Labs

Practical 4G/5G laboratory classes

OFDMA/SCFDMA Transmitter in the LTE System (with the use of LTE PHY Lab)

Version: **1.4.0** (this document is valid for Labs v1.4.x)

DISCLAIMER

PLEASE READ ALL TERMS AND CONDITIONS OF THE LICENSE AGREEMENT BEFORE CONTINUING. USING OUR SOFTWARE INDICATES YOUR ACCEPTANCE OF THIS AGREEMENT. IF YOU DO NOT AGREE TO THE TERMS AND CONDITIONS, REMOVE THE SOFTWARE FROM ALL YOUR SYSTEMS.

THIS SOFTWARE AND DOCUMENTATION ARE PROVIDED BY IS-WIRELESS "AS IS" AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL IS-WIRELESS BE LIABLE FOR ANY GENERAL, DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS SOFTWARE AND/OR DOCUMENTATION, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

IS-Wireless is disclosing this software, user guide, manual, release notes, and/or specification to you solely for use in conformity with the License Terms. You may not reproduce, distribute, republish, download, display, post, or transmit the Documentation in any form or by any means including, but not limited to, electronic, mechanical, photocopying, recording, or otherwise. IS-Wireless expressly disclaims any liability arising out of your use of the Documentation and reserves the right, at its sole discretion, to change the Documentation without notice at any time. You are responsible for obtaining any rights you may require in connection with your use or implementation of this Software.

TABLE OF CONTENTS

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

1 Exercise target

The aim of this exercise is to familiarize students with the transmission techniques as well as observation of problems related to downlink and uplink transmission.

The laboratory will mainly cover the following topics:

a. Generation and observation of the OFDMA/SCFDMA waveforms with the help of plots in time and frequency.
b. Cyclic prefix observation in the OFDMA/SCFDMA waveforms
c. Understanding the PAPR and its impact on OFDMA system.

After this laboratory student shall be able to notice the transmission scheme characteristics in OFDMA/SCFDMA and understand the factors influencing the performance such as PAPR.

NOTE! This exercise shall last approximately 3 hours in order to fulfill all the included tasks. The exercise can be done by a single student or a group of students.

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

2 Required background

Prior to laboratory exercises, students should prepare and get familiar with the necessary range of material including:

- Principles and parameters of OFDMA system (including transmission processing chains and block diagrams)
- Basics of radio-communication systems
- Basic knowledge of LTE frame structure
- Principles and basics of LTE system and main LTE physical layer parameters
- Basic knowledge about digital signal processing like clipping of signal

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

3 Theoretical introduction

3.1 Theoretical background for the OFDMA/SCFDMA system

LTE is based on Orthogonal Frequency Division Multiplexing (OFDM) with cyclic prefix (CP) in the downlink, and on Single-Carrier Frequency Division Multiple Access (SC-FDMA) with cyclic prefix in the uplink. Orthogonal Frequency-Division Multiple Access (OFDMA) is a multi-user version of the orthogonal frequency-division multiplexing (OFDM) digital modulation scheme. Multiple access is achieved in OFDMA by assigning subsets of subcarriers to individual users, which allows for simultaneous low data rate transmission for several users. These subsets are called sub-channels. The subcarriers that form a sub-channel need not be adjacent. In the downlink, a sub-channel may be intended for different receivers whereas, in the uplink, a transmitter may be assigned one or more sub-channels.

The basic transmitter and receiver architecture in OFDMA and SC-FDMA is very similar (nearly identical) and it offers the same degree of multipath protection. Figure 1 describes the transmission and receiver chain using OFDMA/SCFDMA.

