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Space Frequency Parallel Cancellation Based for ICI in OFDM System

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Abstract: orthogonal frequency division multiplexing is the multicarrier technique that utilizes high data rate. A signal get splits into multiple sub carriers which are orthogonal to each other. The drawback of OFDM is its sensitivity to the carrier frequency offset, time variations due to Doppler shift which tends to lose orthogonality and generate the intercarrier interference i.e. ICI. Different methods are introduced to mitigate the ICI such as self cancellation method that reduces the ICI at the cost of lowering transmission data rate. In this paper, the parallel cancellation (PC) scheme is used to mitigate the ICI of OFDM. Further expanding PC scheme to space frequency (SF) coded system.

Keywords: OFDM, Multipath Channel, OFDM, Self Cancellation (SC), Parallel Cancellation (PC), Space Frequency (SF).

I. INTRODUCTION

The Advancement of communication technology has resulted into requirement of higher data rate. Orthogonal frequency division multiplexing is an emerging technology for high data rates. In OFDM a large number parallel channels are used to carry data on closely spaced orthogonal sub-carrier. One of the modulation skill like quadrature amplitude modulation or phase-shift keying is used to modulate every sub carriers at a low symbol rate, provided that total data rates is maintained, similar to conventional single-carrier modulation schemes in the same band-width.

OFDM has ability to decompose the frequency selective fading channel into several no. of flat fading channels. The disadvantage of OFDM is that it is sensitive to the carrier frequency offset due to Doppler shift resulting in intercarrier interference. This ICI degrades the performance of the system thus ICI reduction is necessary to correctly demodulate the receiver data. In order to reduce ICI several methods are proposed. ICI self-cancellation (SC), frequency-domain equalization, and the parallel cancellation (PC) are example of such methods the difference between SC method and PC method lies in the fact that although both use repetitive transmission, one uses on per-subcarriers basis while other uses per-OFDM symbol basis respectively. The PC scheme is used to mitigate ICI, expansion with SF coded system. PC scheme has advantages like robust to block size therefore SFPC will also be robust. It has higher signal to noise ratio than regular OFDM system in presence of Doppler shift or Carrier Frequency Offset. Hence the PC scheme lowers error floor for OFDM system in frequency selective fading channels with Doppler frequency. This characteristic is inherently extended to the SFPC-OFDM system and improves the BER significantly [1].

II. REGULAR OFDM

OFDM is multi–transmission technique in which the signal is divided into number of multiple narrowband signals to transmit the data efficiently.

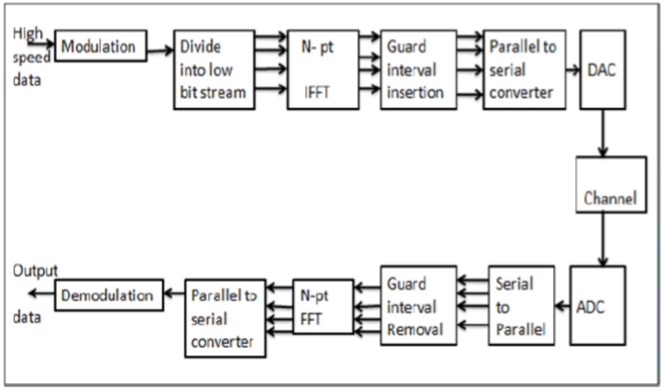


Fig.1. Block diagram of OFDM.

