:
   - Modulation:
   - Redundance Version:

   It is important to note that PRBSET contains indices corresponding to the resource allocation for this PDSCH transmission.

5) What is the Transport Block Length ($trblklen$) according to the DCI?

Go to line 546.

6) How many bits are in the PSDCH ($dlschBits$)?

   After decoding PDSCH we obtain SIB1 ($sib1$).

7) How many bits are there in the SIB1? Was it expected?

I. Captured data

The variable $loadFromFile$ (line 60) indicates if input data comes from an LTE model (in which case the generated signal is ideal) or captured data (which contains the effect of a real channel).

You can select captured data by setting $loadFromFile = 1$ and see the differences.