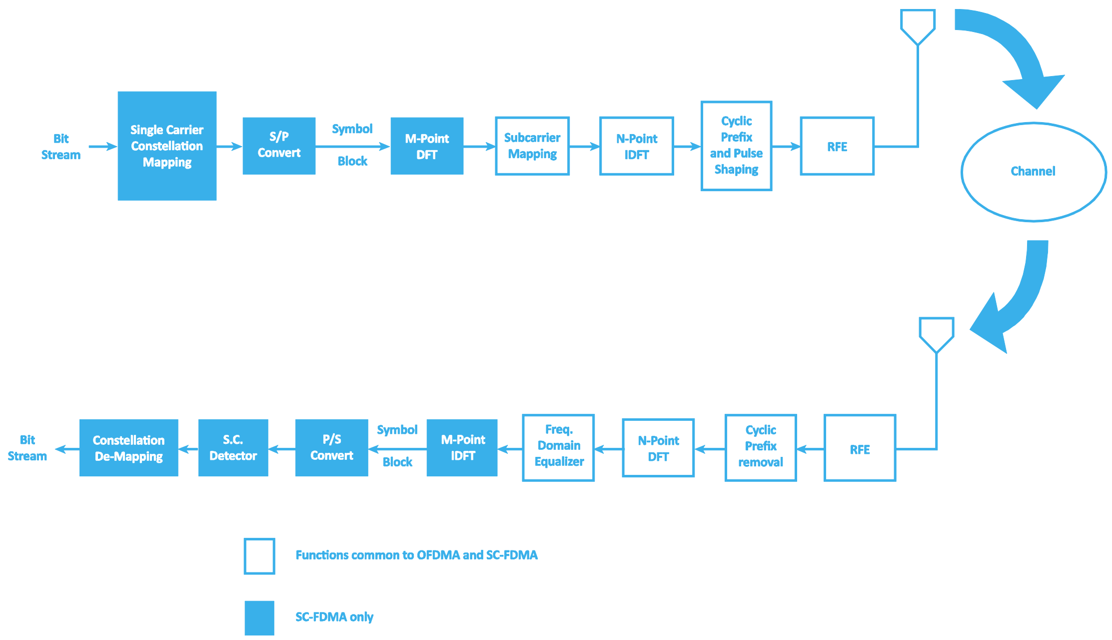

Figure 1 Block Diagram describing transmission and receiver chain using OFDMA/SC-FDMA

The block diagram of above shows a basic SC-FDMA transmitter / receiver arrangement. Note that many of the functional blocks are common to both SC-FDMA and OFDMA, thus there is a significant degree of functional commonality between the uplink and downlink signal chains. The functional blocks in the transmit chain are:

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

1. Constellation mapper: Converts incoming bit stream to single carrier symbols (BPSK, QPSK, or 16QAM depending on channel conditions)
2. Serial/parallel converter: Formats time domain SC symbols into blocks for input to FFT engine
3. M-point DFT: Converts time domain SC symbol block into M discrete tones
4. Subcarrier mapping: Maps DFT output tones to specified subcarriers for transmission. SC-FDMA systems either use contiguous tones (localized) or uniformly spaced tones (distributed). The current working assumption in LTE is that localized subcarrier mapping will be used.
5. N-point IDFT: Converts mapped subcarriers back into time domain for transmission
6. Cyclic prefix and pulse shaping: Cyclic prefix is pre-pended to the composite SC-FDMA symbol to provide multipath immunity in the same manner as described for OFDM. As in the case of OFDM, pulse shaping is employed to prevent spectral regrowth. In this lab our main focus will be in observing this aspect of the transmission scheme and its effects.
7. RFE: Converts digital signal to analog and up convert to RF for transmission

As in the case of OFDM, SC-FDMA transmissions can be thought of as linear summations of discrete subcarriers. Multipath distortion is handled in the same manner as in OFDM.

Now, once we know the functional blocks for generating the transmission waveforms, it's quite important to understand about some properties of OFDMA/SC-FDMA.

Cyclic Prefix: The Cyclic Prefix is a periodic extension of the last part of an OFDM symbol that is added to the front of the symbol in the transmitter, and is removed at the receiver before demodulation. The Cyclic Prefix has two important benefits:

1. The Cyclic Prefix acts as a guard space between successive OFDM symbols and therefore prevents Inter-symbol Interference (ISI), as long as the length of the CP is longer than the impulse response of the channel.
2. The Cyclic Prefix ensures orthogonality between the sub-carriers by keeping the OFDM symbol periodic over the extended symbol duration, and therefore avoiding Inter-carrier Interference (ICI).

Mathematically, the Cyclic Prefix / Guard Interval convert the linear convolution with the channel impulse response into a cyclic convolution. This results in a diagonalised channel, which is free of ISI and ICI interference.