In fig.1 the high speed data is given to the input of transmitter where the data is modulated with different modulation techniques. Further data is converted into parallel stream through IFFT resulting number of narrowband spectra. The transmitted signal Xk after IFFT is

$$Xk = \sum_{n=0}^{N-1} dn e^{\frac{j2\pi kn}{N}} \quad k=0,\ 1,2,\ldots.N\text{-}1 \tag{1}$$

Where d_n is data symbol and exp[j2πkn/N] k=0,1,….N-1 represents the corresponding orthogonal frequencies of N subcarriers. G is length after adding cyclic prefix and after parallel to serial conversion the signal transmitted is

$$X^g = [X_{N-G} \ldots X_{N-1} X_0 \ldots X_{N-1}] \tag{2}$$

The received signal is convolution of X_g and channel impulse response. This signal is mixed with local oscillator signal which gives ε above the correct carrier frequency with phase noise, additive Gaussian noise (AWGN). At the receiver, cyclic prefix is removed after serial to parallel conversion. The baseband recovered signal after FFT is

$$dm = \frac{1}{N}\sum_{k=0}^{N-1} rke^{\frac{-j2\pi mk}{N}} \quad \textbf{(2)}$$

$$\frac{1}{N}\sum_{n=0}^{N-1}\sum_{k=0}^{N-1} Hndne^{\frac{j2\pi(n+\varepsilon)}{N}}e^{\frac{-j2\pi mk}{N}}$$

$$= H0dmu0 + \textstyle\sum_{n=0,n=m}^{N-1} Hndnun - m$$

m=0…..

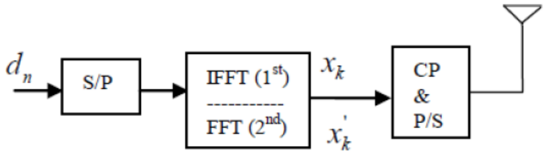
Where

$$Un - m = \frac{e^{j\pi\frac{N-1}{N}(n-m+\varepsilon)}\sin[\pi(n-m+\varepsilon)]}{N.\sin[\left(\frac{\pi}{N}\right).(n-m+\varepsilon)}$$

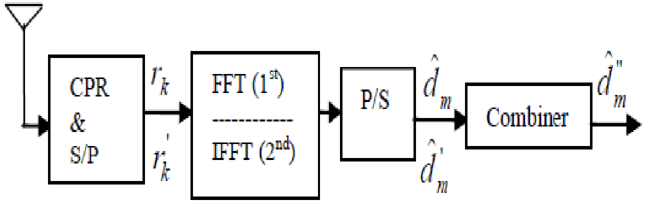
r_k is the received signal to FFT. k is sampling index, exp[2πkε/N] , k=0,1,…N-1 represents the frequency offset of the received signal ε is frequency offset; m is receiver subcarrier index. Un-m is the weighting factor. Weighting function helps to visualize the impact of local oscillator phase noise on the operation of OFDM. The average weighting function verses normalized frequency is plotted with the value of normalized frequency =16, ε=0, m=1 to7. So it results Uo is -1. This means it holds orthogonality and has no crosstalk among subcarriers. When ε>0, the curve of weight function of fig. 2 Shifting towards left side losing its orthogonality [1]. The weighting function helps to find out the constraints of system designer.

III. PC-OFDM SYSTEM

The PC-OFDM scheme has reversed the FFT at transmitter and IFFT at the receiver than regular OFDM. The fig shown below



(a) PC-OFDM transmitter



(b) PC-OFDM receiver

Fig. 2. PC-OFDM Transmitter and Receiver.

The PC-OFDM scheme has two branch operations as shown in fig.2. The first branch is a regular OFDM system which has IFFT processing at the transmitter and FFT processing at the receiver. And second branch has FFT at transmitter and IFFT at receiver. At the transmitter, the second branch requires a FFT operation as

$$Xk = \textstyle\sum_{n=0}^{N-1} dne^{\frac{-j2\pi kn}{N}} \qquad \text{k=0,1,2,3,……..N-1} \quad \textbf{(3)}$$

