OFDM Communication System Based on PAPR Reduction Technique

M. Papez, R. Jasek and K. Vlcek

Abstract— In wireless communication reception, the reliability of OFDM is limited because of the time-varying nature of the channel. This causes inter-carrier interference (ICI) and increases inaccuracies in channel tracking. This can effectively be avoided at the cost of power loss and bandwidth expansion by inserting a cyclic prefix (guardian interval) before each block of parallel data symbols stream. One of the challenging issues for OFDM system is its high Peak-to-Average Power (PAPR). In this paper are discussed some methods of PAPR reduction for OFDM broadband communication systems.

Keywords—OFDM, communication system, transmission channel, ISI, PAPR, Clipping

I. INTRODUCTION

With the development of modern wireless communication technologies available frequency bands began to dwindle very significantly. The decrease led to considerations of communication systems using the frequency bands more efficiently than other current systems. The issue of available frequency-bands shortage led to the concept of systems using cognitive radio. The initial idea was to build devices that would be able to find available frequencies on basis of various frequency-band parameters from surrounding measurements appropriately changing their transmission parameters, particularly frequency. Currently, attention is focused on adaptability of cognitive radios extension possibilities based on specific situation in a bandwidth to change the type of used modulation, coding or communication protocol.

During digital signal transmission on a single-carrier frequency in a real communication channel, undesirable interactions of the transmitted information occur due to additive noise, impulse noise, interference from other sources of high-frequency signal and also by multipath propagation. While transmission speed increasing, occupied frequency-bandwidth is expanding as well as the level of additive noise. In the case of Digital Video Broadcasting – Terrestrial (DVB-T), a high transmission speed, especially if the length of one signal is comparable to signal propagation-time from a transmitter to a receiver. In this case the reverberation may significantly increase the inter-symbol interference (ISI).

This effect can be suppressed by transmission speed reduction per one single-carrier frequency, and therefore by the symbol period extension. In order to maintain the desired transmission capacity, it is required to use a larger amount of sub-carrier frequencies. When using a spread-spectrum technique, a guard interval is implemented to avoid interference between adjacent sub-carriers. However, it causes an efficiency reduction of the frequency-bandwidth used. Significant increase in spectral efficiency transmission is achieved by using OFDM system.

II. COMMUNICATION CHANNEL

The communication channel is the set of devices and systems that connects the transmitter to the receiver. The transmitter and receiver consist of an encoder and decoder, respectively, which translate the information stream produced by the source into a signal suitable for channel transmission.

Four general rules of communication channel have to be followed in the design state:

• The modulation must not expand the required transmission bandwidth beyond the available bandwidth
• BEM based systems must be interoperable with other technologies
• The required optical signal to noise ratio must be met even under worst-case scenario
• The hardware and software needed for BEM implementation must be simple and inexpensive

For further understanding of the communication system is necessary to recognize the individual elements of communication channel. These individuals subsequently determine the characteristics proprieties of transmitting.

III. OFDM (ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING)

The OFDM system is based on transmission in communication channel by thousands of sub-carrier frequencies. Furthermore, these sub-carriers are modulated
according to different requirements of robust modulations (BPSK, QPSK or M-QAM).

In OFDM, the sub-carrier frequencies are chosen so that they are orthogonal to each other (Fig. 1, right), meaning that cross-talk between the sub-channels is eliminated and inter-carrier guard bands are not required. This immensely simplifies the design of transmitter and receiver; unlike conventional FDM, a separate filter for each sub-channel is not required. The principle of OFDM is to distribute data stream into $M$ parallel blocks, where every single block is modulated on a different sub-carrier frequency. With the comparison of the system using only one-carrier frequency, a transmission rate of one block is $M$-times smaller, which is caused by symbol duration extension. Practically, this effect increases the resistance to frequency-selective fading, attenuation of high frequencies or narrowband interference. In this case, time scattering signals caused by signal propagation of more sub-carriers is not applied [1][4]. The mathematical description of propagation in the time-domain is assumed by the following formula (1):

$$s(t) = \sum_{n=-\infty}^{\infty} \sum_{m=0}^{M-1} a_{n,m} \text{rect}_{T_s}(t - nT_s) e^{-j2\pi fmT_s},$$

where $m$ corresponds to a sub-carrier, $n$ represents an order of symbol. Function $\text{rect}_{T_s}$ determines the time-duration of single transmitted OFDM symbol.