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

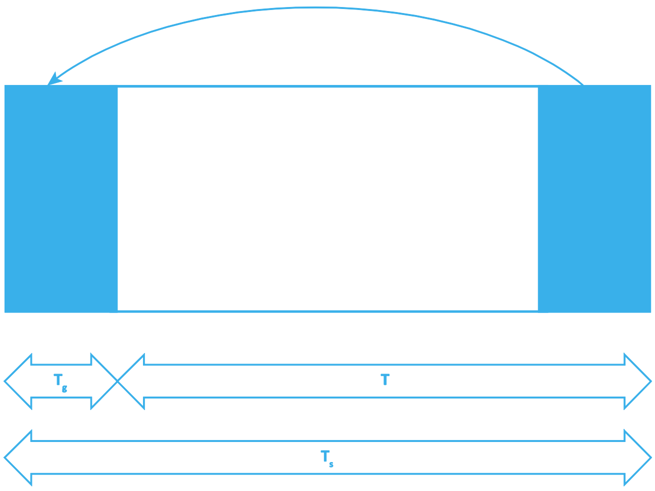

Figure 2 Structure of the OFDM cyclic prefix

In order for the IFFT to create an OFDM waveform with ISI-free channel, the channel must appear to provide a circular convolution. The time period is referred to as the useful symbol time T. A copy of the last T_g of the useful symbol period, called the cyclic prefix (CP), is appended at the beginning of the useful symbol period. Figure 2 shows the structure of the OFDM cyclic prefix.

However, the cyclic prefix comes at the expense of both bandwidth and power. Since redundant symbols are sent, the required bandwidth for OFDM must be increased by

$$\frac{(T + T g)}{T}$$

Similarly, the transmitter energy increases with the length of the guard time while the receiver energy remains the same (the cyclic extension is discarded), so there is a loss in signal-to-noise ratio (SNR). The CP overhead fraction and the loss of SNR could be reduced by increasing the FFT size, which would adversely affect the sensitivity of the system to phase noise of the oscillators. Using a cyclic prefix, the samples required for performing the FFT at the receiver can be taken anywhere over the length of the extended symbol. This provides multipath immunity while maintaining the orthogonality of the tones.

PAPR Analysis: After studying about OFDM it should be well known that along with the advantages this technology brings to the wireless networks there are some disadvantages as well among which is a high peak-to-average power ratio (PAPR). The instantaneous transmitted RF power can vary dramatically within a single OFDM symbol. The OFDM symbol is a combination of all of the subcarriers whose voltages can add in-phase at some points within the symbol, resulting in very high instantaneous peak power—much higher than the average power.

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

A high PAPR drives dynamic range requirements for A/D and D/A converters. Even more importantly, it also reduces efficiency of the transmitter RF power amplifier (RFPA). Single carrier systems sometimes use constant envelope modulation methods, such as Gaussian Minimum Shift Keying (GMSK) or Phase Shift Keying (PSK). The information in the signal of a single carrier system is conveyed by varying the instantaneous frequency or phase while the signal amplitude remains constant. The RFPA does not require a high degree of linearity. In fact, the PA can be driven so hard that the signal is “clipped” as the signal swings between the minimum and maximum voltages. Harmonic distortion due to clipping can be eliminated by output filtering. When RFPAs are operated in this manner, they can achieve efficiencies on the order of 70 percent.

In contrast, OFDM is not a constant envelope modulation scheme. Within each symbol, the amplitude and phase of each sub-carrier is constant. Over the duration of an OFDM symbol, there can be several large peaks. The RFPA must be capable of handling peak voltage swings without clipping, thus requiring a larger amplifier to handle a given average power. Efficiency is therefore lower. RFPA efficiencies for OFDM signals can be less than 20 percent. Although there are measures that can be taken to reduce voltage peaks, PAPR for OFDM results in RFPA efficiencies that are generally lower than for single-carrier constant envelope systems.

Influence of pulse shaping filtering on the OFDMA signal: The OFDMA signal consisting of multiple subcarriers in the frequency domain results in out-of band emissions providing interference to neighboring systems / carriers. Therefore it is required to cut-off the Out-of Band (OoB) signal by shaping the pulse which is normally done in the time domain. By doing so, the undesired power is lowered, but the filter also distorts the in-band part of the signal. Figure 3 shows the influence of the pulse shaping filter in the time and frequency domains.

