A Technique for Sidelobe Suppression in OFDM System to Design a Successful Spectrum Sharing Systems

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Abstract

In this paper, we propose a method for sidelobe suppression in orthogonal frequency division multiplexing (OFDM) system. Sidelobe suppression is essential topic to design a successful OFDM based overlay system. We consider two approaches: the multiple choice sequence (MCS) which is based on producing set of sequences and choosing the one sequence which has lowest power in sidelobes and another technique is the conventional windowing of OFDM signal in time domain. We combine MCS with windowing technique. Simulation results show that by combining MCS with conventional windowing technique, the sidelobes in OFDM system can be significantly reduced.

1. Introduction

Orthogonal frequency division multiplexing (OFDM) has been succesfully used by standards such as the digital audio broadcasting and the digital video broadcasting for modulation. In OFDM system individual subcarriers can be switched on or off, which makes OFDM system very attractive to implement in so called spectrum sharing systems [1]. The main drawback of OFDM system is the sidelobes. In OFDM based overlay system the out-of-band radiations can create interference with the existing legacy system. Therefore, the sidelobe suppression has been an essential topic. As described in [3], Fig. 1, illustrates the concept of coexistance between OFDM based overlay system and existing legacy system in frequency band assigned to the existing legacy systems.

In [2] the combination of windowing with cancellation carriers is proposed and analyzed. In this paper, we combine multiple choice sequence (MCS) [3] with windowing technique. The introduction about combining MCS with windowing is given in [3]. Results show that by combining MCS with windowing technique sidelobes can be significantly reduced which enables to design a successful OFDM based overlay system.

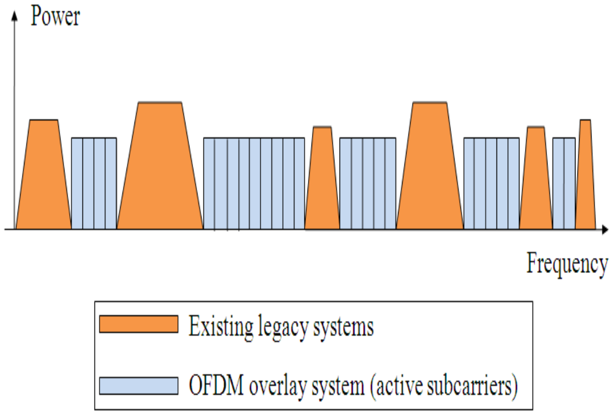

Figure 1. concept of implementing OFDM system within frequency band assigned to existing systems.

The paper is organized as follows. In Section 2, the system model is described. In Section 3, the sidelobe suppression techniques are explained. Section 4 contains the results. Finally, Section 5 is the conclusion.

2. System Model

We consider an OFDM system with total number of N subcarriers. The block diagram of the OFDM transmitter which includes combination of MCS with windowing is illustrated in Fig. 2. The input bits are symbol-mapped by applying the modulation technique of phase-shift keying (PSK) or quadrature amplitude modulation (QAM) and N data symbols d_n, $n = 1, 2, ..., N$, are generated and then these symbols are serial-to-parallel (S/P) converted which results into an vector $\mathbf{d} = (d_1, d_2, ..., d_N)^T$, where $(.)^T$ denotes transposition. The vector $\mathbf{d}$ is fed into the MCS sidelobe suppression unit, which outputs the sequence denoted by $\mathbf{q} = (q_1, q_2, ..., q_N)^T$. Resulting sequence $\mathbf{q}$ is modulated onto N subcarriers using the inverse discrete fourier transform (IDFT). After that, parallel-to-serial (P/S) conversion is performed, cyclic prefix is added with P/S converted signal, then signal is digital-to-analog (D/A) converted. Next, D/A converted time domain signal is multiplied with a windowing function $w^{RC}(t)$.

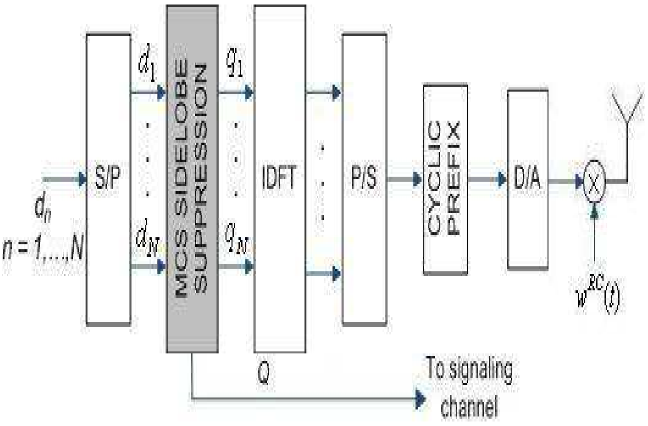

Figure 2. Block diagram of the OFDM transmitter with MCS and windowing.

