스펙트럼 공유를 위한 직교 주파수 분할 다중 (OFDM) 시스템에서의 사이드로브 억압 기법

논 문
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Sidelobe Suppression Technique in OFDM Systems for Spectrum Sharing

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Abstract – We propose a new technique for sidelobe suppression in orthogonal frequency division multiplexing (OFDM) systems. Sidelobe suppression is an essential technique to design OFDM based overlay system. The proposed technique is based on the combination of the multiple choice sequence (MCS) with the conventional windowing of OFDM signal in time domain. The MCS is choosing the one sequence which has lowest power in sidelobes from the produced set of sequences. The main advantage of proposed technique is that it fully utilizes the available bandwidth to transmit data. Simulation results show that by combining MCS with conventional windowing technique, the sidelobes in OFDM system can be significantly reduced

Key Words : OFDM, Sidelobe Suppression, Out-of-Band Radiations, Rultiple Choice Sequence, Windowing Technique

1. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) has been successfully 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 [2], Fig. 1 illustrates the concept of coexistence between OFDM based overlay system and existing legacy system in frequency band assigned to the existing legacy systems.

In [3] the combination of windowing with cancellation carriers (CC) is proposed and analyzed. The proposed method in [3] has drawback of waste of available bandwidth due to insertion of CC and also CC technique involves complex optimization technique that adds to the system complexity when number of subcarriers are large. In [4] the combinations of multiple choice sequences (MCS) with subcarrier weighting (SW) and MCS with CC are proposed and analyzed. Also, the combination windowing technique with MCS and windowing technique with SW is proposed in [5]. The main disadvantage of these techniques is that they do not fully utilizes the available bandwidth to transmit data.

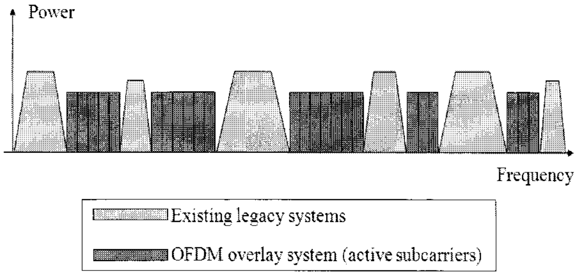

Fig. 1 OFDM system within frequency band assigned to existing systems

In this paper, we combine MCS with windowing technique. The main advantage of proposed technique is that it fully utilizes the available bandwidth to transmit data. Results show that by combining MCS with windowing technique sidelobes can be significantly reduced, which enables to design a successful OFDM based overlay system.

The paper is organized as follows. In Section 2, the system model is described. In Section 3, the proposed sidelobe suppression technique is explained. In Section 4, simulation results are given to demonstrate the effectiveness of the proposed technique. Finally concluding remarks are given in the Section 5.

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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. D/A converted time domain signal is multiplied with a windowing function $w(t)$.

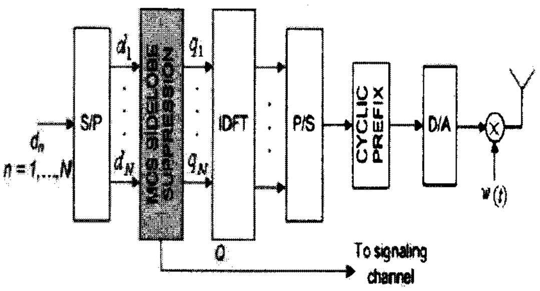

Fig. 2 Block diagram of the OFDM transmitter with MCS and windowing

3. SIDELOBE SUPPRESSION TECHNIQUES

The principle of MCS [2] is to produce set of mapped sequences from the original transmission sequence and select the one sequence from the MCS set for transmission 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

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

where f denotes the frequency, f_n is the carrier frequency of the n^{th} 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 $=fT_0$ 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 $\mathbf{d}^{(p)}$. In order 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 illustrated in Fig. 3 is divided in two approximately equal parts. As explained in [2], $\mathbf{A}^{(p)}$ is given by

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

In Eq. (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

$$Q=\mathbf{arg}\min_p\mathbf{A}^{(p)}, p=1,2,...,P \tag{3}$$

The sequence $\mathbf{d}^{(Q)}=(d_1^{(Q)},d_2^{(Q)},...,d_N^{(Q)})$ is the one selected from the MCS set, i.e. $\mathbf{q}=\mathbf{d}^{(Q)}$. There are few promising MCS algorithms that are proposed and analyzed 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 constellation 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.

