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Study of ICI Cancellation techniques in OFDM

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Abstract: *OFDM (Orthogonal frequency division multiplexing) is a well known technique in 4G Broadband wireless communication systems. OFDM has high spectral efficiency but it suffers from frequency offset problem due to the difference between transmitter and receiver local oscillator frequencies which causes loss of orthogonality between subcarriers leading to ICI. This degrades the performance of system so there is a need to suppress it. In this paper we studies three different ICI Cancellation techniques namely Self Cancellation, two path complex conjugate and Phase Rotated complex conjugate technique in OFDM.*
Keywords: *CIR(carrier to interference ratio),SC(self cancellation), CC(conjugate cancellation), PRCC(phase rotated complex conjugate), ICI(intercarrier interference)*

I. INTRODUCTION

OFDM is emerging as the preferred modulation scheme in the modern high data rates wireless communication systems. OFDM is a special case of MC(Multicarrier modulation).MC is the concept of splitting a signal into a no. of signals, modulating each new signal to several frequency channels and combining the data received on the multiple channels at the receiver.

OFDM has been used in many communication systems such as WLAN (wireless LAN),DVB(Digital video broadcasting), WiMAX etc. However one of the major problems in OFDM is its vulnerability to frequency offset which leads to loss of orhogonality resulting into ICI. For suppressing ICI there are self cancellation, conjugate cancellation and phase rotated conjugate cancellation techniques in OFDM.

Self-cancellation is a two stage technique that uses predefined weighting coefficients to reduce ICI for OFDM systems whereas conjugate cancellation is a two path transmission technique ,here the first path represents the standard OFDM signal and the second represents the conjugate of first path's. Main advantages of CC scheme are backward compatibility with the existing OFDM system, low receiver complexity and high signal to interference power ratio. PRCC is a special case of CC technique so its also inherits the advantages of CC technique.

The rest of the paper is organised as follows: Section II describes the OFDM system model. Section III describes the several Self-cancellation techniques. Section IV represents the conjugate cancellation technique. Section V represents the PRCC technique and finally some conclusions are given in Section VI.

II. OFDM MATHEMATICAL MODEL

Figure 1 shows the block diagram of baseband OFDM system. The complex baseband OFDM signal at the output of IFFT block at transmitter is given by

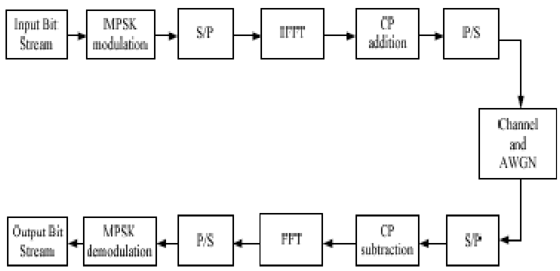

Figure 1: Block diagram of a baseband OFDM System

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} X(k)\, e^{j2\pi nk/N} \qquad (1)$$

X(k) denotes the transmitted symbol on kth subcarrier, N is the total number of subcarriers. At the receiver the signal in time-domain after suffering from frequency offset and AWGN is given by

$$y(n) = x(n)e^{j2\pi n\varepsilon/N} + w(n) \qquad (2)$$

where ε denotes the frequency offset and w(n) is a zero-mean AWGN. The received signal in frequency domain after fast fourier transform block at kth subcarrier can be written as

$$Y(k)=\sum_{n=0}^{N-1} y(n)e^{-j2\pi nl/N} \quad (3)$$

$$Y(k)=X(k)S(0)+\sum_{\substack{l=0\\ l\neq k}}^{N-1} X(l)S(l-k)+W(k) \quad (4)$$

Where S(l-k) are the complex coefficients of the ICI components in received signal and W(k) is the FFT of w(n). S(l-k) complex coefficients are given by

$$S(l-k)=\frac{\sin[\pi(l+\varepsilon-k)]}{N\sin[\pi(l+\varepsilon-k)/N]}\exp[j\pi(1-\frac{1}{N})(l+\varepsilon-k) \quad (5)$$

The CIR(carrier-to-interference ratio) is ratio of the signal power to the power of interference components. The CIR of OFDM system is given by

$$CIR=\frac{E[|C(k)|^2]}{E[|ICI(k)|^2]}=\frac{|S(0)|^2}{\sum_{l=1}^{N-1}|S(l)|^2} \quad (6)$$

III. ICI SELF CANCELLATION TECHNIQUE

In ICI self-cancellation schemes one symbol is mapped onto two subcarriers with predefined coefficients to self cancel ICI. Real and imaginary parts of ICI coefficients are changed with respect to the subcarrier index and difference between consecutive ICI coefficients [S(l-k) and s(l-k+1)] is very small. Some self-cancellation schemes are as follows

