

# USE OF MATLAB IN THE MULTICARRIER SIGNAL SENSING, OPTIMIZATION AND IMPLEMENTATION

*Roman Marsalek, Jiri Dvorak, Karel Povalac, Jitka Pomenkova*

Department of Radio electronics, Brno University of Technology

## Abstract

This contribution deals with the use of MATLAB in the area of the multicarrier communication systems, represented by the Orthogonal Frequency Division Multiplexing (OFDM). The application of MATLAB to OFDM signal spectrum sensing, optimization of subcarrier parameters and in the practical implementation is briefly described.

## 1 Introduction

Many of the current and future communication standards, like the WiFi, DVB-T/T2, WiMAX or cognitive radio based IEEE 802.22 [1] use the principle of multicarrier communications. One of the most widespread representatives of the multicarrier systems is the OFDM. The basic structure of OFDM modulator is shown in Figure 1. The input data are divided into parallel streams corresponding to individual subcarriers. The number of data subcarriers usually spans from tens (48 in the case of IEEE 802.11a) to thousands (DVB-T/T2). The data on each subcarrier are mapped according to selected constellation diagram (usually BPSK, QPSK or M-QAM) and the OFDM modulation is implemented using the Fast Fourier Transform operation.

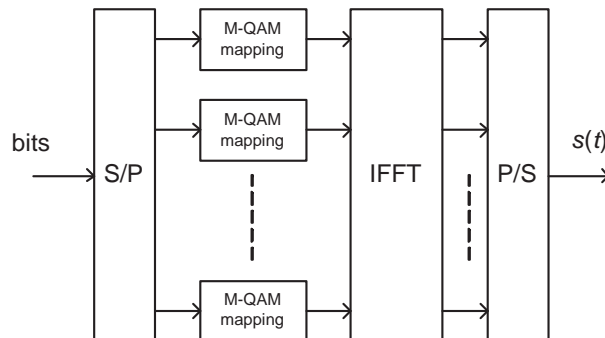


Figure 1: Structure of OFDM modulator

## 2 Use of MATLAB in OFDM signal spectrum sensing for the cognitive radio applications

The first example is the use of MATLAB in the evaluation of spectrum sensing for cognitive radio dynamic spectrum access. It is a classical hypothesis testing problem - the aim is to distinguish, whether the primary (licensed) user signal is present or not. The first hypothesis  $H_0$  assumes the presence of noise only, while the second hypothesis  $H_1$  assumes the reception of primary user's signal corrupted by additive noise component. Many spectrum sensing methods have been proposed in the literature, [2]. Probably the most well known are

- energetic detector
- matched filter detector
- cyclostationarity detector
- eigenvalues based detector.

In [3], the use of Kolmogorov-Smirnov test (K.-S. test) has been proposed in order to sense the free channels for cognitive radios. The basic idea of K.-S. test lies in the comparison between two cumulative distribution functions (CDF) [4] according to the equation:

$$T = \max \{|F(x_i) - G(x_i)|\}, \quad (1)$$

where  $F(x_i)$  is the theoretical CDF corresponding to hypothesis  $H_0$  evaluated at point  $x_i$ ,  $G(x_i)$  is the empirical (measured) CDF and  $T$  is the test statistics. The value of the test statistics  $T$  is then compared with the critical value  $k(\alpha, N)$ , where  $\alpha$  is the false alarm probability and  $N$  is the sample size. The MATLAB can be easily used for the efficient implementation of the spectrum sensing detectors. For example, the K.S. test can be simply used through in-built *KSTEST* function:

`Hypothesis = KSTEST(sample,theoreticalCDF,ALPHA,'unequal')`.

In our experiments, several spectrum sensing methods (energy detector, cyclostationarity detector, cyclic prefix correlation or K.-S. test) have been tested. The MATLAB software controlling the high speed acquisition card has been used in order to capture the data generated by the vector signal generator, as shown in Figure 2. The performance of statistical Kolmogorov-Smirnov test for detection of the WiMAX signal is shown on Figure 3, while the most important WiMAX PHY layer parameters are summarized in Table 1.

