Analysis of the opportunities for reduction of Intercarrier Interference in OFDM

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Abstract – **In this article are described the possibilities of reduction Intercarrier Interference in OFDM. Also has made analysis of the populares methods- Frequency-domain equalization, Time-domain windowing, ICI Self-cancellation scheme, Partial transmit sequences & Selected mapping, M-ZPSK modulation and Correlative coding.**

Keywords – **OFDM, ICI, Correlative coding.**

I. Introduction

It is a fact, that OFDM has a big popularity with many priorities, but in these systems there are a few problems. For example the receiving signals through OFDM have a high coefficient between Peak and Average Power Ratio (PARP). OFDM system is a sensibly to frequency mistake between the supporting generators of transmitter and receiver [1]. Carrier frequencies offset [2] makes many problems: amplitude attenuation and phase moving for all of the carrier and inter-carrier interference (ICI). They are sensitive in mobile communication channel. As a result of the moving, there is a Doppler displace of carrier frequency [3]. This makes the synchronization difficult between carrier of transmitter and receiver- breaking the orthogonal between the different carriers, where we have an inter-symbol interference and ICI. The interference among different sub carrier (ICI), which is from carrier offset of the channel, is one of the most problems in the systems with OFDM. Currently a few different approaches for reducing ICI have been developed. These approaches includes- Frequency-domain equalization, Time-domain windowing, ICI Self-cancellation scheme, Partial transmit sequences & Selected mapping, M-ZPSK modulation and Correlative coding [4-11]. The point of this paper is to see the possibilities for reduction of ICI in OFDM communications systems.

II. Current ICI reduction methods

Frequency-domain equalization

Frequency domain equalization can be used to remove the effect of distortions causing ICI. Frequency domain equalization is used to remove the fading distortion in an OFDM signal where a frequency non-selective, time varying channel is considered. Once the coefficients of the equalizer is found, linear or decision feedback equalizers are used in frequency domain. One interesting point here is how the coefficients are calculated. Since ICI is different for each OFDM symbol, the pattern of ICI for each OFDM symbol needs to be calculated. ICI is estimated through the insertion of frequency domain pilot symbols in each symbol. A pilot symbol is inserted to adjacent a silence among two sub-blocks. This method is demonstrated in Fig. 1

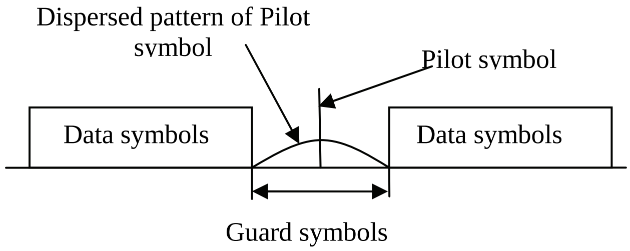

Fig. 1 Dispersed pattern of a pilot in an OFDM data symbol

Time-domain windowing

Time domain windowing is used to reduce the sensitivity to linear distortions and to reduce the sensitivity to frequency errors (ICI). Window may be realized with a raised cosine or other kind of function that fulfills the Nyquist criterion. Raised cosine window is used in order to reduce the ICI effects in . The FFT can be considered as a filter bank with N filters where N is the FFT size. The frequency response of the *n-th* filter $H_n(F)$ is:

$$\left|H_n(F)\right| = \left|\frac{\sin[\pi(F-n)]}{\sin[\pi(F-n)/N]}\right| \quad (1)$$

where $F = N \cdot f/f_s$ and f_s is the sampling rate at the receiver. This filter has the shape of a periodic sinc function.

The maximum of one filter coincides with the zero crossing of all others; this fact allows to separate the carriers without suffering any ICI.. The use of a window on N samples (in time domain) before the FFT reduces the side lobe amplitude of this sinc function but also leads to an orthogonality-loss between carriers. A window which reduces the side lobes and preserves the orthogonality is called Nyquist window. This window will reduce the amplitude of the filter side lobes depending on the roll-off factor. The side

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lobe magnitudes of the frequency response of a raised cosine window for different roll-off factors are given in Fig. 2.