A. Data-conversion scheme

In the data-conversion self-cancellation scheme the subcarrier signal is mapped as follows: X'(k)=X(k),X'(k+1)=-X(k) so the received signal on subcarrier k is given by

$$Y''(k)=\frac{1}{2}[Y'(k)-Y'(k+1)]$$

$$=\frac{1}{2}\{X(k)[2S(0)-S(1)-S(-1)]+$$

$$\sum_{\substack{l=0\\ l=even\\ l\neq k}}^{N-2} X(l)[2S(l-k)-S(l-k-1)-S(l-k+1)]\}+W''(k)$$

So, the CIR of this scheme can be written as:

$$CIR=\frac{|2S(0)-S(1)-S(-1)|^2}{\sum_{\substack{l=2\\ l=even}}^{N-2}|2S(l)-S(l+1)-S(l-1)|^2} \quad (7)$$

B. Data-conjugate scheme

In the data-conjugate scheme the subcarrier signal is mapped as follows:
X'(k)=X(k),X'(k+1)=-X*(k) and the received signal on subcarrier k is given by

$$Y'(k)=\frac{1}{2}[Y'(k)-Y'^*(k+1)]$$

$$=\frac{1}{2}\{X(k)[S(0)+S^*(0)]-X^*(k)[S(1)+S^*(-1)]+$$

$$\sum_{\substack{l=0\\ l=even\\ l\neq k}}^{N-2}(X(l)[S(l-k)+S^*(l-k)]-X^*(l)[S(l-k+1)+S^*(l-k-1)])\}+W'(k)$$

The CIR of Data-conjugate scheme is given by:

$$CIR=\frac{|S(0)+S^*(0)|^2+|S(1)+S^*(-1)|^2}{\sum_{\substack{l=2\\ l=even}}^{N-2}\left[|S(l)+S^*(l)|^2+|S(l+1)+S^*(l-1)|^2\right]} \quad (8)$$

C. Symmetric data-conversion scheme

In symmetric data-conversion scheme, subcarrier signal is mapped as follows:
X'(k)=X(k),X'(N-k-1)=-X(k) and the received signal on subcarrier k is given as

$$Y''(k)=\frac{1}{2}[Y'(k)-Y'(N-k-1)]$$

$$=\frac{1}{2}\sum_{\substack{l=0\\ l=even}}^{N-2}X(l)[S(l-k)+S(k-l)-S(N-l-k-1)$$

$$-S(l-N+k+1)]+W''(k)$$

$$Y''(k) = \frac{1}{2}\{X(k)[2S(0) - S(N-2k-1) - S(2k-N+1)] + \sum_{\substack{l=0 \\ l=even \\ l \neq k}}^{N-2} X(l)[S(l-k) + S(k-l) - S(N-l-k-1) - S(l-N+k+1)]\} + W''(k)$$

So, the CIR of symmetric data-conversion scheme is given by:

$$CIR = \frac{|2S(0) - S(N-1) - S(1-N)|^2}{\sum_{\substack{l=2 \\ l=even}}^{N-2} |S(l) + S(-l) - S(N-l-1) - S(l-N+1)|^2} \qquad (9)$$

From the CIR's calculated above it can be analysed that the CIR obtained from Self-cancellation schemes is better than the CIR of the normal OFDM systems.

IV. CONJUGATE CANCELLATION TECHNIQUE

Conjugate cancellation is a two path ICI cancellation technique. From the first path standard OFDM signal is to be transmitted while its conjugate is to be transmitted from the second path. In receiver the signal at first path is same as (2) whereas the signal at the second path is expressed as

$$y'(n) = x^*(n) e^{j2\pi n \epsilon / N} + w'(n) \qquad (10)$$

where $x^*(n)$ denotes the conjugate of x(n) and w'(n) is zero-mean AWGN. By performing conjugate operation on (10) and passing the signal through FFT block, the resultant signal would be

$$Y'(k) = \sum_{n=0}^{N-1} (y'(n))^* e^{-j2\pi nl/N}$$

$$= \sum_{l=0}^{N-1} X(l) S(k-l+\epsilon) + W'(k) \qquad (11)$$

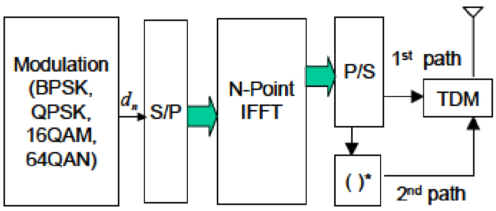

Fig.2(a) Transmitter of CC Scheme

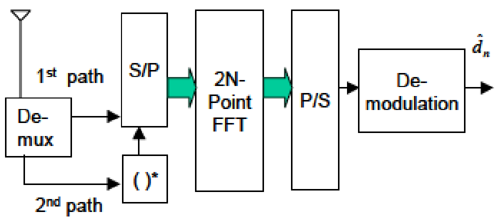

Fig.2(b) Receiver of CC scheme

By taking the average of two transmission path we get

$$Z(k) = \frac{1}{2}[Y(k) + Y'(k)]$$

$$= \frac{1}{2}\{\sum_{l=0}^{N-1} X_l (S(k-l-\epsilon) + S(k-l+\epsilon) + (W(k) + W'(k))\} \qquad (12)$$