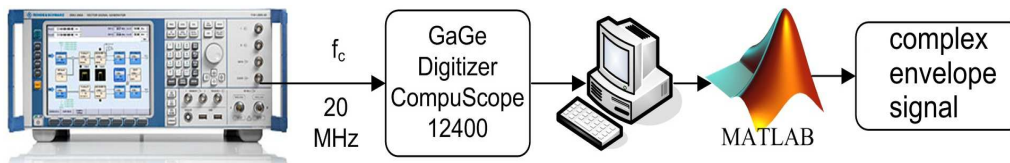


Figure 2: Measurement setup for algorithms evaluation in MATLAB

Parameter	Fixed WiMAX	Mobile WiMAX
FFT length	256	128, 512, 1024, 2048
$N_{data}$	192	72, 360, 720, 1440
$N_{pilot}$	8	12, 60, 120, 240
$N_{null}$	56	44, 92, 184, 368
CP	1/32 1/16 1/8 1/4	1/32 or 1/16 or 1/8 or 1/4
$f_s/B$	7/6	according bandwidth
$B$ [MHz]	3.5	1.25, 5, 10, 20

Table 1: WiMAX PHY parameters

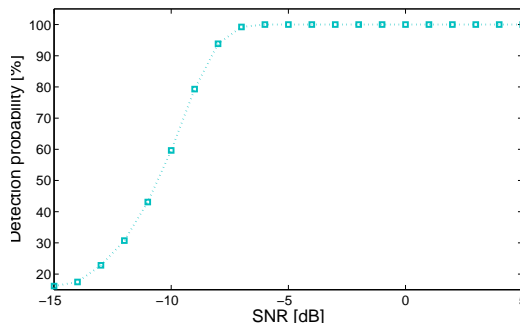


Figure 3: Detection probability for WiMAX OFDM-based signal

### 3 Use of MATLAB in OFDM signal optimization

Another application is the optimization of OFDM parameters according to the communication channel state. The subcarriers corresponding to low signal attenuation can carry more information (bits), than the subcarriers affected by high attenuation.

#### 3.1 Greedy algorithm

The OFDM system parameters can be optimized using a greedy algorithm [5]. It iteratively assigns one bit at a time to selected subcarriers. The basic function of the greedy algorithm can be described as follows. If  $n$ -th subcarrier already carries  $b_n$  bits, the power  $\Delta P_n^+$  needed to transmit one additional bit is given by:

$$\Delta P_n^+ = \frac{2^{b_n}}{g_n}. \quad (2)$$

The  $g_n$  is the channel gain to noise ratio of  $n$ -th subcarrier and is defined by:

$$g_n = \frac{|H_n|^2}{N_n}, \quad (3)$$

where  $H_n$  is the channel frequency response and  $N_n$  denotes the noise power. Maximum number of bits that can be assigned to the each subchannel is defined by, [5]:

$$\bar{b}_n = \lfloor \log_2 (1 + \bar{P}_n g_n) \rfloor \quad (4)$$

. As presented in [6] it is sometimes desirable that the channel frequency response  $H_n$  is replaced by the channel quality metric. For example the Error Vector Magnitude parameter (EVM) defined [7] mostly in the rms form as:

$$EVM_{rms} = \frac{\sqrt{\frac{1}{N_s} \sum_{k=1}^{N_s} |\mathcal{E}(k)|^2}}{\sqrt{\frac{1}{N_s} \sum_{k=1}^{N_s} |A(k)|^2}}, \quad (5)$$

can be used. Here  $N_s$  is the number of constellation points used, the term in a denominator normalizes the EVM to rms value of ideal transmitted constellation points  $A(k)$  and

$$\mathcal{E}(k) = \frac{V(k)W^{-k} - C_0}{C_1} - A(k). \quad (6)$$

$V(k)$  is received constellation point (measured vector) at symbol instant  $k$ , and the constants  $C_0$ ,  $C_1$  and  $W$  compensate the constellation offset, constellation complex attenuation and frequency offset caused by the transmission chain imperfections, respectively. These constants are found to minimize the term  $\sum_{k=1}^{N_s} |\mathcal{E}(k)|^2$ . For this application, simple MATLAB code could be implemented. First, the function according to the Equation 6 is written as (for the simplicity only the case of  $C_1$  will be considered):

```
function er=evm(PAR)
    er=abs((V/(PAR(1)+j*PAR(2))) - A);
    er=sum(er.*er);
end
```

PAR(1) and PAR(2) represent the real and imaginary part of  $C_1$  that we are searching for. This function is then minimized using the in-built *fminsearch* function:

```

C1=fminsearch('evm',[initR,initI]);
evmValue=evm(x);
evm_normalized=sqrt(evmValue/sum(abs(A).*abs(A)));

```

Here the  $initR$ ,  $initI$  are the initial conditions (e.g. set to 1) for parameter search. The value of  $C_1$  is then found and used for EVM calculation with subsequent normalization. An example of the OFDM optimization result using the greedy algorithm is shown in Figure 4. In the corresponding simulation, system with 128 subcarriers has been considered. The modulation on subcarriers can vary between BPSK, QPSK, 16QAM or 64 QAM. The SUI-3 channel model [8] has been used and modeled using a MATLAB *ricianchan* function.