Sub-carriers in the OFDM system are, in comparison with the other systems using spread spectrum techniques, mutually orthogonal (2).

$$d_{lk} = \int e^{-j2\pi \frac{t}{T}} \sum_{n=0}^{N-1} d_k e^{-j2\pi \frac{n}{T}} dt$$

The smallest distance between two adjacent sub-carriers is $1/T$. Individual sub-carrier frequencies are then given by formula (3):

$$\omega = 2\pi f_m = \frac{2\pi m}{T}$$

The performance of OFDM transmission system may differ by various parameters properties including:

- Bandwidth
- Size of IFFT modulator
- Number of sub-carrier
- Sub-carrier modulation scheme
- Sub-carrier spacing
- Length of useful symbol $T_{sU}$ and guard interval $T_G$
- Length of cyclic prefix

<table>
<thead>
<tr>
<th>Standard name</th>
<th>DVB-T</th>
<th>IEEE 802.11a</th>
<th>WiMAX 802.16d</th>
<th>T - DAB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency range</td>
<td>470–862 MHz 174–230 MHz</td>
<td>4.915–6.100 GHz</td>
<td>1,536</td>
<td></td>
</tr>
<tr>
<td>Channel spacing, $B$ [MHz]</td>
<td>6, 7, 8</td>
<td>20</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>FFT size (k=1,024)</td>
<td>2k, 8k</td>
<td>64</td>
<td>256</td>
<td></td>
</tr>
<tr>
<td>Number sub-carriers, $N$</td>
<td>2K mode: 1.705 8K mode: 6.817</td>
<td>52</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Sub-carrier modulation scheme</td>
<td>QPSK, 16QAM 64QAM</td>
<td>BPSK, QPSK,[18] 19QAM or 64QAM</td>
<td>DQPSK</td>
<td></td>
</tr>
<tr>
<td>Useful symbol length, $T_{sU}$ (μs)</td>
<td>2K mode: 224 8K mode: 896</td>
<td>3.2</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Additional guard interval, $T_G$</td>
<td>1/4, 1/2, 3/4, 1</td>
<td>1/4, 1/2, 3/4, 1</td>
<td>0.246</td>
<td></td>
</tr>
<tr>
<td>Sub-carrier spacing (Hz)</td>
<td>2K mode: 4.464 8K mode: 1.116</td>
<td>312.5K</td>
<td>15,625</td>
<td></td>
</tr>
</tbody>
</table>

Table I. Standards using the OFDM
IV. CHOOSING A MODULATION SCHEME

Single sub-carrier frequency in the OFDM system can be transmitted by a different modulation scheme, which depending on specific transmission channel requirements, such as data rate and bit error rate (BER). Frequently used modulations are BPSK, QPSK, DQPSK, 16QAM and 64QAM.

The OFDM system (Figure 2) shows that modulated signal with \( N \) sub-carriers is enhanced by the cyclic prefix and broadcasted by channel with time-varying impulse response \( h(\tau,t) \) and additive noise AWGN [6]. Cyclic prefix is removed from the receiver, and the data samples are converted by the FFT to the time domain, where behave as \( R_n \) symbols (4) (5).

\[
y(n) = \sum_{k=0}^{N-1} H(k)X(k)e^{j2\pi kn/N}, \quad (4)
\]

\[
H(k) = \sum_{n=0}^{N-1} h(n)e^{j2\pi kn/N} \quad (5)
\]