The CIR of CC scheme can now be expressed as

$$CIR_{cc} = \frac{|S(-\epsilon) + S(\epsilon)|^2}{\sum_{l=1}^{N-1} |S(l-\epsilon) + S(l+\epsilon)|^2} \qquad (13)$$

Now the CIR evaluated here has higher value than the SC scheme CIR when the frequency offset is small.

V. PRCC TECHNIQUE

Like CC technique PRCC is also a two path transmission technique. PRCC is a special case of CC technique. In this technique from the first path the standard OFDM signal is to be transmitted while from the second path the conjugate of standard OFDM with artificial phase rotation of $-\emptyset$ is to be transmitted. In the receiver the output of two transmission path after suffering from frequency offset and AWGN is expressed as:

$$y^1(n) = x(n)e^{j\emptyset}e^{j2\pi n\epsilon/N} + w^1(n) \qquad (14)$$

and

$$y^2(n) = x^*(n)e^{j\emptyset}e^{j2\pi n\epsilon/N} + w^2(n) \qquad (15)$$

where $w^1(n)$ and $w^2(n)$ are AWGN

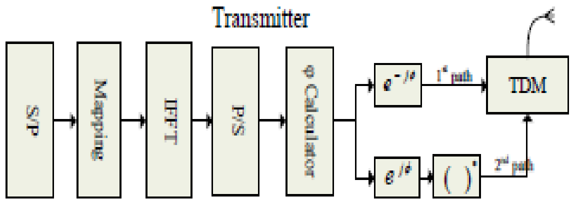

Fig 3(a) Tansmitter of PRCC Technique

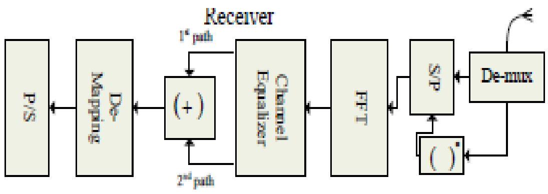

Fig 3(b) Receiver of PRCC technique

The receiver first passes $y^1(n)$ and the conjugate of $y^2(n)$ and after passing through FFT block we obtain

$$Y^1(k) = FFT\{y^1(n)\} = \sum_{l=0}^{N-1} X(l)\{e^{j\emptyset}S(k-l-\epsilon)\} + w^1(k) \qquad (16)$$

and

$$Y^2(k) = FFT\{y^{2*}(n)\} = \sum_{l=0}^{N-1} X_k\{e^{-j\emptyset}S(l-k+\epsilon)\} + w^2(k) \qquad (17)$$

Now taking average of (16) and (17)

We will get

$$Z(k)=\frac{1}{2}(Y^1(k) + Y^2(k))$$

$$=\frac{1}{2}\{ \sum_{l=0}^{N-1} X(l)(e^{j\emptyset}S(k-l-\epsilon) + e^{-j\emptyset}S(k-l+\epsilon)) +(w^1(k) + w^2(k))\} \qquad (18)$$

Now the CIR of the PRCC technique can be written as:

$$CIR=\frac{|X(k)|^2|e^{j\emptyset}S(k-\epsilon)+e^{-j\emptyset}S(k+\epsilon)|^2}{\sum_{l=1}^{N-1}|X(l)|^2|e^{j\emptyset}S(k-l-\epsilon)+e^{-j\emptyset}S(k-l+\epsilon)|^2}$$

If the average symbol energies are equal then cir will be

$$CIR=\frac{|e^{j\emptyset}S(-\epsilon)+e^{-j\emptyset}S(\epsilon)|^2}{\sum_{l=1}^{N-1}|e^{j\emptyset}S(l-\epsilon)+e^{-j\emptyset}S(l+\epsilon)|^2}$$

From the CIR calculated it can be concluded that PRCC is better than CC at both low and high frequency offset situations.

VI. CONCLUSIONS

In this paper we studies three ICI cancellation techniques; Self cancellation, conjugate cancellation and phase rotated conjugate cancellation. The performance of the different techniques are studied on the basis of CIR calculated and it is concluded that CIR obtained after self cancellation is better than the normal OFDM systems. Conjugate cancellation technique performs better than self cancellation technique at low frequency offset situations while the PRCC technique perform better than two at both low and high frequency offset situations.

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