OFDM Benchmark for demodulation impairments evaluation

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Abstract—**Orthogonal Frequency Division Multiplexing (OFDM) is a modulation method with superior performance, being one of the most efficient method of using the spectral band. The present paper proposes the development of an OFDM benchmark for demodulation impairments evaluation consist of two modules: transmitter and receiver module. The tests have been made with LabView RF Communications/Modulations Toolkit.**

Keywords—OFDM benchmark; demodulation impairments evaluation

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a modulation method with superior performance, being an efficient method of using the spectral band. OFDM can be found in Wi-Fi networks, WiMAX, 4G mobile communication Long Term Evolution (LTE), digital subscriber line (DSL), majority of power-line communications applications (PLC), ADSL and VDSL internet access modems, military applications and satellite communications [1-4].

OFDM extends the concept of data transmission from single carrier modulation to parallel data transmission on multiple subcarriers at the same time on a single transmission channel. In other words, a frequency band, which represents a channel, is divided into multiple frequencies belonging to subcarriers (Frequency Division) and the information is transmitted simultaneously on subcarriers (Multiplexing). Each subcarrier can be modulated differently according to a conventional digital modulation scheme and each channel is separated from the others through a guard area in which no information is transmitted (subcarrier zero). Figure 1 shows the structure of a transmission channel, which comprises the following: subcarriers which transmit the data, pilots which evaluate the transmission environment and guard area.

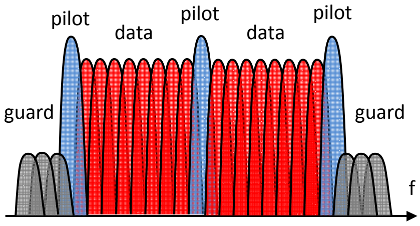


Fig. 1. Structure of an OFDM channel

Operation of the OFDM method is based on achieving the orthogonality condition between the subcarriers. The orthogonality is achieved if the frequency distance between each consecutive subcarriers is the same (Δf) and it is equal with the inverse of the OFDM symbol period. In these conditions, in frequency, maximum power of each subcarrier corresponds to the minimum of any other subcarrier, thus no interference is recorded between them.

II. OFDM INTERFERENCE

To remove the effect several subcarriers called pilot are used, which are transmitted with the role to estimate the behavior of the transmission environment between the transmitter and receiver. The most used method is to transmit the pilot subcarriers in each OFDM symbol. The subcarriers between two pilots are corrected (equalized) [5,6] by interpolating the amplitude and phase information obtained from the pilots. In figure 2.b the overlapping of reflections (R1), (R2) and (R3) over the original signal (O) can be observed.

In order to prevent inter-symbol interference (ISI), insertion of a cyclic prefix (CP) before each symbol to be transmitted is used (figure 2.a).

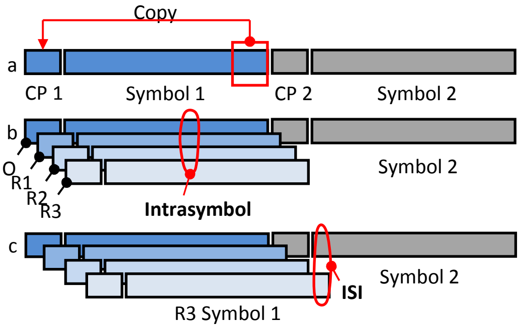


Fig. 2. Intra and Inter Symbol Interference

CP represents a section from the end of the symbol which is added to its beginning. As long as CP duration is greater than the delay introduced by the transmission environment, every reflected copy of the original signal will be received before the beginning of the useful part of next symbol. This prevents ISI. In figure 2.b it can be observed that R1, R2 and R3 overlap only the CP of the second symbol, thus not causing ISI. In figure 2.c, reflection R3 overlaps the useful part of the second symbol, causing ISI.

The most important drawback of OFDM is represented by ICI (Inter Carrier Interference). ICI occurs when the subcarriers are no longer orthogonal. It can have two main causes: Frequency offset and Clock offset [7,8].

Frequency offset appears if the delay spread exceeds the CP duration or if Doppler effect appears, when there is movement between the transmitter and the receiver. The effect is caused by the fact that the decoder is not synchronizing with the OFDM signal, i.e. the bins (digital points/frequencies used in frequency computation of FFT transform) do not coincide with the real frequencies of the subcarriers. In figure 3 the case where there is not frequency offset is presented.

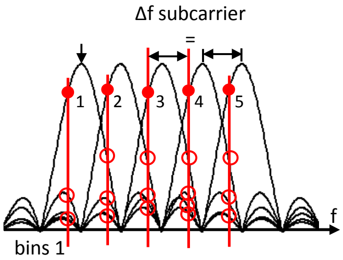


Fig. 3. ICI – frequncy offset

The points where FFT is computed coincide with the maximum power of the subcarriers. In this situation, in these computation points, all the other subcarriers have minimum power.

