MIMO OFDM Space Time Coding – Spatial Multiplexing Increasing Performance and Spectral Efficiency in Wireless Systems

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Abstract— OFDM is a multicarrier modulation technique in which a high rate bit stream is split into N parallel bit-streams of lower rate and each of these are modulated using one of N orthogonal sub-carriers. OFDM is robust to multi-paths fading and delay because it has high data transmission capability with high bandwidth efficiency that's why it has recently been applied in wireless communication systems. It is highly sensitive to frequency offset introduced by the wireless channels and causes loss of orthogonality and amplitude reduction of OFDM signal and lead to Inter Carrier Interference (ICI). There are two deleterious effects caused by frequency offset one is the reduction of signal amplitude in the output of the filters matched to each of the carriers and the second is introduction of ICI from the other carriers a main problem in OFDM is its vulnerability to frequency offset errors due to which the orthogonality is destroyed that result in Inter carrier Interference (ICI). ICI causes power leakage among subcarriers thus degrading the system performance. This paper studies ICI cancellation scheme in MIMO-Ofdm which performs better than standard OFDM system. Later we proposed Self cancellation method in MIMO OFDM to enhance the performance of the system by reducing the BER for different values of signal to noise ratio (SNR).

Key words: OFDM, MIMO OFDM Model, inter carrier interference self-cancellation (ICI SC)

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) has become a popular technique for transmission of signals over wireless channels. OFDM has been adopted in several wireless standards such as digital audio broadcasting (DAB), digital video broadcasting (DVB-T), the IEEE 802.11a local area network (LAN) standard and the IEEE 802.16a [10] metropolitan area network (MAN) standard. OFDM is also being pursued for dedicated short-range communications (DSRC) for road side to vehicle communications and as a potential candidate for fourth-generation (4G) mobile wireless systems. OFDM systems though quite effective in avoiding inter-symbol interference (ISI) due to multipath delay [11], suffers from the front-end distortions such as carrier frequency offset (CFO) which destroys the orthogonality among subcarriers in one OFDM symbol and thus causing inter-carrier interference (ICI) [11]. These frequency differences are often caused by the Doppler shift and/or mismatch between oscillators in the transmitter and receiver [11]. This ICI due to frequency offset can be reduced by decreasing the sensitivity of the OFDM systems towards the frequency offset errors.

A number of techniques have been developed for reducing ICI in OFDM systems. These techniques include the frequency domain equalization [12], the time domain windowing [13] and the ICI self-cancellation schemes [14], [15] and [16]. Among these, much attention has been paid to the ICI self cancellation scheme because of its implementation simplicity. Its main idea is to map one data symbol onto a group of subcarriers with predefined weighting coefficients. By doing so, the ICI signals generated within a group could be "self-cancelled". The objective of the present study is to investigate some techniques to eliminate the effect of carrier frequency offset (CFO) on MIMO-OFDM systems for cancellation of ICI. To eliminate the effect of CFO on MIMO-OFDM systems, ICI self-cancellation scheme are applied here for MIMO-OFDM systems and then compared to the ICI self cancellation scheme for OFDM system.

A. OFDM

OFDM is emerging as the preferred modulation scheme in modern high data rate wireless communication systems. OFDM has been adopted in the European digital audio and video broadcast radio system and is being investigated for broadband indoor wireless communications. Standards such as HIPERLAN2 (High Performance Local Area Network) and IEEE 802.11a and IEEE 802.11b have emerged to support IP-based services. Such systems are based on OFDM and are designed to operate in the 5 GHz band. OFDM is a special case of multi-carrier modulation. Multi-carrier modulation is the concept of splitting a signal into a number of signals, modulating each of these new signals to several frequency channels, and combining the data received on the multiple channels at the receiver. In OFDM, the multiple frequency channels, known as sub-carriers, are orthogonal to each other. One of the principal advantages of OFDM is its utility for transmission at very nearly optimum performance in unequalized channels and in multipath channels.