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

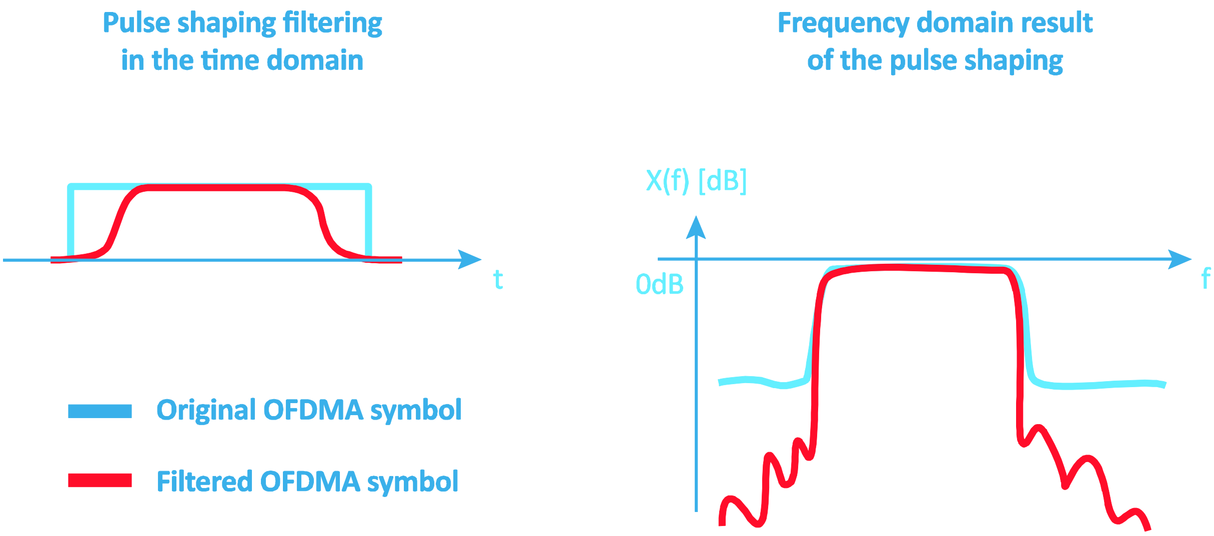

Figure 3 Pulse shaping filtering in the time and frequency domain

In the uplink transmission scheme SC-FDMA modulated signal can be viewed as a single carrier signal on which a pulse shaping filter can be applied to transmit signal to further improve PAPR which allows operation of the power amplifier close to saturation resulting in higher efficiency.

There are a number of filters which could be utilized to achieve pulse shaping, among them the ones we shall discuss are listed under:

- the raised cosine filter,
- the root/squared raised cosine filter.

Raised Cosine Filter

The raised cosine filter is one of the most common pulse-shaping filters in communications systems, an implementation of a low-pass Nyquist filter. It is used to minimize intersymbol interference (ISI) by attenuating the starting and ending portions of the symbol period. Because these portions are most susceptible to creating interference from multi-path distortion, the shaping characteristics of the raised cosine filter helps reduce ISI.

$$h_{RC}(n) = \frac{\pi}{4} sinc\left(\frac{\pi n}{R}\right) . \left[sinc\left(\frac{\pi}{2} - \alpha\frac{\pi n}{R}\right) + \frac{\left(\frac{\pi}{2} - \alpha\frac{\pi n}{R}\right)}{\left(\frac{\pi}{2} + \alpha\frac{\pi n}{R}\right)} \right]$$

The filter rolloff parameter, alpha($\boldsymbol{\alpha}$), can range between values of 0 and 1.

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

Root/Squared Raised Cosine Filter

The root raised cosine filter produces a frequency response with unity gain at low frequencies and complete at higher frequencies. It is commonly used in communications systems in pairs, where the transmitter first applies a root raised cosine filter, and then the receiver then applies a matched filter.