If the decoder doesn't synchronize with the signal, then the frequencies where the FFT bins will be calculated will be different from those of the subcarriers. Because Δf bins is equal with Δf subcarrier, the loss of synchronization spreads across the entire spectrum. In this situation, for each subcarrier, the contribution of the others will not be minimum.

If there are differences between the oscillator of the transmitter and the one of the receiver, then even if for the first subcarrier the bins coincide with the maximum power, as result to synchronization, for the others a gap will appear as shown in figure 4.

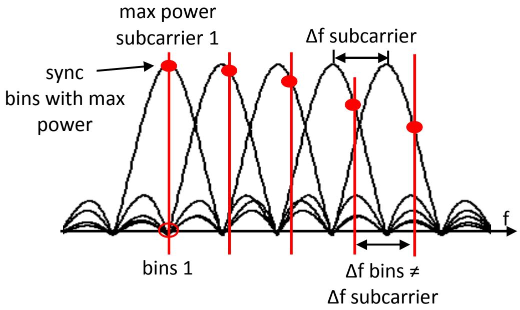


Fig. 4. ICI – clock offset

To remove/reduce the ICI numerous researches were conducted [9,10].

III. OFDM BENCHMARK FOR DEMODULATION IMPAIRMENTS EVALUATION. EXPERIMENTAL RESULTS.

OFDM benchmark comprise two modules: transmitter module and receiver module. The tests have been made with LabView RF Communications/Modulations Toolkit.

The transmitter module has the purpose of transmitting the data (received on binary input) to the receiver module, in OFDM format. The transmitter module is made up of the nine main structures, shown below.

Bits number initialization to be transmitted (1250) and 4QAM map (QPSK), The number of bits to be sent is determined per transmitter cycle and the type of modulation, also. It was chosen to transmit, in one cycle, 1250 bits, using a QPSK-type modulation.

Generation of 1250 random bits string based on the MT Generate Bits function. PN sequences are used in many applications and standards such as 802.11a and DVB. Some examples of PN sequences are M Sequences (also called maximum length shift register sequences), Gold Sequences and Kasami Sequences. An M Sequence generates a periodic sequence with length $L = 2m - 1$ bit and is generated by linear feedback shift registers (LFSRs). Two types of implementations are known: Fibonacci implementing and Galois implementing.

In figure 5 the transmitter module responsible for pseudo-random generating and a graphical representation of the first 100 data from a 1250 sequence is presented.

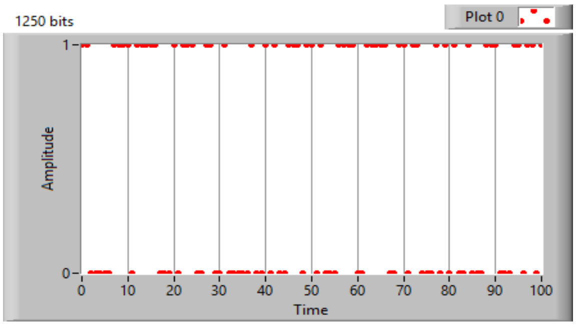
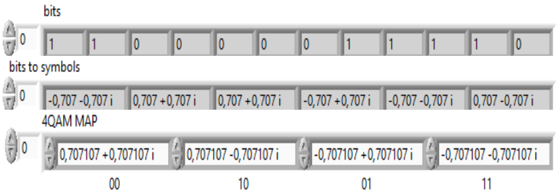


Fig. 5. First 100 data of pseudo-random bits

Mapping bits in complex symbols (625, 1250/2) represents the process by which, to a group of bits, is assigned a complex symbol (complex number), depending on the type of mapping used. For 4QAM, there are 4 complex symbols that can be assigned to a 2-bit groups that can only be in one of the following states: 00; 01; 10; 11 (figure 6).


bits

0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0

bits to symbols

0 | -0,707 -0,707 i | 0,707 +0,707 i | 0,707 +0,707 i | -0,707 +0,707 i | -0,707 -0,707 i | 0,707 -0,707 i

4QAM MAP

0 | 0,707107 +0,707107 i | 0,707107 -0,707107 i | -0,707107 +0,707107 i | -0,707107 -0,707107 i

00 | 10 | 01 | 11

Fig. 6 Mapping bits in complex symbols

In figure 6, 4QAM mapping is depicted on a 12 bits example, that has correspondence in 6 complex symbols. After mapping all the 1250 bit string turns into a string of 625 complex symbols.