At the receiver, the lower branch requires an IFFT as

$$d'm = \frac{1}{N}\sum_{k=0}^{N-1} r'k\, e^{\frac{j2\pi mk}{N}} \quad \textbf{(4)}$$

$$=\frac{1}{N}\textstyle\sum_{n=0}^{N-1} \quad \sum_{k=0}^{N-1} dn\, Hne^{\frac{j2\pi(-n+\varepsilon)k}{N}}\ e^{\frac{2\pi mk}{N}}$$

$$=H'mv0dm + \textstyle\sum_{n=o,n\neq m}^{N-1} H'nVn - m\ dn \quad \text{m=0,…..}$$

$$V_{n\text{-}m} = \frac{e^{j\pi\frac{N-1}{N}}\sin(m-n+\varepsilon)}{N\sin[(\pi/N).(m-n+\varepsilon)}\Big|_{\text{(n-m)mod N}} \quad \textbf{(5)}$$

Here r’k represents 2nd received signal and dm’ is the output of IFFT. m is receiver subcarrier index, H’n in nth element of the N-point IFFT with impulse response h=[h_0…h_k..h_{L} $_0$….0]T and Vn-m is the weighting factor. We use both 1st and 2nd branches assuming that they are combined coherently without interfering with each other by using a division multiplexing such as frequency division multiplexing (FDM), time division multiplexing (TDM), code division multiplexing (CDM) then the final detected symbol is the sum detected symbols as follows:

$$d°m = dm + d'm \quad \textbf{(6)}$$

$$=(HmUo + H'mvo)dm + \textstyle\sum_{n=0n=m}^{N-1}(HnUn - m + H'nVn - m)dm$$

In this scheme the 1st term is desired signal component and 2nd term is ICI. Fig. 2 shows the result of regular OFDM and PC-OFDM together. In this we found that the regular OFDM has higher ICI then the PC-OFDM system. By adding weights together in above equation the weights become a real valued function at ε=0.02.

IV. SF-OFDM SYSTEM

It is based on per-OFDM symbol basis. It is shown in fig.3 the transmitter , d=[d_0… d_1… d_{N-2} d_{N-1}] T is the data stream. In this [2x1] system of length N blocks are formed via SF coding as two parallel input data vectors for two upper and lower branches as follows:

$$\mathbf{d_1} = [d_0\ -d_1{}^*\ \dots\ d_{N-2}\ -d_{N-1}{}^*]^T,$$
$$\mathbf{d_2} = [d_1\ d_o{}^*\ \dots\ d_{N-1}\ \ d_{N-2}{}^*]^T \quad \textbf{(7)}$$

Further two length N/2 even and odd polyphase component vectors of d are defined as follows:

$$\mathbf{d_e} = [d_0\ \ d_2\ \dots\ d_{N-4}\ \ d_{N-2}]^T,$$
$$\mathbf{d_o} = [d_1\ \ d_3\ \dots\ d_{N-3}\ \ d_{N-1}]^T, \quad \textbf{(8)}$$

Hence d_1 and d_2 can be expressed as the corresponding even and odd polyphase component vectors as follows:

$$\mathbf{d_{1e} = d_e,\ d_{1o} = -d_o{}^*}$$
$$\mathbf{d_{2e} = d_o,\ d_{2o} = d_e{}^*} \quad \textbf{(9)}$$

At time t, after performing two parallel IFFT’s d_1 and d_2, are transmitted with CP through transmit antennas T_{x1} and T_{x2}, respectively, as depicted in Fig. 3. At the receiving end, different operations like the filtering process or the Demultiplexing are to be performed first. After CPR, the two received signal vectors y_1 and y_2 at time t after FFT are combined as

$$y = y_1 + y_2 = H_1 d_1 + H_2 d_2 \tag{10}$$

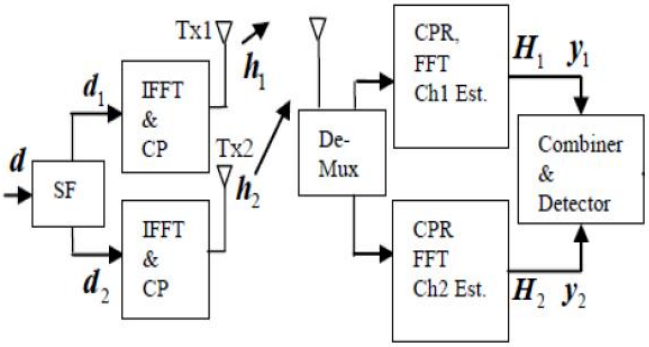


Fig.3. Block diagram of the regular SF-OFDM.