3. Sidelobe Suppression Techniques

3.1. Sidelobe Suppression by MCS

The principle of MCS [3] is to produce set of mapped sequences from the original transmission sequence and select the one sequence from the MCS set for tranmission which has lowest power in sidelobes. The MCS system is divided into two parts, where first part produces MCS sets and the second part selects the sequence which has lowest power in sidelobes.

A single subcarrier in frequency domain is represented as

$$s_n(f) = d_n.\mathbf{si}(\pi(f - f_n)T_0), n = 1, 2, ..., N \qquad (1)$$

where f denotes the frequency, f_n is the carrier frequency of the nth subcarrier, and T_0 is the OFDM symbol duration including guard time T_G, i.e., $T_0 = T_s + T_G$, where T_s is the OFDM symbol duration without guard time. The spectrum of each subcarrier is equal to a si-function which is defined as $\mathbf{si}(x) = \sin(x)/x$, where x is the normalized frequency.

Using MCS a specific set of $P > 1$ sequences, $\mathbf{d}^{(p)} = (d_1^{(p)}, d_2^{(p)}, ..., d_N^{(p)})^T$, $p = 1, 2, ..., P$, are generated from the original data sequence $\mathbf{d}$. The average sidelobe power denoted with $\mathbf{A}^{(p)}$, $p = 1, 2, ..., P$, is calculated for each MCS generated sequence $\mathbf{d}^{(p)}$. To determine the average sidelobe power, a certain frequency range called optimization range spanning several OFDM sidelobes are considered using discrete frequency samples. The optimization range is illustrated in Fig. 3, the optimization range is divided in two approximately equal parts. As explained in [3], $\mathbf{A}^{(p)}$ is given by

$$\begin{aligned} \mathbf{A}^{(p)} = 1/K \sum_{k=1}^{K} \left| \sum_{n=1}^{N} d_n^{(p)} \frac{\sin(\pi(y_k - x_n))}{\pi(y_k - x_n)} \right|^2 &, p = 1, 2, ..., P \\ n &= 1, 2, ..., N \\ k &= 1, 2, ..., K \end{aligned} \qquad (2)$$

In Equation (2), $x_n, n = 1, 2, ..., N$, denotes the normalized subcarrier frequencies and K samples at the normalized frequencies $y_k, k = 1, 2, ..., K$, are considered, which are in the frequency range where the optimization of the sidelobes is performed.

The index Q of the selected sequence from the MCS set which has lowest power in sidelobes is given by

$$Q = \mathbf{arg} \, \underset{p}{\mathbf{min}} \mathbf{A}^{(p)}, p = 1, 2, ..., P \qquad (3)$$

So, the sequence $\mathbf{d}^{(Q)} = (d_1^{(Q)}, d_2^{(Q)}, ..., d_N^{(Q)})$ is the one selected from the MCS set, i.e. $\mathbf{q} = \mathbf{d}^{(Q)}$.

To generate MCS set many MCS algorithms can be derived. There are few promising MCS algorithms that are proposed and analysed to produce the MCS set, i.e. symbol constellation approach, phase approach and interleaving approach. Using symbol constellation approach, the MCS set is produced such that the elements $d_n^{(p)}, n = 1, 2, ..., N$, of $\mathbf{d}^{(p)}$ belongs to the same contellation as elements of original sequence. In symbol constellation approach the P index vectors are defined, the MCS vectors $\mathbf{d}^{(p)}, p = 1, 2, ..., P$ are obtained by taking the symbols from the constellation space according to the defined vectors. In the phase approach, the random phase shifts are applied to the original data symbols to produce the MCS set. In the interleaving approach, the original sequence is permuted in pseudorandom order to produce the MCS set. Above explained approaches are not the only approaches to generate MCS set. Other approaches can be developed to generate MCS set.

3.2. Sidelobe Suppression by Windowing

As illustrated in Fig. 2, the time domain transmit signal is multiplied with windowing function. Windowing can be

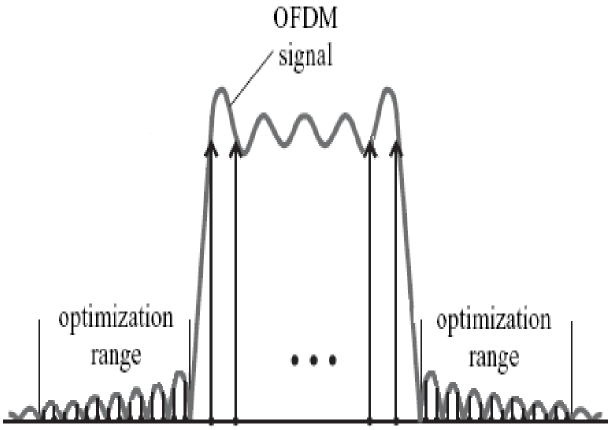

Figure 3. Block diagram of the optimization range and OFDM signal in frequency domain.