Mathematically, the raised cosine filter can be defined by the following equation:

$$h_{SRC}(t) = \frac{\left[\frac{4\alpha}{\pi} cos\left(\frac{(1+\alpha)\pi n}{R}\right)\right] + \left[(1-\alpha) sinc\left(\frac{(1+\alpha)\pi n}{R}\right)\right]}{\sqrt{R}\left[1-\left(\frac{4\alpha n}{R}\right)^2\right]}$$

In this equation, $\boldsymbol{\alpha}$ is the rolloff factor, which determines the sharpness of the frequency response. In addition, R is the number of samples per symbol. As the equation above illustrates, the sinc pulse is used to shape the filter so that it appears with a finite frequency response.

3.2 System description for the exercise

The course exercises are based on the LTE PHY Lab. LTE PHY Lab is a comprehensive implementation of the 3GPP Release 8 E-UTRA physical layer. It has a form of a MATLAB Toolbox. It includes both the downlink and the uplink processing chains covering all the PHY steps such as FEC, modulation, MIMO processing, resource mapping, OFDMA and SCFDMA signal generation. Due to the available structure baseband models of both the eNB and UE can be created. For the laboratory course exercises it is important to evaluate the role of every single component block, including the transmitter and receiver blocks.

For the purpose of this exercise, the blocks of LTE PHY Lab that are required for evaluation are:

- LTE Downlink PHY transmitter (realizing transmission of OFDMA signal)
- OFDM Modulation
- LTE Uplink PHY transmitter (realizing transmission of SC-FDMA signal)
- SC-FDMA Modulation

The block diagrams that are useful for this exercise are shown below:

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

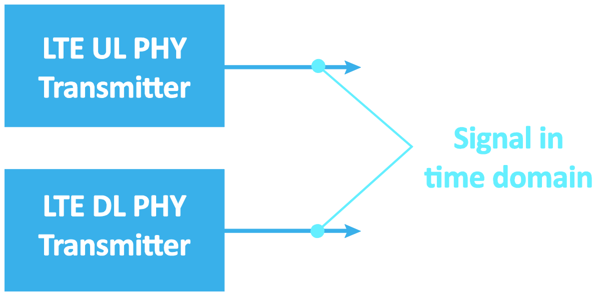

Figure 4 Block diagram for experiments showing the OFDMA/SC-FDMA waveforms and the cyclic prefix observation

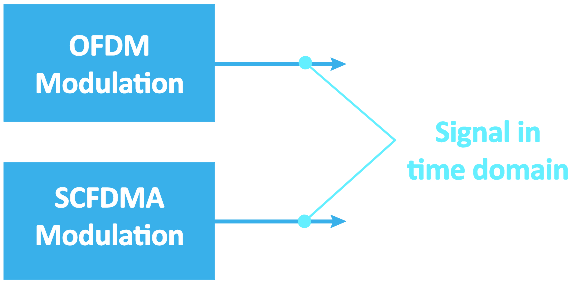

Figure 5 Block diagram for the experiments depicting the calculation of PAPR

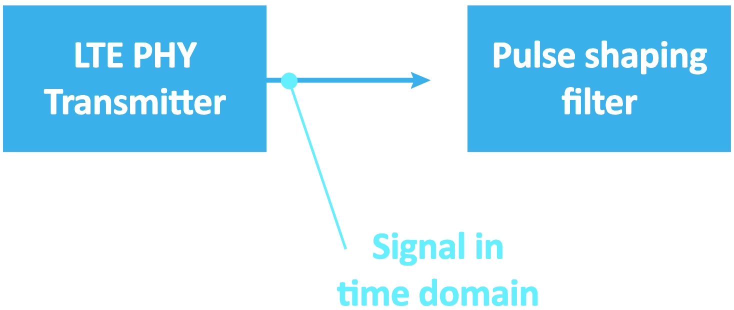

Figure 6 Block diagram for the experiments showing the impact of pulse shaping filtering

The important parameters that are related to the LTE system for this exercise are listed in table 1.