Equivalently, the even and odd vectors of y are

$$Ye = H_{1e}d_{1e} + H_{2e}d_{2e} = H_{1e}d_e + H_{2e}d_o,$$

$$Yo = H_{1o}d_{1o} + H_{2o}d_{2o} = H_{1o}d_o^* + H_{2o}d_o^*, \tag{11}$$

where the diagonal matrices H_1 and H_2 having diagonal elements are FFTs of respective channel impulse responses, h_1 and h_2 for the transmit antenna T_{x1} and T_{x2}, respectively. Similarly, H_1 and H_2 can also be expressed as the corresponding even and odd matrices as H_{1e} and H_{1o}, and H_{2e} and H_{2o} , respectively.

Here we assume that channel responses are known and fading is constant across adjacent subcarriers such that $H_{1e}= H_{1o}$ and $H_{2e}= H_{2o}$, we get the decision variables as follows:

$$d_e = H_{1e}y_e + H_{2o}y_o^* = (|H_{1e}|^2 + |H_{2o}|^2)d_e,$$

$$d_o = H_{2e}^*y_e - H_{1o}y_o^* = (|H_{2e}|^2 + |H_{1o}|^2)d_o. \tag{12}$$

V. SFPC-OFDM SYSTEM

The SF as well as PC is OFDM symbol basis, so they techniques can be integrated naturally. Fig.4 shows the block diagram of SFPC-OFDM transceiver.

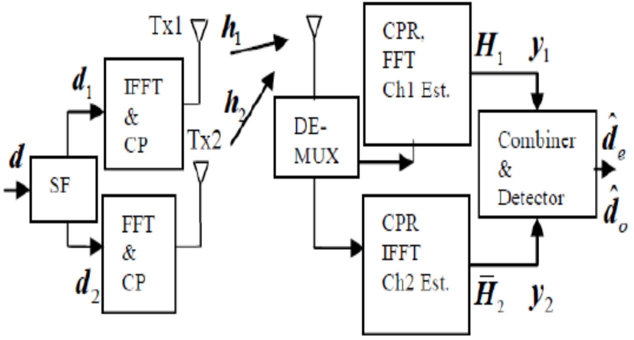


Fig.4. Blok diagram of SFPC-OFDM transceiver.

At time t, upper IFFT and lower FFT are performed on inputs d_1 and d_2 respectively. Then a demux is performed at the receiver end. After CPR, in order to demodulate the received signal from T_{x1}, FFT is employed by the upper branch whereas; an IFFT is performed on the signal received from T_{x2}. The received two signal vectors are

$$y_1 = H_1 d_1 \text{ and } y_2 = \bar{H}_2 d_2 \tag{13}$$

where $\bar{H_2}$ is a diagonal matrix whose diagonal element are N-point IFFT of the channel impulse response h_2. We receive two signal vectors y_1 and y_2 are combined as

$$y = y_1 + y_2 = H_1 d_1 + \bar{H}_2 d_2 \tag{14}$$

VI. SIMULATION RESULTS

SF- and SFPC- OFDM method have been tested using simulations on the basis of their bit error rate (BER). The frequency selective mobile channel parameters are applied with BPSK as shown in Figs.5 and 6. Both the SF and SFPC schemes are compared with three different OFDM block size, N=256, 512, and 1024. They are known or estimated accurately at the receiver, and the corresponding complex channel gain remains constant between adjacent subcarriers in one OFDM symbol. Fig. 7 shows the average BER comparison with the maximum Doppler frequency, fD, equal to 100 Hz. Note fD to subcarrier frequency spacing ratio (i.e ε=fDNTS) ranges from 0.0244 (N=256) to 0.0977 (N=1024). The SFPC scheme outperforms the SF scheme in all cases. Without the PC based ICI cancellation, the SF scheme has a higher error floor when Eb/No > 15 dB.