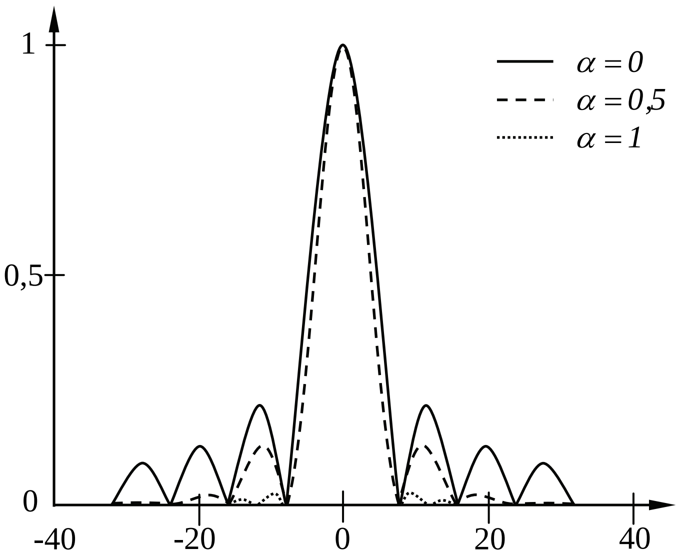


Fig 2 Frequency response of a raised cosine window with different roll-off factors

With Nyquist windowing, the whole filter bank is less sensitive to frequency deviations, disturbances, etc. The reason for the improvement can also be explained through a decrease of the DFT-leakage. Since the leakage is responsible in several cases for an OFDM signal degradation, an overall improvement in demodulation is expected.. A number of different windows (Hanning, Nyquist, Kaiser etc.) have been described in the literature [1]. All of the windows give some reduction in the sensitivity to frequency offset. But only Nyquist windows (of which the Hanning window is one particular example) have no ICI for the case of no frequency offset.

Partial transmit sequences & Selected mapping

Both methods are adapted from Peak-to- average Power Ratio (PAPR) reduction techniques. Since the definition of PAPR and Peak Interference-to-Carrier Ratio (PICR) are analogous to each other, we can adapt PAPR reduction schemes to PICR reduction problem. In these two methods the goal is to reduce ICI by minimizing PICR.

Assume that the modulated data symbol sent at subcarrier k is $X(k)$ and $X = \{X(0), X(1), X(2) \ldots X(N-1)\}$. Let us call this term as $I(k)$, which will have the form:

$$I(k) = \sum_{m=0, m\neq k}^{N-1} X(m) K(m,k) \qquad (2)$$

This term depends only on the transmit data sequence, X, and complex coefficients, $K(m, k)$, which depends on the normalized frequency offset and the value of $m - k$. Peak Interference-to-Carrier Ratio is defined as:

$$PICR(X) = \frac{\max_{0\leq k\leq N-1}|I(k)|^2}{|K(m,m)a(m)|^2} \qquad (3)$$

Now the goal is to minimize this ratio.

M-ZPSK modulation

This method can be used to reduce both PAPR and ICI. Therefore, the M-ZPSK scheme is less sensitive to frequency offset errors than conventional schemes. The frequency of the bit pattern of log_2M bits in an input symbol can be counted. And the most likely bit pattern is mapped to a signal constellation of zero amplitude. This increases the number of vanishing terms in the summation and thus reduces the ICI effects more. The possible signal constellations are given in Fig. 3 for Q-ZPSK modulation.