Table 1 LTE PHY Lab parameters used in exercise

Parameter name	Parameter value	Comment
System bandwidth	3MHz	
FFT size	256	
Transmission direction	Downlink and Uplink	eNB and UE Transmitter
Measured PHY Channel	PDCCH	It occupies all useful subcarriers in OFDMA symbol
Modulation order	QPSK	

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

Subcarrier spacing	15kHz	Subcarrier spacing
Normal CP length	4.6 µs	Normal CP length

3.3 References

[1] 3GPP TS 36.300 "E-UTRAN overall description"
[2] 3GPP TS 36.201 "LTE physical layer, general description"
[3] 3GPP TS 36.211 "Physical channels and modulation"
[4] www.3gpp.org
[5] http://www.ni.com
[6] "SC-FDMA Single Carrier FDMA in LTE", White Paper, IXIA 2009
[7] "OFDM for Wireless Communications Systems", R. Prasad, Artech House 2004

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

4 Workspace setup

In order to properly run all exercises you have to follow these steps:

1. Install Labs and activate it. This should be already done by the teacher or system administrator, and is well described in User guide
2. Launch MATLAB. Switch the work directory (Figure 7, red outline) to path where Labs is installed (e.g. "**`C:\Labs_v1.0.0`**")
3. Open directory with appropriate laboratory case, e.g. "**`Labcase_1`**" (Figure 7, orange outline), and run script "**`Labs_AddPaths`**", to add paths to workspace (Figure 7, blue outline). Each laboratory case has its own separate script to add paths that has to be run (i.e. even if you run "**`Labs_AddPaths`**" from "**`Labcase_1`**", you have to run "**`Labs_AddPaths`**" from "**`Labcase_2`**" in order to do exercises from laboratory case 2)

NOTE! Each time you restart MATLAB you have to perform above steps to properly attach all directories.

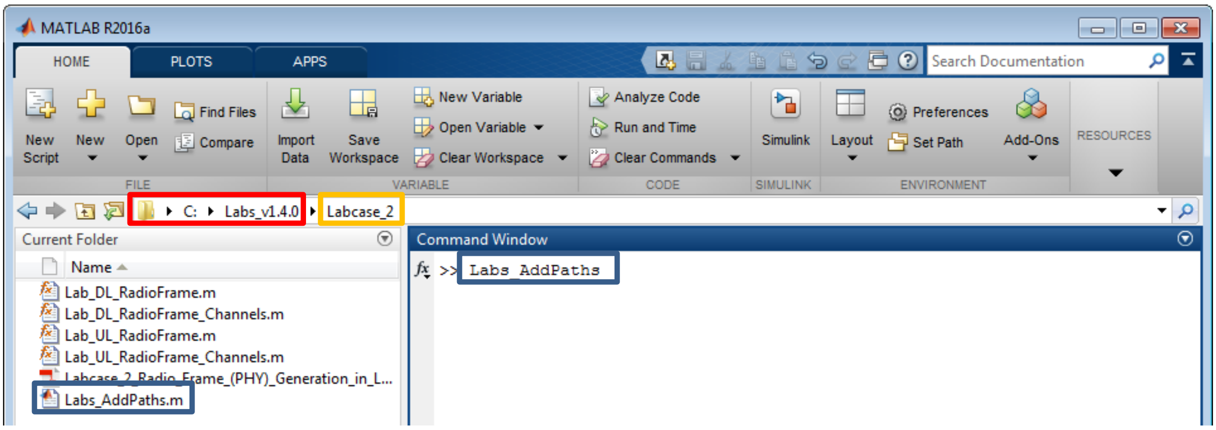

Figure 7 Laboratory exercise workspace setup

NOTE! If scripts for automatic LTE MAC Lab and LTE PHY Lab search fail, you must provide specific path to this tools. To do so, edit "**`AddToolsPaths`**" file, which is located in the main directory of Labs. In this file add path to your tools in functions "**`Add_LTE_PHY_Lab`**" and "**`Add_LTE_MAC_Lab`**". Figure 8 provides an example on how the file should look like in case of explicit tool paths. Edited lines are marked with blue outline.