VII. RESULTS AND CONCLUSION

OFDM is meritorious for applications involving high data rates so it is widely used. But the drawback of OFDM is its sensitivity to CFO. Hence the importance carrier frequency offset estimation, Doppler Effect, Time synchronization error in OFDM systems has been studied here, which causes inter-carrier interference (ICI). Frequency offset or phase noise causes ICI. This ICI substantially affects the signal heavily and minimizes the system performance. From this it can be concluded that CFO, Doppler spread, Time synchronization error are the Major cause for ICI in OFDM system which degrades the performance of OFDM system and doesn't provide efficient data transmission. So, in order to improvise the performance of OFDM system involving frequency offset error in transmitted signal it is necessary to use ICI reduction techniques.

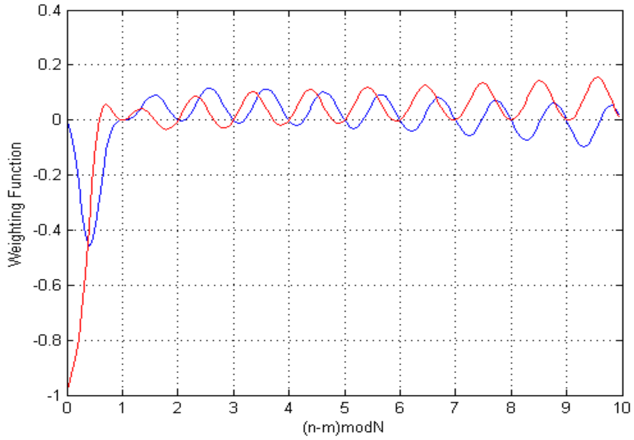


Fig.5. Normalized frequency verses weighting function graph.

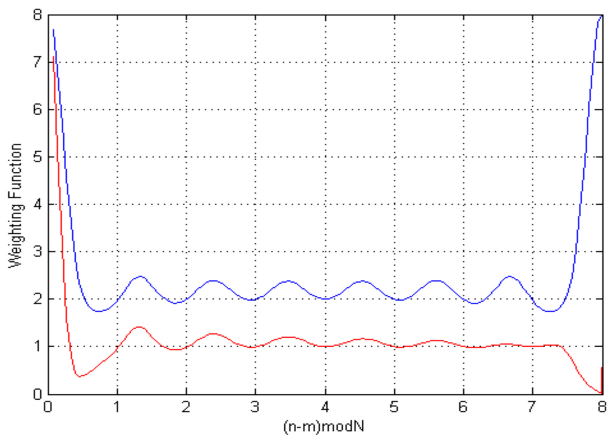


Fig.6. The magnitude of weighting factors of the regular and PC systems.

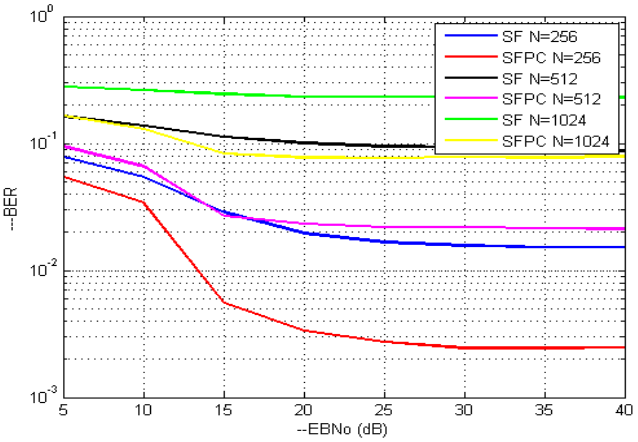


Fig.7. The BER comparison of SF- and SFPC- OFDM schemes with different block sizes. The maximum Doppler frequency is 100 Hz.

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