The 625 complex symbols are divided into 5 sets of 125. A set of 125 complex symbols represent an OFDM symbol Below is the section of the transmitter module responsible for the division in OFDM symbols representation of the last elements of the 5 OFDM symbols (figure 7).

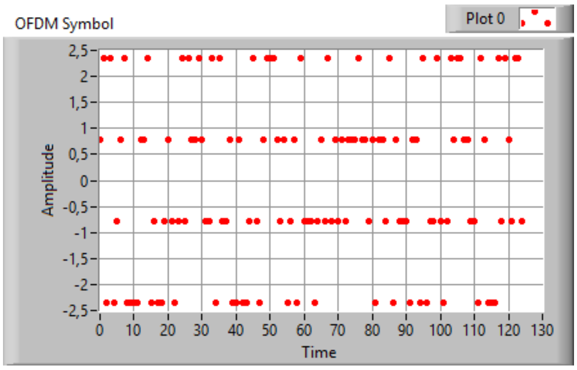


Fig. 7. OFDM symbol

In order to estimate how perturbations influenced the OFDM signal on the transmission channel (from transmitter to receptor), a series of pilots (complex control symbols) are inserted, whose constellation are known. In this sense, after each 5th complex symbol, one pilot was introduced, thus obtaining an OFDM symbol of 150 points. An OFDM symbol are made up of 125 complex symbols, that transmit the information of 250 bits. Each of the 125 complex symbols can have any state of the QPSK constellation. Because the amplitude is constant, only the phase shift in radians is shown in figure 8.

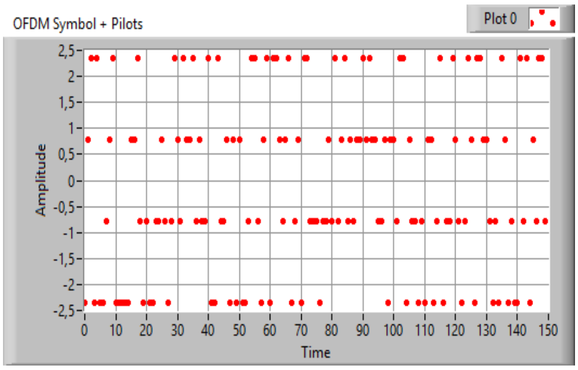


Fig. 8. OFDM symbol with pilots inserted

In the next step, insertion of 106 zeros is performed. Thus, 256 points OFDM is obtained and represents the frequency representation of the OFDM symbol. Graphic representation of OFDM symbol from 256 points is depicted in figure 9 and comprise active data, pilots and zeros.

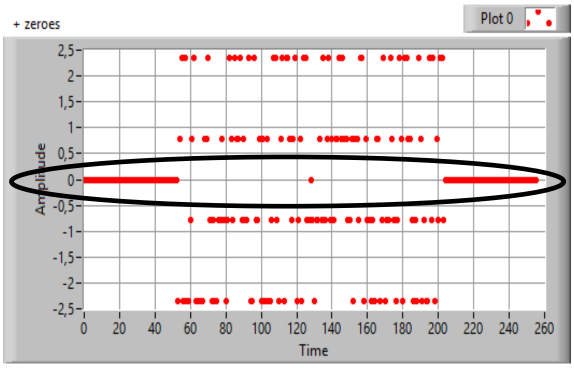


Fig. 9. Insertion of 106 zeros

The conversion from the frequency domain to the time domain is based on the FFT Inverse. Thus, the 256 points from the time domain are converted to the type domain, same in 256 points. The points being complete, can be tracked as two individual signals I and Q (figure 10).

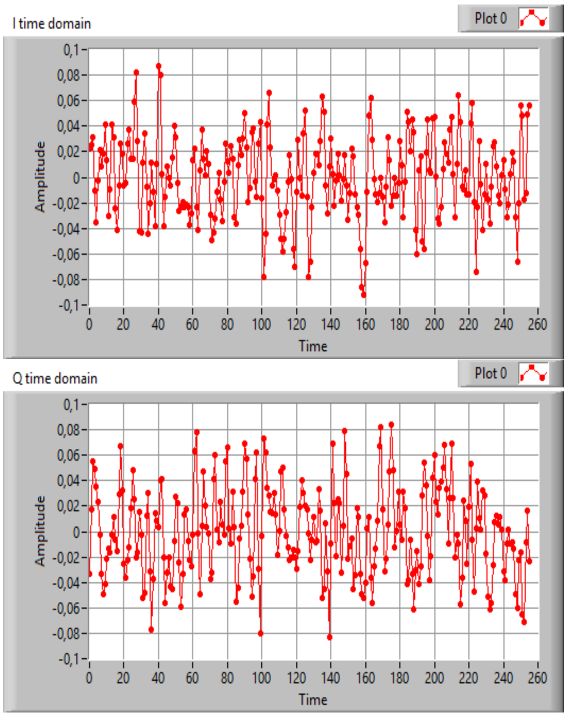


Fig. 10 I,Q time domain signals

In order to prevent ISI, insertion of a cyclic prefix (CP) is used. The cyclic CP is made up of 64 points and is obtained by copying the last 64 points in the signal and introducing them at the beginning of the signal (signals I and Q of 320 points are obtained)

OFDM Benchmark for demodulation impairments evaluation is based on disturbance functions. Below, the functions used to disturb the generated signal are presented.

