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# An Improved Algorithm of Successive Interference Cancellation for STC-OFDM Systems

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**Abstract:** STC-OFDM systems effectively overcome the disadvantage of inter symbol interference and frequency selective fading for Orthogonal Frequency Division Multiplexing communication systems, however, there are still some issues, such as how to suppressing mutual interference due to multi-antenna transmitting. In this paper, an improving algorithm combining with channel frequency response recovery is proposed, which recover the channel frequency response of the pilot before successive interference cancellation and reduce the effects of the channel frequency response estimation. Theoretical analysis and computer simulation shows that the proposal algorithm can improve performance of Bit Error Rate and suppress the interference in the STC-OFDM communication systems. *Copyright © 2014 IFSA Publishing, S. L.*

**Keywords:** OFDM, Space-time coding, Channel frequency response recovery, Successive interference cancellation.

## 1. Introduction

OFDM, due to its realization and overcoming the frequency selective fading, has been widely used in digital transmission and communication systems [1]. In recent years, OFDM combines with Multiple Input Multiple Output (MIMO) and Space Time Coding (STC) to achieve a STC-OFDM communication system which is high capacity in a limited bandwidth, high coding gain, anti-multipath and inter-symbol interference (ISI) [2]. However, multi-antenna transmission could result in interference such as Co-channel Interference (CCI) each other at receiver by signals transmitted from different antennas of either the same transmitters or other transmitters. Consequently, to solve the interference problem is imminent, and the correlation detection algorithm of the receiver in MIMO system is particularly important.

Recently, researchers discovered lots of signal detection methods of MIMO systems, while finding better performance signal detection algorithms of MIMO systems is becoming a research focus. Compared with the maximum likelihood detection algorithm, Successive Interference Cancellation (SIC) has lower computational complexity, while its detection performance is lower than the maximum likelihood detection. This algorithm detects each signal of the minimum level of error probability; the signal detected can be as the interference signal to eliminate the impact of the signal level which is not detected. The accuracy of the signal which was first detected could influence the signal detection of next layer. Detection performance of the entire system was affected by the detection accuracy of the signal which was first detected.

Firstly, the adaptive channel frequency response recovery algorithm can reduce the deviation of signal detection [3, 4]. In addition, SIC algorithm can effectively suppress CCI and improve the system performance. Based on the previous researches, the combination of CFR recovery and SIC suppressing CCI in STC-OFDM systems was given by this paper. Recover the pilot CFR before SIC, and then detect the signal by SIC. Accordingly, theoretical analysis and computer simulation show that the new algorithm can further improve the system bit error rate and suppress the CCI of STC-OFDM system.

In this paper, the certain organization is followed as below: The section 2 describes the model of STC-OFDM system. The section 3 analyzes the algorithm and evaluates a theoretical expression to estimate the system performance. As the section 4, theoretical and simulation curves are presented for comparison and validation. Finally, section 5 presents the conclusions.

## 2. System Modem

A simple STBC-OFDM system is showed in Fig. 1. Here we consider two transmit antennas and one receive antenna for notation simplicity. More receive antennas can be easily extended. For two transmit antennas, data symbol vector is defined as:

$$\mathbf{X}(k)=\begin{bmatrix}X_1(k) & X_2(k)\end{bmatrix}^T \tag{1}$$

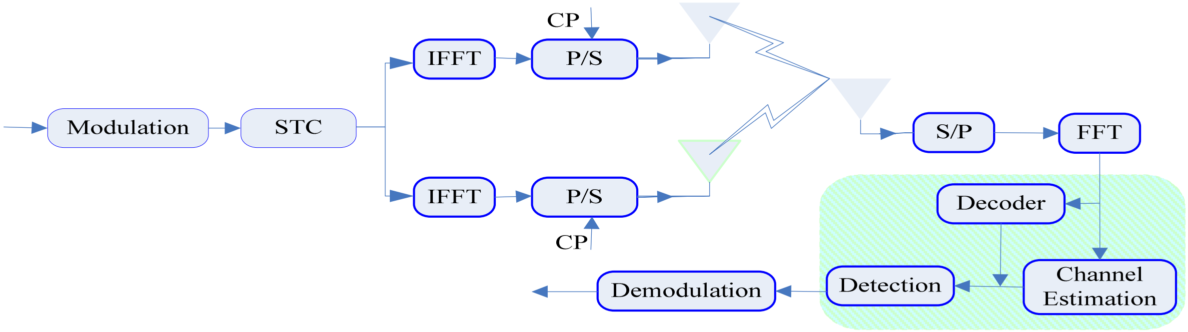

**Fig. 1.** System model.

For each $k \in K$. The set $K=\{0,1,...,N-1\}$ is the index of subcarriers, and $N$ is the number of subcarriers. $(\cdot)^T$ denotes transpose. After the STBC, we can obtain

$$\mathbf{S}(k)=\begin{bmatrix}X_1(k) & X_2(k)\\ -X_2^*(k) & X_1^*(k)\end{bmatrix} \tag{2}$$

If cyclic prefix is longer than the max channel delay spread, the signals can achieve full synchronization. After some manipulation such as an Inverse fast Fourier transform (IFFT), addition and removal of cyclic prefix, serial-to-parallel conversion, and an FFT, before signal detection of receiver we can obtain a following received data symbol vector at the $k$-th subcarrier

$$\begin{aligned}\mathbf{Y}(k)&=\begin{bmatrix}Y_1(k) & Y_2^*(k)\end{bmatrix}^T\\ &=\mathbf{H}(k)\mathbf{S}(k)+\mathbf{I}(k)+\mathbf{W}(k)\end{aligned}, \tag{3}$$

where

$$\mathbf{H}(k)=\begin{bmatrix}H_1^1(k) & H_1^2(k)\\ H_2^{2*}(k) & -H_2^{1*}(k)\end{bmatrix} \tag{4}$$

$$\mathbf{I}(k)=\begin{bmatrix}I_1(k) & I_2^*(k)\end{bmatrix}^T \tag{5}$$

$$\mathbf{W}(k)=\begin{bmatrix}W_1(k) & W_2^*(k)\end{bmatrix}^T \tag{6}$$

In Eq. (4), $H_l^i(k)$ is the CFR of a time-varying multipath channel existing between the $i$-th transmit antenna and a receive antenna. In Eq. (5), $I_l(k)=\sum_{i=1}^{2} I_l^i(k)$, $I_l^i(k)$ is the ICI caused by the time-varying channel existed between the $i$-th transmit antenna and a receive antenna. The ICI can be modeled as a random variable with zero mean and variance of $\sigma_I^2$. In Eq. (6), $W_l(k)$ is an Additive white Gaussian noise with zero mean and variance of $\sigma_W^2$.

Next step is to feed $\mathbf{Y}(k)$ into a linear combiner with a combining coefficient of $\mathbf{H}^+(k)$, resulting in

$$\begin{aligned}\mathbf{Z}(k) &= \left[Z_1(k)\ \ Z_2(k)\right]^T \\ &= \mathbf{H}^+(k)\mathbf{Y}(k) \\ &= \psi(k)S(k)+\Upsilon(k)+\Omega(k)\end{aligned}\quad, \qquad (7)$$

where $(\bullet)^+$ represents Hermitian transpose of a matrix.

$$\begin{aligned}\Upsilon(k) &= \left[\Upsilon_1(k)\ \ \Upsilon_2(k)\right]^T = \mathbf{H}^+(k)\mathbf{I}(k) \\ \Omega(k) &= \left[\Omega_1(k)\ \ \Omega_2(k)\right]^T = H^+(k)W(k) \\ \psi(k) &= \begin{bmatrix} g_{11}(k) & g_{12}(k) \\ g_{21}(k) & g_{22}(k)\end{bmatrix}\end{aligned}\quad, \qquad (8)$$

where

$$\begin{aligned}g_{11}(k) &= \sum_{i=1}^{2}\left|H_i^i(k)\right|^2 \quad, \\ g_{12}(k) &= g_{21}^*(k) = \sum_{i=1}^{2}(-1)^{i-1} H_i^{1*}(k)H_i^2(k), \\ g_{22}(k) &= \sum_{i=1}^{2}\left|H_{3-i}^i(k)\right|^2\end{aligned}$$