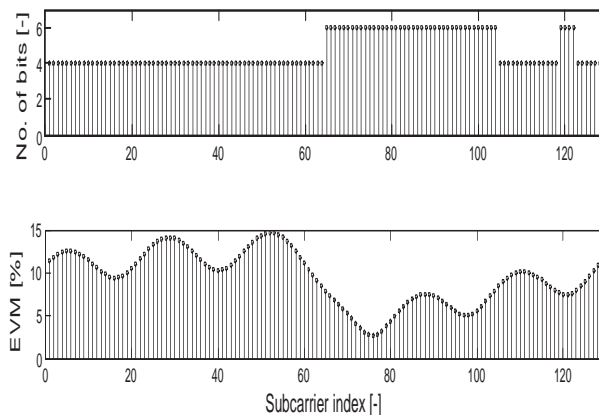


Figure 4: Optimization of bit allocation according to the EVM values

## 4 Use of MATLAB in OFDM signal DSP implementation

The last example illustrates the use of MATLAB for the verification of OFDM modulator implementation in digital signal processor (C6713 Texas Instruments family). The modulator has been implemented using C language according to the schematic from Figure 1. A signal processing library DSPlib has been used. As the main part of the OFDM modulator consists of the IFFT operation, the following C code is a heart of the implemented modulator

```

DSPF_sp_bitrev_cplx ((double*)ofdm_symbol, index, 64);
DSPF_sp_icfftr2_dif (ofdm_symbol, twiddle, 64),

```

where the first line applies the bit reversal operation to the input data corresponding to one OFDM symbol of length 64. The second line performs the IFFT operation itself (corresponding to MATLAB in-built function *IFFT*). The resulting signals have been subsequently loaded into MATLAB, in which the same structure has also been simulated. The output signals corresponding to one 64 point long OFDM symbol for both MATLAB simulation and DSP implementation are shown in Figure 2 (right). There is only scale (equal to the FFT length) difference between two cases.

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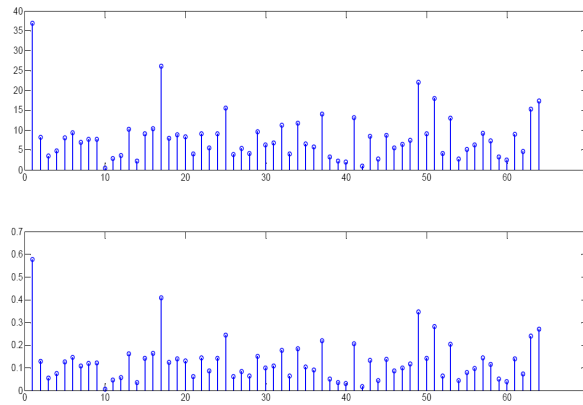


Figure 5: One OFDM symbol from the DSP implementation (top) and from MATLAB simulation (bottom)

## References

- [1] C. Cordeiro, K. Challapali, D. Birru, S.N. Shankar, IEEE 802.22: An Introduction to the First Wireless Standard based on Cognitive Radios. *Journal of Communications*, April 2006, vol. 1, no. 1, p. 38 - 47.
- [2] T. Yucek, H. Arslan, A Survey of Spectrum Sensing Algorithms for Cognitive Radio Applications. *IEEE Communications Surveys & Tutorials*, vol. 11, no. 1, pp. 116 - 130, First Quarter 2009.
- [3] G. Zhang, X. Wang, Y.C. Liang, J. Liu Fast and Robust Spectrum Sensing via Kolmogorov-Smirnov Test. *IEEE Transactions on Communications*. December 2010, Vol. 58, No. 12, s. 3410 - 3416, ISSN: 0090-6778.
- [4] B. Stehlikova, A. Tirpakova, J. Pomenkova, D. Markechova *Metodologie vzkumu a statistick inference. Research methodology and statistical inference*. Vyd. 1. Brno: Mendelova univerzita v Brn, 2009. 270 s. ISBN 978-807-3753-627.
- [5] N. Papandreou, T. Antonakopoulos, Bit and Power Allocation in Constrained Multicarrier Systems: The Single-User Case, *Eurasip Journal on Advances in Signal Processing*, Vol. 2008, ISSN:1110-8657
- [6] R.Marsalek, K. Povalac, J. Dvorak, Use of The Error Vector Magnitude for low-complex bit loading in Orthogonal Frequency Division Multiplexing, In *Proc. of 7th International Symposium on Image and Signal Processing and Analysis (ISPA 2011)* September 4-6, 2011, Dubrovnik, Croatia, p. 42-45.
- [7] L.Lecheminoux, *Analyse de l'influence des non-linearites de l'amplificateur de puissance dans une liaison de communication numerique RF*, PhD thesis, Universite de Marne la Vallee, France, 2000
- [8] IEEE 802.16.3c-01/29r4, Channel Models for Fixed Wireless Applications <http://www.ieee802.org/16>.