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

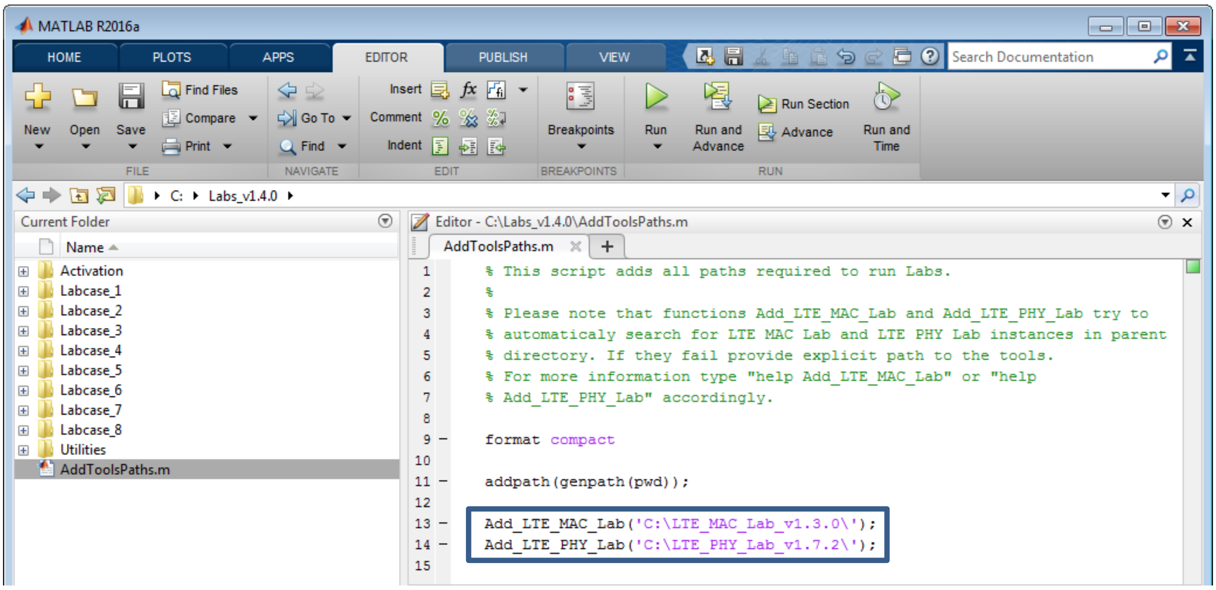

Figure 8 Adding specific path to the tools

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

5 “Warm up” exercises

In this laboratory exercise each of the factors, described in the chapter 3 will be considered separately, to understand the influence that each aspect has on the transmission of OFDMA/SC-FDMA signal.

5.1 Examination of the OFDMA and SC-FDMA signal waveforms

1. Open the script “**`Lab_OFDMA_SCFDMA_signal.m`**“ and examine source code to identify: transmission byte stream creation, the subframe number, channels used, modulation order, and size of CP being added.
2. Use help command to get description of the script (“**`help Lab_OFDMA_SCFDMA_signal`**”).
3. Observe the waveforms generated for each band of the spectrum and how the multiplexing occurs for users.
4. Observe the cyclic prefix property discussed earlier in the theoretical section. Print and mark the cyclic prefix in one example for both the OFDMA as well as SC-FDMA waveform.
5. Run the simulation four times using different conditions for generating the waveform (changing the modulation order, index of PRBs, different size byte stream, different channels in Uplink). Write down in your reports the impact of change of the different parameters on the waveforms.
6. Observe the concept of multiplexing and implement it for more than two users.
7. Answers the following questions:
    a. How many PRBs are available for the default configuration?
    b. Explain the difference between the OFDMA and SC-FDMA in brief.
    c. What is the impact of the PRB selection on the power spectral density?

5.2 Examination of the impact of High PAPR

1. Open the script “**`Lab_PAPR.m`**” and examine source code to identify: OFDM/SC-FDMA signal creation, calculation of PAPR, plotting and creation of PAPR histograms.
2. Use help command to get description of the script (“**`help Lab_PAPR`**”).
3. Observe the generated signals in both the frequency and time domain and comment on the difference between localized and interleaved/distributed SC-FDMA.
4. Observe the PAPR calculation in the code and the parameters involved. Deduce the impact of OFDM/SC-FDMA signals on PAPR value and write it down in

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

your report.

5. Use different parameters for generating the signals (changing the block size, FFT size, mode of data) and observe and note down the influence on PAPR values in your report. Also mention what changes were helpful in reducing the PAPR values, if any.

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland

www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

6 Main exercise tasks

After completion of the tasks mentioned in chapter 5, the student shall write his own files realizing the following tasks.