## 3. Algorithm Descriptions and Analysis

First, recover the pilot CFR, so the error of data CFR estimated by interpolation will be smaller, and then combined with the SIC, the data will be detected better. Fig. 2 shows the block diagram of the algorithm, and the following is the algorithm analysis:

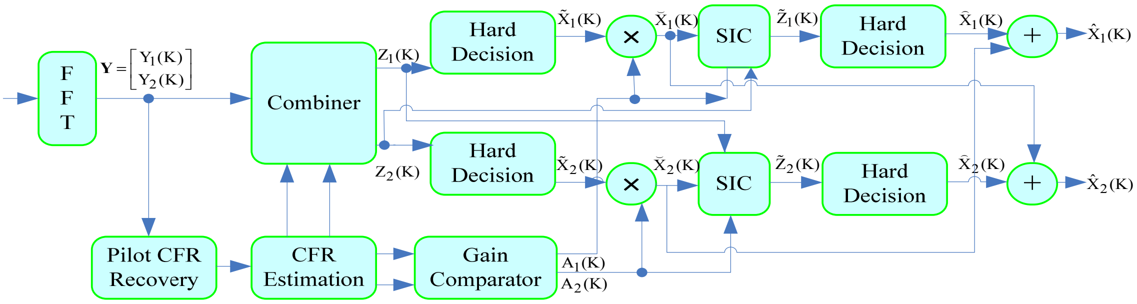

**Fig. 2.** The block diagram of the algorithm.

1) Pilot CFR recovery

For convenience of analysis, we define the following notations: $\lambda_j$ – the position of the $j$-th pilot in an OFDM symbol; $\hat{H}_n(\lambda_j)$ – the estimated CFR of the $j$-th pilot in the $n$-th OFDM symbol; $\delta_n^j$ – the difference between $\hat{H}_n(\lambda_{j+1})$ and $\hat{H}_n(\lambda_j)$, $\delta_n^j = \hat{H}_n(\lambda_{j+1}) - \hat{H}_n(\lambda_j)$; $\Re(\delta_n^j)$ – the real part of $\delta_n^j$; $\Im(\delta_n^j)$ – the imaginary part of $\delta_n^j$.

If CFR $H_n(k)$ is varying slowly with subcarrier index $k$. Hence, the difference between the adjacent pilot CFRs should be small. Thus, we can use the following equation to detect the affected pilot CFRs and recover them.

$$\tilde{H}_n(\lambda_j) = \begin{cases} \dfrac{\hat{H}_n(\lambda_{j-1})}{2} + \dfrac{\hat{H}_n(\lambda_{j+1})}{2} & \begin{array}{l} \mathit{if}\ \left|\Re(\delta_n^j)\right| > \varepsilon\ \mathit{and}\ \left|\Re(\delta_n^{j-1})\right| > \varepsilon; \\ \mathit{or}\ \left|\Im(\delta_n^j)\right| > \varepsilon\ \mathit{and}\ \left|\Im(\delta_n^{j-1})\right| > \varepsilon, \end{array} \\ \hat{H}_n(\lambda_j) & \mathit{otherwise}, \end{cases} \quad, \qquad (9)$$

where $\tilde{H}_n(\lambda_j)$ is the recovered pilot CFR and $\varepsilon$ is a predetermined threshold. The real and imaginary parts of pilot CFRs are examined independently to detect the affected pilots. If discontinuity exits in any of the real or imaginary part, a corrupted pilot is detected. The discontinuity is checked among the adjacent three pilots by using threshold $\varepsilon$. If the $j$-th pilot is affected by CCI, its CFR is recovered as the average of the $j-1$-th and the $j+1$-th pilot CFRs.