IQ Impairments, allows to set the following parameters:

- I DC offset specifies the desired DC gap. The default value is 0.0. Valid values are from -100 to +100, inclusive;
- Q DC offset specifies the desired DC gap. The default value is 0.0. Valid values are from -100 to +100, inclusive;
- IQ gain balance specifies the desired gain ratio in dB. Valid values are between -6.0 and +6.0. The default value is 0.0;
- Quadrature skew specifies the squareness of the quadrature. Valid values are between -30.0 and +30.0 degrees. The default value is 0.0;
- Impairment definition specifies which set of equations is used to represent deficiencies (vertical or axial)
- Frequency offset specifies the frequency gap in Hertz (Hz), the default value is 0.0.

Sample offset, is based on a resampling of the signal so that it is transformed into a noncoherent sampled signal. It consists of a time overlay over time (x10) followed by a decimation in translation time. It can have values from 0 to 9, corresponding to the samples from which decimation begins.

Fading Profile, applies a frequency-fall profile. The waveform can be used to test the receptor immunity on the channels with gaps caused by Doppler effect. The Doppler effect is the frequency variation of a wave emitted by a source if it is moving comparative with the receiver. The Doppler effect can be observed for both, electromagnetic waves and elastic waves.

AWGN generates a Gaussian white noise (AWGN) with uniform power density and adds it to the complex waveform. Returns a signal waveform plus noise, with an E_b/N_0 specified by the user, where E_b represents the energy per bit and N_0 represents the noise variation.

Phase Noise creates phase noise by first generating white noise and then applying a 1/f filter (inverse f). The output of the filter is sized so that the density of the generated noise to be equal with the specified offset frequency. The phase component of the input signal is then modulated by the filtered noise and allows setting the following parameters:

- Offset frequency specifies the offset frequency, in hertz (Hz), for the specified density of the noise. Valid entries for this parameter must be in the range of 0.7 mHz to fs/2, where fs is the sampling frequency (1/dt) of the complex input waveform. The default value is 200.000 Hz;
- Noise density specifies the contribution of noise in a bandwidth of 1 Hz from total power at the specified offset frequency (Hz). The default value is -120 dBc/Hz;
- Inverse f exponent for noise shape specifies the exponent of the desired 1/f curve. The inverse curve f specifies the phase noise spectral form. The default value is 2. Valid values are from -3.0 to 3.0, inclusive.

At transmitter last part, I and Q signals are multiplied by a carrier (in quadrature) and summed. After applying a filter, the signal is emitted to the receiver.

The receiving module has the role of retrieving the data from the transmitter, after the data has passed through the communication channel and has been influenced by it. The data reception are made in the time domain and starts by multiplying in the quadrature with the carrier and applying a low pass filter, ensuing the signals I and Q.

The conversion from the time domain points to the transmitted bits are made with inverse operations comparative with transmitter mode, thus the following steps are performed:

- Estimation of frequency offset. The Van De Beek algorithm is used to detect the cyclic prefix as the location and estimate the offset frequency based on the position of the prefix.
- Removing the cyclic prefix, From the 320 complex points in the time domain, the cyclic prefix is removed and 256 points remain.
- Offset frequency compensation. Based on the evaluation made at the offset frequency estimation, the correction on the signal is applied in this step.
- Calculation of the FFT. Leads to the transformation of time domain points in the frequency field (256 complex symbols).
- Separation of the pilots and removing the zeros. Extracting the 25 pilots and 106 zeros and get 125 complex symbols.
- Calculation of equalization coefficients. Calculate the channel equalization factors based on the known position of the pilots and the values obtained from the transmission channel.
- Equalizing the channel. Apply equalization coefficients to 125 complex symbols
- Conversion of complex symbols into bits. Convert the symbols into bits and get a 250-bit string. The 5 sequences are concatenated and the total of 1250 bits, initially transmitted, are obtained.
- Calculation of BER. Compare the bits received with transmitted bits and report BER as the ratio between the number of wrong bits received and the total number of bits

CONCLUSIONS

The paper presents an OFDM user friendly benchmark that allows configuration of both the transmission channel impairments and the setup of decoder. Based on BER, comparative analyzes between various types of decoders can be made.

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