An objective of adaptive modulation is to choose an appropriate method for the data transmission of each sub-carrier in the respective of SNR \( (\gamma_n) \). In the order to suitably compromise between the transmission data speed and total BER. The modulation scheme selection is performed by individual modulations assigning variable \( M_n \), where \( m \) denotes a number of bits required for the modulation. In order to encourage low system complexity, modulation schemes are not assigned particularly to each sub-channel, but to every single subbandwidth composed of several adjacent sub-channels. Most widely used algorithms for correct modulation selection are [1]:

- Fixed threshold adaptation algorithm
- Subband BER estimator adaptation algorithm
- Constant throughput adaptation algorithm

V. FIXED THRESHOLD ADAPTATION ALGORITHM

Communication channel for Fixed threshold adaptation algorithm must be invariable for all transmitted symbols with the same modulation selected depending on SNR level. Commutation levels for modulation scheme with higher number of bits per symbol (BPS) were designed based on calculations (Table II.) by Liu and Li [8].

<table>
<thead>
<tr>
<th>Sound [dB]</th>
<th>1_0</th>
<th>1_1</th>
<th>1_2</th>
<th>1_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data [dB]</td>
<td>-(\infty)</td>
<td>7.98</td>
<td>10.42</td>
<td>16.76</td>
</tr>
</tbody>
</table>

When the SNR level of sub-channel for data transmission occurs between \( I_0 \) and \( I_1 \), BPSK modulation is used. Additionally, if the level of \( I_1 \) exceeds \( I_2 \) than, QPSK modulation is processed.

VI. SUBBAND BER ESTIMATOR ADAPTATION ALGORITHM

Subband BER estimator adaptation algorithm considers from continuously changing SNR levels \( \gamma_n \) for every \( N \) sub-carrier of the \( j \) subband. For application of this algorithm is required an estimation of probability error for all modulations \( M_n \) in each subband, which if given by formula (6):

\[
\overline{p}_n = \frac{1}{N_\xi} \sum_{j} p_n(\gamma_j, M_n) \quad (6)
\]

Modulation scheme, which provides the highest data rate assuming, that the bit error rate (BER) is significantly lower than a given threshold is selected for every single subband [7].

VII. CONSTANT THROUGHPUT ADAPTATION ALGORITHM

Adaptive modulation scheme uses channel frequency-selectivity fadings and maintains constant data rate, which is fundamental for audio and video transmissions sensitive to synchronization delays. Accordingly, transmission cost \( c_{n,s} \) is calculated for each of \( n \) subband by given formula (7):

\[
c_{n,s} = \frac{e_{n,s+1} - e_{n,s}}{b_{n,s+1} - b_{n,s}} \quad (7)
\]

Subbands allocation is based on the lowest transmission cost \( c_{n,s} \), which is determined by the anticipated number of bit errors \( e_{n,s} \) and the bit rate \( b_{n,s} \). Bit error rate is calculated for all modulation schemes, which consist of \( n \) sub-bandwidth [3].

VIII. MULTIPATH PROPAGATION

Another issue that needs to be addressed from OFDM system is multipath propagation. Transmitted signal is heading to the receiver over various paths and many different delayed replicas of the signal originally send occur on the receiving side. There is a scattering of wave propagation time \( \tau_s \). This corresponds to the extension of the channel impulse response is usually marked as \( h(t) \) given by formula (8) [2]:

\[
h(t) = \sum_{k=0}^{\infty} h_k e^{j2\pi f_k t} \quad (8)
\]
Inter-symbol Interference (ISI) and mutual interference between sub-carriers Inter-carrier Interference (ICI) occurs in characteristic environment. To avoid mutual overlap between transmitted symbols ISI, following condition must be accomplished (9):

\[ T_s = \frac{1}{f_s} \gg \tau_s , \]

where \( T_s \) denotes the symbol period. As a result of extended duration of the OFDM symbol (\( T_s = T_{OFDM} \)), ISI in partial sub-channels interruption influence is exceptionally higher than in systems with a single carrier. ISI can be suppressed to the minimum by implementation of guard interval (GI). The guard interval is characterized by a short delay between the transmitted symbols [1].