2) Estimate the data CFR:

Using the recovery pilot CFR estimate the data CFR by interpolation, we can obtain $\tilde{H}_l^i(k)$, and calculate $\tilde{\psi}(k)$.

3) Obtain the 1st temporary symbol from (7):

$$\tilde{X}_l(k) = \prod\left\{Z_l(k)\right\}, \qquad (10)$$

where $\prod\{\bullet\}$ is the hard decision.

4) Set selection parameters:

$$\begin{aligned}A_1(k) &= \begin{cases} 1, & \mathit{if}\ g_{11}(k) \geq g_{22}(k), \\ 0, & \mathit{else}, \end{cases} \\ A_2(k) &= \begin{cases} 1, & \mathit{if}\ g_{22}(k) < g_{11}(k), \\ 0, & \mathit{else}, \end{cases}\end{aligned} \qquad (11)$$

5) Obtain the 2nd temporary symbol from:

$$\check{X}_l(k) = A_l(k)\tilde{X}_l(k) \tag{12}$$

6) Cancel the CCI from (7):

$$\begin{aligned}\tilde{Z}_1(k) &= \left\{Z_1(k) - \tilde{g}_{12}(k)\check{X}_2(k)\right\}A_2(k)\\ \tilde{Z}_2(k) &= \left\{Z_2(k) - \tilde{g}_{21}(k)\check{X}_1(k)\right\}A_1(k)\end{aligned}, \tag{13}$$

where $\tilde{g}_{12}(k)$ and $\tilde{g}_{21}(k)$ are estimation values of $g_{12}(k)$ and $g_{21}(k)$, respectively.

7) Obtain the 3rd temporary symbol from:

$$\widehat{X}_l(k) = \Pi\left\{\tilde{Z}_l(k)\right\}, \tag{14}$$

8) Detect the final data symbol by using:

$$\hat{X}_l(k) = \widehat{X}_l(k) + \check{X}_l(k), \tag{15}$$

In forward error correction, the Viterbi algorithm is used for decoding, a commonly used upper bound of the probability of bit error is [5]

$$P_b < \frac{1}{k}\sum_{d=d_{free}}^{\infty} B_d P_d , \tag{16}$$

where $k$ is the number of the information bits per trellis branch, $d$ is the output weight of a specific path, $P_d$ is the probability that the decoder selects a code sequence that is a Hamming distance $d$ from the correct code sequence, and $B_d$ represents the total information weight of all code sequences of weight $d$ and represents the sum of all possible bit errors that can occur when the all-zero code sequence is transmitted. Finally, $d_{free}$ is the minimum Hamming distance between all pairs of non-zero paths.

The probability $P_d$ for hard decision decoding is

$$\begin{aligned}P_d &= \sum_{i=\frac{d+1}{2}}^{d}\binom{d}{i}p^i(1-p)^{d-i} && d \text{ is odd}\\ P_d &= \frac{1}{2}\binom{d}{d/2}p^{d/2}(1-p)^{d/2} + \sum_{i=\frac{d+1}{2}}^{d}\binom{d}{i}p^i(1-p)^{d-i} && d \text{ is even}\end{aligned} \tag{17}$$

The probability of bit error after the $j$-th cancellation, is given by [6]

$$P_d^{j+1} = Q\left(\sqrt{r_{j+1}}\right), \tag{18}$$

where

$$r_{j+1} = \frac{A_{j+1}^2}{\frac{1}{3N}\sum_{k=j+2}^{K} A_k^2 + \frac{N_o}{T} + \frac{1}{3N}\sum_{i=1}^{j}\eta_i} \tag{19}$$