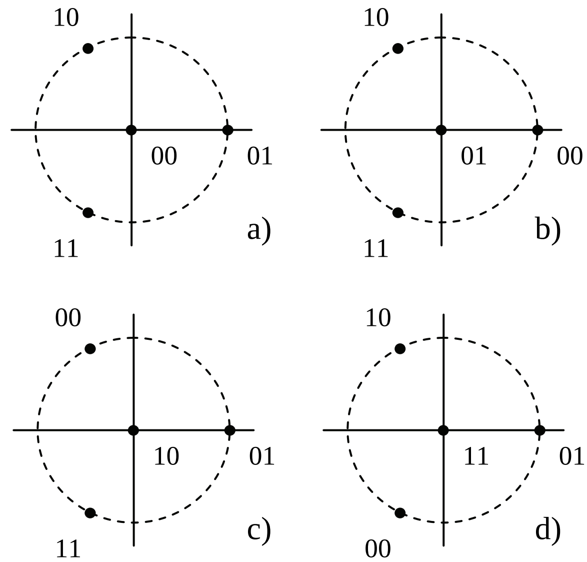


Fig 3 All possible different signal constellation for 4-ZPSK

Therefore, we need only one mapping and one IFFT calculation, as in the conventional system. However, transmission of side information is necessary to let the receiver which mapping is used.

ICI Self-cancellation scheme

The method is also called as Polynomial Cancellation Coding (PCC) or (half-rate) repetition coding . The main idea in self-cancellation is to modulate one data symbol onto a group of sub-carriers with predefined weighting coefficients to minimize the average carrier to interference ratio (CIR). But this will yield a decrease in bandwidth usage by half.

Cancellation in modulation and demodulation.

By using the ICI cancellation modulation, each pair of subcarriers, in fact, transmit only one data symbol. The signal redundancy makes it possible to improve the system performance at the receiver side. The demodulation for self-cancellation is suggested to work in such a way that each signal at the ($k + 1$)th subcarrier (k is even) is multiplied by −1 and then summed with the one at the kth subcarrier. Then the resultant data sequence is used for making symbol decision. It can be represented as:

$$\hat{X}''(k)=\hat{X}'(k)-\hat{X}'(k+1)=$$
$$=\sum_{m=0,m=even}^{N-2} X(m)\{-K(m-1,k)+2K(m,k)-K(m+1,k)\}+ \quad (4)$$
$$+Z(k)-Z(k+1)$$

The corresponding ICI coefficients then becomes:

$$K''(m,k)=-K(m-1,k)+2K(m,k)-K(m+1,k) \quad (5)$$

Thus, the ICI signal become smaller when applying ICI cancellation modulation. On the other hand, the ICI canceling demodulation can further reduce the residual ICI in the received signals. ICI canceling demodulation also improves the system signal-to-noise ratio. One can obtain more ICI reduction by mapping one symbol onto more than two subcarrier (three, four . . .). Although it will yield a better ICI reduction, it will cause a larger bandwidth loss. Also two modulated symbols can be mapped onto three adjacent sub-channels or three modulated symbols onto four adjacent sub-channels, etc. . But in this case, ICI reduction is not uniform and we expect two level of ICI reduction among these subcarriers, one for repeated symbols and the other one for non-repeated symbols.

A diverse self-cancellation method

This method is very similar to the self-cancellation schemes, the only difference is that, in this method the odd symmetry of interference term $K(m, k) = K(m,-k)$ is used by mapping data to the subcarriers at the points k and ($N - 1 - k$). Since it is highly unlikely that both subcarrier k and ($N - 1 - k$) expose to same fade together, this method offers a frequency diversity effect in a multipath fading channel. However, the ICI term does not vanish with the approximation but getting reduced. This is because of the different fading on the subcarrier k and ($N - 1 - k$). If the normalized frequency offset is smaller than 0.35, this method gives a better CIR then ordinary self-cancellation..

Correlative coding (PRS) of reduce ICI.

For an OFDM system, which can be viewed as a dual system in the frequency domain of a conventional single carrier system, the correlative coding (PRS) will be carried out in the frequency domain. Frequency-domain correlative coding is a simple solution to ICI problems, and makes OFDM systems less sensitive to frequency errors . In addition, system bandwidth efficiency will be not reduced by introducing correlative coding into the system. A simplified block diagram of the proposed binary phase-shift keying (BPSK)-OFDM system using correlative coding is shown in Fig. 4. The signal sequence before correlative coding is expressed by , where is the subcarriers index with and is the total number of subcarriers. Considering BPSK modulation, takes values of , that fulfill zero mean and independence conditions.