In this paper, the effects of ICI have been analyzed and a solution to combat ICI has been presented. Self-cancellation scheme [1], in which redundant data is transmitted onto adjacent sub-carriers such that the ICI between adjacent sub-carriers cancels out at the receiver. The average carrier to power interference ratio CIR is used as the ICI level indicator and the theoretical CIR expression is derived for the proposed scheme. The Fig. 1 describes a simple idealized OFDM system model suitable for a time-invariant AWGN channel

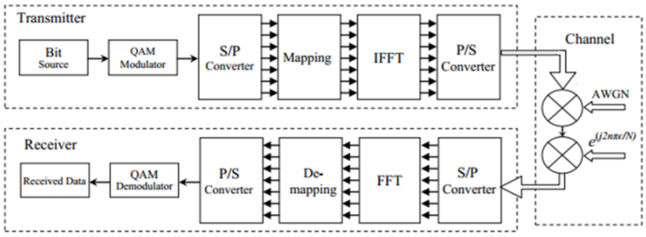


Fig. 1: A block diagram of an OFDM system

In an OFDM system, the complex baseband OFDM signal after the IFFT block at the transmitter can be expressed as

$$x(n)=\frac{1}{N}\sum_{k=0}^{N-1}X(k)e^{j\frac{2\pi nk}{N}},\qquad n=0,1,2...N-1 \qquad ....(1)$$

where N is the total number of subcarriers, X(k) denotes the transmitted quadrature amplitude modulation (QAM) or M-ary phase-shift keying (PSK) modulated symbol on the subcarrier k with k = 0, 1, 2, …, N −1. The received signal after being affected by the frequency offset can be written as

$$y(n) = x(n)e^{j\frac{2\pi\varepsilon}{N}} + w(n) \qquad ....(2)$$

Where,€ represents the frequency offset normalized by the subcarrier separation and is given by ΔfNT_s with Δf being the frequency difference between the transmitted and received carrier frequency, T_s is the symbol period, and w(n) which is invariant AWGN introduced in the channel.

At the receiver, after the FFT block, the received signal on the subcarrier k suffering from the frequency offset can be written as

$$Y(k) = \sum_{n=0}^{N-1} y(n)e^{\frac{-j2\pi nk}{N}},\qquad k = 0,1,\ldots,N-1 \qquad .... (3)$$

Carrier to interference ratio (CIR) can be defined as a ratio between the wanted power and unwanted power. It increases when normalized frequency shift (ε) decreases and vice versa. It is used to determine the performance of the whole system. The goal of all ICI reduction algorithms is to get a larger value of CIR.

The theoretical CIR for standard OFDM can be written as:

$$\text{CIR} = \text{abs}(S(0)) \div \sum_{\substack{l=0\\ l\neq k}}^{N-1} \text{abs}\,(S(l-k)) \qquad ...... (4)$$

This equation can be applied for all kinds of modulation and any number of subcarriers; but the derivation assumes that: the standard transmitted data has zero mean, the symbols transmitted on the different subcarriers are statistically independent, and the additive noise is omitted.

II. MIMO OFDM SYSTEM

MIMO wireless technology is a potential scheme that seems to fulfill these demands by offering increased spectral efficiency through spatial-multiplexing gain, and improved link reliability due to antenna diversity [2], [3- 4].

The MIMO antennas when combined with OFDM can further improve system performance and is considered as an attractive solution for next generation systems. Similar to SISO-OFDM systems, the major problem in MIMO-OFDM systems are their sensitivity to phase noise and carrier frequency offset (CFO), which induces ICI [5].

The objective of this study is to investigate some techniques to eliminate the effect of CFO on MIMO-OFDM systems for cancellation of ICI. To eliminate the effect of CFO on MIMO-OFDM systems, the previously mentioned ICI cancellation schemes (e.g. ICI self-cancellation [6], PCSC [7] scheme) are extended here for MIMO-OFDM systems and a novel scheme to cancel ICI by equalization of the weighting coefficients is proposed for MIMO-OFDM systems.

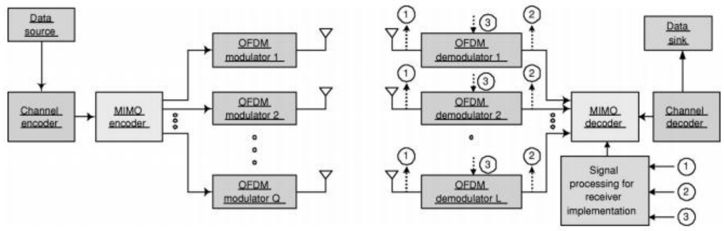


Fig. 2: Q L MIMO-OFDM system, where Q and L are the numbers of inputs and outputs,respectively.