NOTE! These tasks can be done in the class or at home or used as a separate project.

6.1 Examination of OFDM/SC-FDMA waveforms

1. Using the example source code from file "**`Lab_OFDMA_SCFDMA_signal.m`**" as well as "**`Lab_PAPR.m`**" focusing on the OFDM and SC-FDMA symbol generation part, write a script to generate OFDM symbols with and without CP. Plot the waveforms in a single window and observe the differences. Write down the characteristic difference between the two signals.
2. Using the same script check the influence of both kinds of waveforms on PAPR values.
3. Describe in the report the advantage of choosing OFDMA and SC-FDMA for LTE system with the help of diagrams.

6.2 Examination of the impact of the High PAPR

1. Using as the example source code from file "**`Lab_PAPR.m`**", write a script that will help plot a spectrogram to depict the PAPR values. Change the input parameters for this script in such a manner so as to obtain the lowest PAPR, keeping in mind the practical implementation. Write down your results along with the plots and histograms and comment.
2. Using as the example source code from file "**`Lab_PAPR.m`**", write a script that will implement the Amplitude clipping on the samples of OFDM/SC-FDMA generated. Observe the PAPR values and comment on the results.

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

7 Test questions

After all the tasks are fulfilled, the student shall answer for these questions in the report:

1. Why do you think cyclic prefix plays a significant role in OFDM/SC-FDMA transmissions? Explain.
2. Draw a block diagram to describe a method implemented to reduce PAPR value.
3. Explain the role of FFT in OFDM/SC-FDMA signals. How change in FFT size impacts these signals?
4. Write down the formula to convert the magnitude of OFDM symbol in frequency domain to dB domain.
5. What method should be used to get info about maximum possible PAPR for a given subcarrier used?
6. Write down the formula to calculate PAPR.
7. Using diagrams, describe the difference between the implementation/working of OFDM and OFDMA.
8. Explain with the help of a practical example considering few user equipment the difference between the working of OFDM and SC-FDMA.

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

8 Report content

The report shall include:

- answers for questions from chapters 5 and 6;
- required descriptions from chapters 5 and 6;
- required plots / simulation results and source codes from chapters 5 and 6;
- answers for questions from chapter 0;
- required block diagrams from chapter 0;
- related conclusions and observations from the exercise.

The example report header is presented below:

Wireless communication course		
Exercise title: "OFDMA-SCFDMA Transmitter in the LTE system"		
Group ID:	**Students' names:** **1.** **2.** **3.** **4.**	**Date and time of the exercise:**
Student providing report:	**Date of the report:**	**Grade and lecturer signature:**

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298

About IS-Wireless

IS-Wireless (www.is-wireless.com) is a Polish software developer and IP provider specializing in advanced solutions for wireless systems. IS-Wireless develops 4G and 5G algorithms, protocols and tools. Our clients are primarily early technology adopters including ODMs, OEMs, chip vendors, and operators. We operate globally delivering our services to companies and organizations from Europe, USA, Africa and Asia. The company is engaged in EU FP7 projects on 5G and is active in delivering technical courses on advanced telecom.

Changelog

Date	Version	Who	Comment
25.07.2012	1.0	SP	Initial release
12.12.2014	1.1.0	PR	• New versioning scheme (X.Y.Z) of this document • New document layout and styles
03.03.2015	1.1.1	PR	• Images in new vector format
10.09.2015	1.2.0	PR	• Change product name from “4G University Suite” to “University Suite” • New company logo • Updated “About IS-Wireless” chapter • Supported software version (on title page) described more precisely
24.11.2015	1.2.1	PR	• New styles applied • Supported software version (on title page) described more precisely
09.08.2016	1.3.0	MB	• Description and exercises updated • Update for the new software release
06.06.2017	1.3.1	ŁK	• Small text updates
07.09.2017	1.4.0	ŁK	• Change product name from “University Suite” to “Labs”
10.01.2018	1.4.1	ŁK	• Chapter “Workspace setup” updated

IS-Wireless (brand of Innovative Solutions) ul. Pulawska 45b 05-500 Piaseczno Poland
www.is-wireless.com info@is-wireless.com phone: +48 22 213 8297 fax: +48 22 213 8298