applied to OFDM symbols. Windowing technique can be used to suppress the sidelobes in OFDM system. A well known window is the raised cosine window [5], which can be defined as

$$w^{RC}(t) = \begin{cases} 0.5 + 0.5\cos(\pi + \frac{\pi t}{\alpha T_{rc}}) & 0 \le t < \alpha T_{rc} \\ 1.0 & \alpha T_{rc} \le t < T_{rc} \\ 0.5 + 0.5\cos(\frac{\pi(t-T_{rc})}{\alpha T_{rc}}) & T_{rc} \le t < (1+\alpha)T_{rc} \\ 0 & else \end{cases} \tag{4}$$

where α, $0 \le \alpha \le 1$ denotes roll-off factor. The symbol duration is equals to

$$T_{rc} = (T_s + T_{prefix} + T_{postfix})/(1+\alpha) \tag{5}$$

After applying windowing, the time structure of OFDM signal is shown in Fig. 4. The length of segment has been enlarged by prefix T_{prefix} and postfix $T_{postfix}$. The length of prefix covers the roll-off region and guard time, i.e., $T_{prefix} = \alpha T_{rc} + T_G$, and the length of postfix only covers the roll-off region, i.e., $T_{postfix} = \alpha T_{rc}$. After windowing the transmit signal the sidelobes in OFDM system can be significantly reduced. By taking Fourier transform of Equation (4), the spectrum of single subcarrier of the windowed trasmit signal is equal to

$$s_n^{rc}(f) = \mathrm{si}(\pi f T_{rc}).\frac{\cos(\alpha \pi f T_{rc})}{1-(2\alpha f T_{rc})^2} \tag{6}$$

To achieve higher reduction of out-of-band radiations the MCS can be combined with windowing. The samples of original transmit signal in the optimization range have to be determined according to Equation (6)

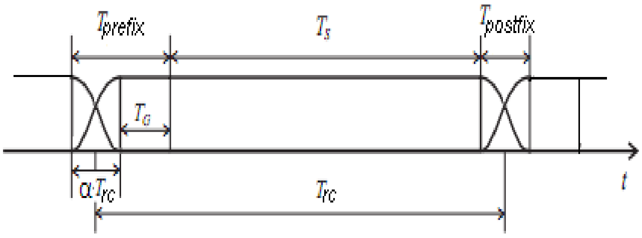

Figure 4. OFDM cyclic extension and windowing.

4. Numerical Results

Numerical results illustrate the effectiveness of the combination of MCS with windowing concept. Binary phase shift keying modulation is applied and no channel coding is considered. The number of used subcarriers is set to $N = 16$. The spectra of the OFDM signals with combination of MCS with windowing and without combination of MCS with windowing are illustrated in Fig. 5. Here we use the MCS set of $P = 4$ to generate MCS sequences. The roll-off factor is set to $\alpha = 0.2$. The MCS with windowing reduces OFDM sidelobes by more than 26 dB. If the MCS set size is increased then even higher sidelobe suppression results can be achieved but it degrades the system performance.

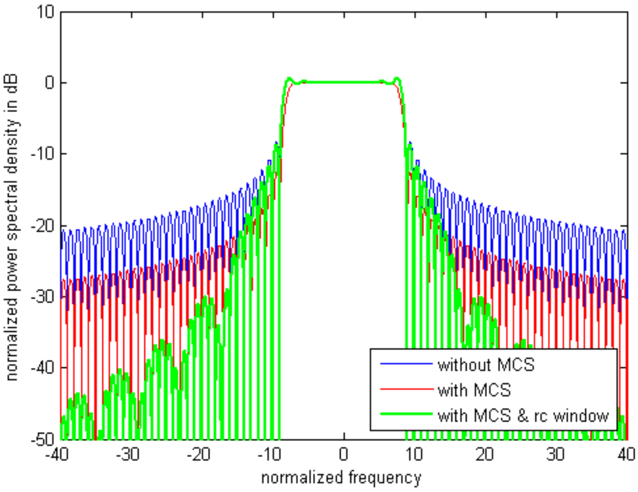

Figure 5. OFDM spectrum with MCS and raised cosine window.

5. Conclusion

We combined MCS technique with windowing to suppress the sidelobes of OFDM transmission signal. By combining MCS with windowing the spectral efficiency of OFDM based transmission systems can be improved and this approach can be applied to OFDM based overlay system to avoid interference towards the legacy system sharing the same frequency band. MCS with windowing reduces OFDM sidelobes by more than 26 dB.

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