A multicarrier system can be efficiently implemented in discrete time using an inverse FFT to act as a modulator and an fft to act as a demodulator. The transmitted data are the "frequency" domain coefficient and the samples at the output of the IFFT stage are "time" domain samples of the transmitted waveform. Fig 1 show a MIMO OFDM implementation.

A. Broadband MIMO Fading Channel

The main motivation for using OFDM in a MIMO channel is the fact that OFDM modulation turns a frequency-selective MIMO channel into a set of parallel frequency- at MIMO channels. This renders multi-channel equalization particularly simple, since for each OFDM-tone only a constant matrix has to be inverted [8].

In a MIMO-OFDM system with N subcarriers (or tones) the individual data streams are first passed through OFDM modulators which perform an IFFT on blocks of length N followed by a parallel-to-serial conversion.

III. ICI SELF-CANCELLATION SCHEME

ICI self-cancellation is a scheme that was introduced by Yuping Zhao and Sven-Gustav Häggman in to combat and suppress ICI in OFDM.

The main drawback of OFDM and MIMO-OFDM, however, is its receptiveness to small differences in frequency at the transmitter and receiver, normally referred to as frequency offset. This frequency offset is due to Doppler shift causes relative motion between the transmitter and receiver, or by differences between the frequencies of the local oscillators at the transmitter and receiver. It is seen that the difference between the ICI co-efficient of two successive sub-carriers are very small. The main idea is to modulate the input data symbol onto a group of subcarriers with predefined coefficients such that the generated ICI signals within that group cancel each other, hence the name self- cancellation.

A. Self cancellation in OFDM System

In an OFDM communication system, self cancellation of OFDM model is as shown in fig3

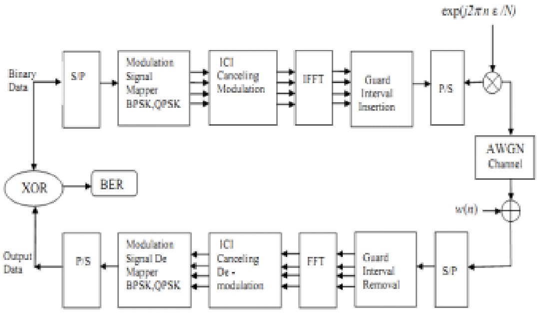


Fig. 3: OFDM Model with Self cancellation

for example, if symbol X is transmitted, then it will be mapped into two adjacent sub-carriers with (X, -X) values, assuming the channel frequency offset normalized by the subcarrier separation is ε, and then the received signal on subcarrier k can be written as

$$Y_k' = \sum_{l=0,2,4,\cdots}^{N-2} X(l)[S(l-k) - S(l+1-k)] + n_k \qquad \text{.... (5)}$$

Where n_k denotes the additive noise symbol introduced in sub-carrier k , and Y'_k denotes the received symbol in sub-carrier k

The received symbol in sub-carrier k+1 is represented by:

$$Y_{k+1}' = \sum_{l=0,2,4,\cdots}^{N-2} X(L)[S(l-k-1) - S(L-k)] + n_{k+1} \qquad \text{.... (6)}$$

And the ICI coefficient S'(l-k) is referred to as:

$$S'(l-k) = S(l-k) - S(l+1-k) \qquad \text{.... (7)}$$

which is better than the original one. Better coefficient can be achieved by subtracting the two adjacent carriers, the result will be:

$$Y''(k) = Y'(k) - Y'(k+1) = \sum_{l=0,2,4,\cdots}^{N-2} X(l)[-S(l-k-1) + 2S(l-k) - S(l-k+1) + n_k - n_{k+1}]$$

….(8)

Subsequently, the ICI coefficients for the received signal become:

$$S''(l-k) = -S(l-k-1) + 2S(l-k) - S(l-k+1)$$

….(9)

The coefficient of the eq(9) provides a better value. Eq. (8) can be rewritten so as the received signal becomes:

$$Y''(k) = x(k)(-S(-1) + 2S(0) - S(1)) + \sum_{\substack{l=0,2,4,6\cdots \\ l\neq k}}^{N-2} X(1)(-S(l-k-1) + 2S(l-k) - S(l+1-k)) + n_k - n_{k+1}$$

….(10)

Eq. (10) represents the received signal at sub-carrier k. In the right side of Eq. (10) there are three parts: first part represents the wanted signal, the second part represents the unwanted signal, and the last part represents the Gaussian noise. From Eq. (10) it can be derived that the CIR for self cancellation is given by:

$$CIR = \frac{-S(-1) + 2S(0) - S(1)}{\sum_{\substack{l=0,2,4,6\cdots \\ l\neq k}}^{N-2} (-S(l-k-1) + 2S(l-k) - S(l+1-k))}$$

… (11)

The derivation assumes that: the standard transmitted data has zero mean; the symbols transmitted on the different sub-carriers are statistically independent, and the additive noise is omitted.