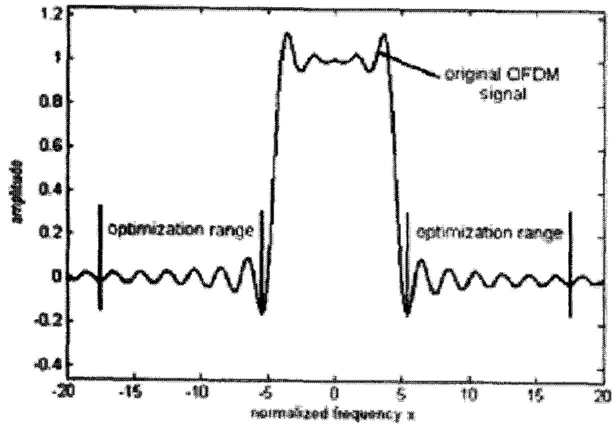

Fig. 3 Block diagram of the optimization range and OFDM signal in frequency domain

As illustrated in Fig. 2, the time domain OFDM transmit signal is multiplied with windowing function. Windowing technique can be used to suppress the sidelobes in OFDM system. A well known window is the raised cosine window [7], which can be defined as

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

where, $0 \le \alpha \le 1$ 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 Fouriertransform of Eq. (4), the spectrum of single subcarrier of the windowed transmit signal is equal to

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

In order 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 Eq. (6).

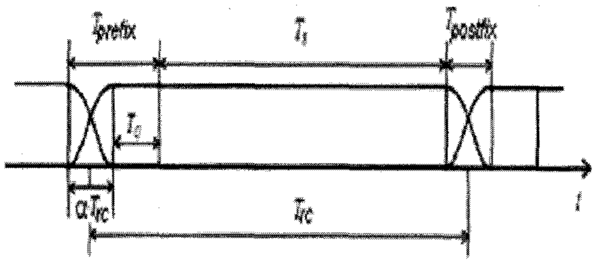

Fig. 4 OFDM cyclic extension and windowing

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 $\alpha = 0.2$.

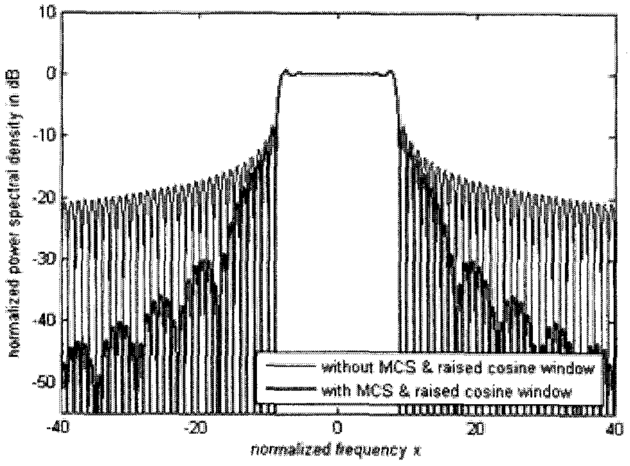

Fig. 5 OFDM spectrum with MCS and raised cosine window

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.

The existing method in [2] which analyzes the combination of windowing with CCs has few drawbacks as compared to the proposed method. Fig. 6 shows the spectra of OFDM signals with combination of CC with windowing and without the combination of CC with windowing. The number of used subcarriers is set to $N = 16$.

To suppress the sidelobes of transmission signal we insert W_l and W_r CC on the left and on the right hand side of the used OFDM spectrum, respectively. Here we insert $W_l = 2$ CC at left and $W_r = 2$ CC at the right side, i.e. $W = 4$.

Fig. 6 shows the spectra of OFDM signals with combination of CC with windowing and without the combination of CC with windowing. The number of used subcarriers is set to $N = 16$.

As a result, the bandwidth of the OFDM spectrum is increased by $W = W_l + W_r$. The power spent on CC is limited to 25 %. The roll off factor is set to $\alpha = 0.2$. The CC with windowing reduces OFDM sidelobes by more than 30 dB.

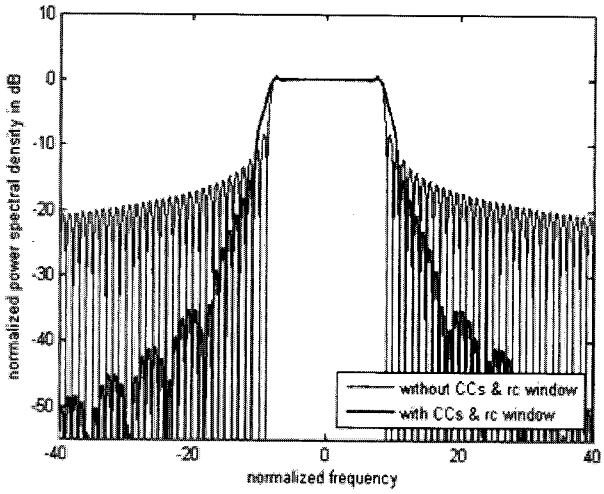

Fig. 6 OFDM spectrum with CC and raised cosine window

The main drawback of CC with windowing is the extra usage of bandwidth due to the insertion of CC which carries complex weighting factor. However the proposed method does not uses extra bandwidth. CC also involves the complex optimization problem that adds the complexity to system when the number of subcarriers is large. The other drawback of CC with windowing is the extra power of 25% is spent on CC.

5. CONCLUDING REMARKS

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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