The PAPR is a related measure that is defined as the peak amplitude squared \( \max_{t \in T} |x(t)|^2 \) divided by the \( E[|x(t)|^2] \) value squared giving the average power of signal.

\[ PAPR \{x(t),T\} = \frac{\max_{t \in T} |x(t)|^2}{E[|x(t)|^2]} \]

(10)

IX. PEAK TO AVERAGE POWER RATIO (PAPR)

One of the disadvantages of OFDM system is the large ratio of Peak to Average Power Ratio (PAPR). The PAPR is the relation between maximum power of a sample in a given OFDM transmit symbol divided by the average power of that OFDM symbol [4] [11]. Due to presence of large number of independently modulated subcarriers in an OFDM system, the peak value of the system can be very high as compared to the average of the whole system. Therefore, PAPR is defined by the formula (10):

The PAPR is a related measure that is defined as the peak amplitude squared \( \max_{t \in T} |x(t)|^2 \) divided by the \( E[|x(t)|^2] \) value squared giving the average power of signal.
Figure 6 shows typical transfer characteristics of an amplifier. In order to avoid signal distortions, it is fundamental to operate in the linear part of this characteristic (around the point A). Lower efficiency is achieved in this part of the transmission characteristic. Therefore, there are attempts to use a region at higher level $U_{IN}$ in the amplifier, an area around the point B, where it has non-linear characteristic.

**X. PAPR REDUCTION - CLIPPING**

The simplest and most widely used technique of PAPR reduction is called Clipping. It is a smooth reduction of the signal in the time domain. Generally, clipping is performed as the transmitter. However the receiver need to estimate the clipping that has occurred and to compensate the received OFDM symbol accordingly. Typically, at most one clipping occurs per OFDM symbol, and thus the receiver has to estimate location and size of the clip [4].

If the absolute instantaneous level of signal at a given time is higher than the maximum required level, the value is being reduced to maximum desired level. The required maximum of signal level can be set absolutely or relatively. Absolute limit setting is adjustable, but less transparent.

![Fig. 6 Transfer characteristic of an amplifier](image)

Figure 7 shows an example of reduced signal to clipping threshold level. Therefore, in these case, relative reduction of the maximum level - CLIP is used. Achieved signal peak level after clipping would be given by following formulas (11)(12):

$$y_{c \text{ max}} = CLIP \cdot y_{\text{max}},$$  
(11)

$$CLIP = \frac{y_{c \text{ max}}}{y_{\text{max}}},$$  
(12)

where $y_{c \text{ max}}$ is the maximum level of the signal after clipping and $y_{\text{max}}$ is the maximum level of the original signal. If a large degree of limited signal is selected, for example $CLIP << 1$, high reduction dynamics is achieved. Besides that, addition noise increase, which leads for significant signal degradation. Errors in obtaining the original information occur, in case of large degree of trimming signal (a low value of CLIP).

**XI. CONCLUSION**

In this paper, the principle of OFDM communication system is described. OFDM converts a wideband frequency channel to the amount of narrowband subchannels. Orthogonality of these subchannels guarantees an investigation of a frequency band. Additionally, OFDM provides an efficient data transmission in a wireless dispersive environment with multipath signal propagation.

In addition, the article also discusses algorithms which are used to select modulation schemes. Correct selection of these schemes is an essential benchmark for accuracy and quality of the transmitted signal. Finally, this paper describes the principle of reducing the dynamics of the transmitted signal, which performs a consequential aspect in the processing of the transmitted signal. In the case of a breach dynamics reduction leads to a significant distortion of transmitted information. These techniques to reduce PAPR can be used to reduce the PAPR at the cost of loss in data rate, transmit signal power increase, BER performance degradation, computational complexity increase, etc.

Due to transmission properties of OFDM such as high data throughput, flexibility and simple implementation, OFDM has become a fundamental into current standards such as DSL, Advanced LTE (Long Term Evolution), DAB (Digital Audio Broadcasting), DVB (Digital Video Broadcasting), WLAN (Wireless Local Area Network) IEEE 802.11g and WiMAX [5][8].

**REFERENCES**


ISBN: 978-1-61804-235-4 73