Fig.4.1.3 shows a comparison between |S"(l-k)| and |S(l-k)| on a logarithmic scale. It is seen that |S"(l-k)| << |S(l-k)| for most of the l-k values. Hence, the ICI components are much smaller in (7). Also, the total number of interference signals is halved in (9) since only the even subcarriers are involved in the summation. comparision of |S(1-k)|,|S"(1-k)|, and |S""(1-k)| for ε=0.2 and N=64

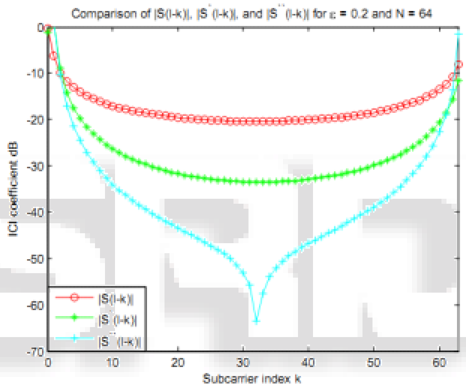
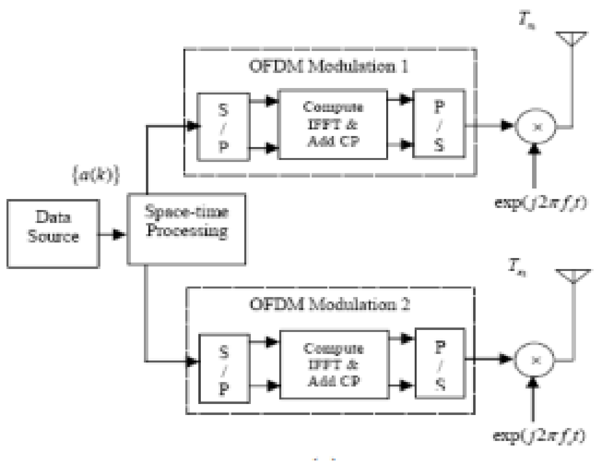


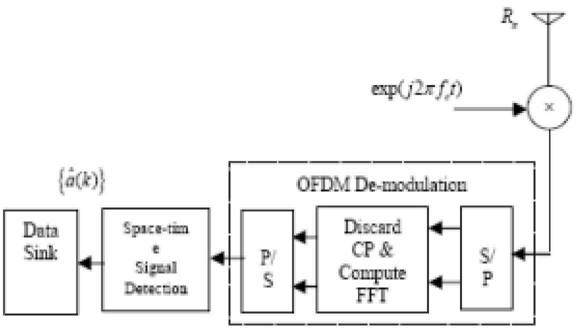
Fig. 4: comparison of S' (l-k) and S''(l-k) Vs subcarrier k

B. Self Cancellation in MIMO OFDM System

In this section, we propose self-cancellation (SC) in multiple-input and multiple-output (MIMO) OFDM systems as shown in



(a) Transmitter



(b) Receiver

Fig, 5: Block diagram of MIMO-OFDM system: (a) Transmitter (b) Receiver

The self-cancellation was proposed in [9]. This method maps the modulated symbols onto lthand (N−1−l)th transmitting subcarriers in symmetrical structure. At the transmitter, the modulated symbols are mapped as Denoted by Xl=(X0,X1,...,XN/2−1,X∗N/2−1,...,X∗1,X∗0,for l = 0,...,N − 1, respectively). At the receiver, the received signals on symmetric pair of subcarriers are combined and the combined received signal can be denoted as Rk=(Yk+Y∗N−1−k)/2, for k = 0,...,N/2−1, respectively. The weighting function of U∗k−l can be expressed as

$$U^{*}_{k-l}=\frac{1}{N}\sum_{n=0}^{N-1}e^{j\frac{2\Pi}{N}n(l-k-\Delta/T)} \quad \text{.... (12)}$$

it is worth noting that, the weighting function U*k-1 for symmetric conjugate self-cancellation is exactly the same as the weighting function of conjugate path for two-path complex conjugate scheme as described in [11], when the frequency offset is small, the property of the self cancellation should be written as

$$\frac{U_{l-k}+U^{*}_{k-l}}{2}\approx\begin{cases}1 & if \ \ l=k\\ 0 & if \ \ l\neq k\end{cases} \quad \text{....(13)}$$