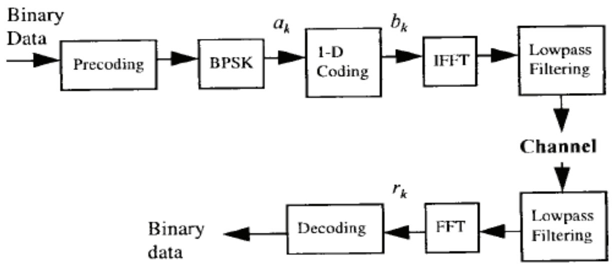


Fig. 4 Block diagram of OFDM system using Correlative coding

Denoting “D ” as the unit delay of the subcarrier index $\boldsymbol{k}$, the proposed coding with correlation polynomial $F(D)=(1-D)$ is performed as:

$$b_k = a_k - a_{k-1} \quad (6)$$

Then the coded symbols $b_k, k \in [0, N-1]$ are modulated on $\boldsymbol{N}$ subcarriers. The symbol b_k takes three possible values (-2, 0, 2). Equation (2.6) introduces correlation between the adjacent symbols (b_k, b_{k-1}), therefore the independence condition is no longer maintained. To avoid error propagation in the decoding procedure due to correlative coding, precoding (modulo 2) is performed before BPSK modulation, in a similar way to the duobinary signaling in single carrier communication systems . In OFDM systems, the ICI signal on each subcarrier is a function of the channel frequency offset and the signal values modulated on all subcarriers. Due to the randomness of the information signals, ICI is also a random process. The CIR of an OFDM system with (1-D) type correlative coding is:

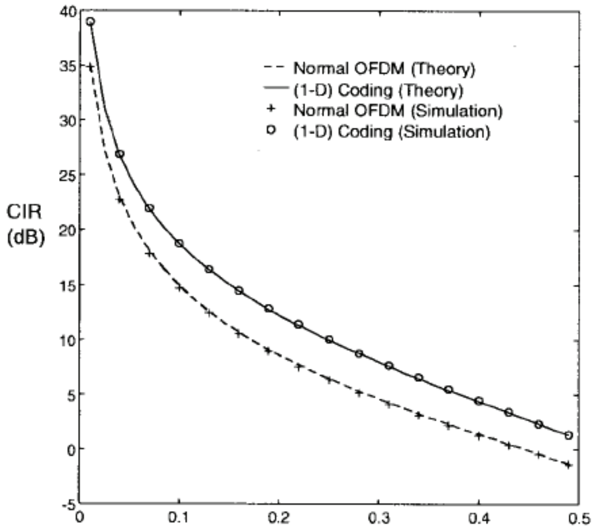
$$CIR=\frac{\sin^2(\pi\varepsilon)/(\pi\varepsilon)^2}{\sum_{l=1}^{N-1}|S(l)|^2-\frac{1}{2}\sum_{l=2}^{N-1}[S(l)S^*(l-1)+S(l-1)S^*(l)]} \quad (7)$$

In order to show the performance improvement of the proposed system, this CIR value is compared with that of an OFDM system without correlative coding. It is evident that for a normal OFDM system, $b_k = a_k$ holds true and CIR expression for a normal OFDM system is:

$$CIR=\frac{\sin^2(\pi\varepsilon)/(\pi\varepsilon)^2}{\sum_{l=1}^{N-1}|S(l)|^2} \quad (8)$$

The CIR levels versus ε calculated by (7) and (8) are plotted in Fig. 5.

Compare to normal OFDM systems, the carrier-to-interference power ratio is increased by 3.5 dB without decreasing bandwidth efficiency or increasing system complexity .



Normalized Frequency Offset (ε)

Fig. 5 CIR comparisons with and without correlative coding.

III. CONCLUSIONS

For a conclusion, it is possible to say that, that the most efficient method for reduction inter carrier interference at using OFDM modulation communication channel is Correlative coding(PRS), of discrete source signal. In addition it have to be noted that the result of using Correlative codec is not decreasing bandwidth efficiency or increasing system complexity. The question of literal estimating the efficiency of Correlative coder parameters must be considered latter.

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