From the above equations carrier to ICI power ratio (CIR) of self-cancellation scheme on even and odd subcarriers at k = 0 in MIMO-OFDM systems can be expressed as follows

$$CIR_0=\frac{4}{ICI_0} \qquad CIR_1=\frac{4}{ICI_1} \quad \text{.... (14)}$$

And Where

$$ICI_0=\sum_{l=1}^{\frac{N}{4}-1}\left|U_{2k}+U^{*}_{-2l}\right|^2+\sum_{l=0}^{\frac{N}{4}-1}\begin{pmatrix}\left|U_{2l+1}+U^{*}_{-(2l+1)}\right|^2\\+\left|U_{N-1-2l}+U^{*}_{-(N-1-2l)}\right|^2\\+\left|U_{N-2-2l}+U^{*}_{-(N-2-2l)}\right|^2\end{pmatrix} \quad \text{.... (15)}$$

And

$$ICI_1=\sum_{l=1}^{\frac{N}{4}-1}\left|U_{2l}+U^{*}_{-2l}\right|^2+\sum_{l=0}^{\frac{N}{4}-1}\begin{pmatrix}\left|U_{2l-1}+U^{*}_{1-2l}\right|^2\\+\left|U_{N-2-2l}+U^{*}_{-(N-2-2l)}\right|^2\\+\left|U_{N-3-2l}+U^{*}_{-(N-3-2l)}\right|^2\end{pmatrix} \quad \text{.... (16)}$$

The CIR of the MIMO OFDM System was as given below

$$CIR=\frac{\left|U_0\right|^2}{\sum_{l=1}^{N-1}\left|U_l\right|^2}\approx\frac{1}{\sum_{l=1}^{N-1}\left|U_l\right|^2} \quad \text{....(17)}$$

IV. RESULT

The MIMO OFDM system and OFDM system with the self cancellation has been analysis and their BER and SNR is compared and plotted in Fig. 5 based on Alamouti scheme with two transmit and one receive antenna having 64 subcarriers in each OFDM block, CP length N_g=6 and carrier frequency f_c = 2.4 GHz are considered in the simulations.

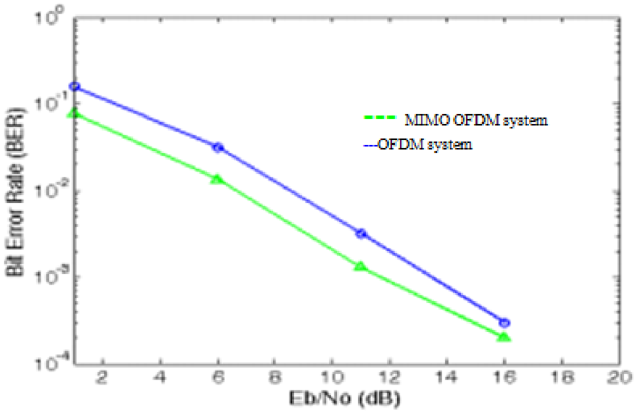


Fig. 6: BER comparison of the MIMO OFDM and OFDM system for time-varying frequency offset.

V. CONCLUSION

In this paper, the self-cancellation in MIMO-OFDM systems has been proposed over multipath fading channel. The proposed system can be used in the realistic fading channels. As compared to the OFDM systems, the proposed system offers better CIR than the ordinary one. Simulation results show that the proposed system achieves lower BER in AWGN channels as compared to the ordinary OFDM systems. In this section, the proposed self-cancellation scheme in OFDM systems is examined the performance through a computer simulation. Total power of the system is 1 Watt. The transmitted power of this scheme is a half of the ordinary OFDM systems. Moreover in this method all the signal processing is dependent on one independent process i.e. estimation of the FFT window and hence the question of dependency of two independent process does not arise at all. The method is more promising for large delay spread channels and provides a significant Eb/N0 improvement in the detection process.

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