After $j$ cancellation, the variable of the decision variable conditioned on $A_k$ as follows

$$\eta_{j+1} = \frac{1}{3N}\sum_{k=j+2}^{K} A_k^2 + \frac{N_o}{T} + \frac{1}{3N}\sum_{i=1}^{j}\eta_i \quad \textit{for Asynchronous}, \tag{20}$$

where $K$ is the total number of active users. $A_k$ is the amplitude of $k$-th user. $N_o/2$ is the side band power spectral density. $N = T/T_c$, $T$ is the bit period and $T_c$ is the chip period. $A_k$, which is the ordered set of amplitudes of $K$ users, is assumed to be Rayleigh distributed with unit mean square value, i.e., its probability density function is given by $f(x) = 2xe^{-x^2}$, and its cumulative density function is given by $F(x) = 1 - e^{-x^2}$, so the pdf of the ordered $A_k$ is denoted by $f_{A_k}(x)$ and is obtained as follows:

$$f_{A_k}(x) = \frac{K!}{(K-k)!(k-1)!}F^{K-k}(x)\bullet\left[1-F(x)\right]^{k-1} f(x) \tag{21}$$

Then

$$P_d^{j+1} = \int_0^{\infty} Q\left(\frac{A_{j+1}}{\sqrt{E_{A_k}\left[\eta_{j+1}\right]}}\right) f_{A_{j+1}}(x)dx \tag{22}$$

,

where

$$E\left[A_k^2\right] = \int_0^{\infty} x^2 f_{A_k}(x)dx ,$$

$$E_{A_k}\left[\eta_{j+1}\right] = \frac{1}{3N}\sum_{k=j+2}^{K} E\left[A_k^2\right] + \frac{N_o}{T} + \frac{1}{3N}\sum_{i=1}^{j}\eta_i \quad \textit{for Asynchronous} \tag{23}$$

## 4. Computer Simulations and Analysis

In order to illustrate the BER performance of the proposed algorithm based on CFR recovery and SIC, some parameters are shown by Table 1.

**Table 1.** Parameters.

| Parameter | Value |
|---|---|
| FFT | 1024 |
| $B_d$ | 1 |
| $K$ | 2 |
| $d_{free}$ | 3 |
| $N_o$ | $10^{-8}$W/Hz |
| $T_c$ | 8Mc/s |
| Modulation | QPSK |

Fig. 3 shows the BER curves with the SNR's changes. Due to introduce pilot CFR recovery before the SIC algorithm, the data CFR estimated will bring a smaller error. So BER of the new algorithm is lower than the traditional in Rayleigh fading for different users. It is obvious that, the fewer the number of users, the lower the error rate. The BER of 10 users is lower than 20 users in Rayleigh fading.

Fig. 4 shows the BER curves with the number of users' changes. It can be seen the BER is growing larger with the increase of users in Rayleigh fading. And the BER of the given algorithm is growing lower with the increase of SNR under Rayleigh fading close to the BER of Gaussian state. This indicates that the given algorithm is more favorable than the traditional method to eliminate CCI to a certain extent.

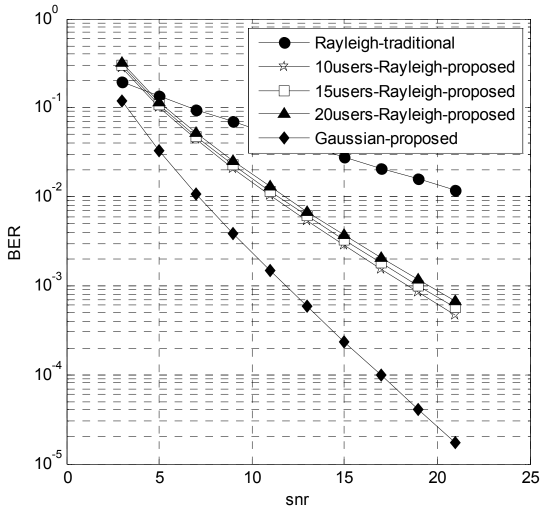

**Fig. 3.** BER vs. SNR.

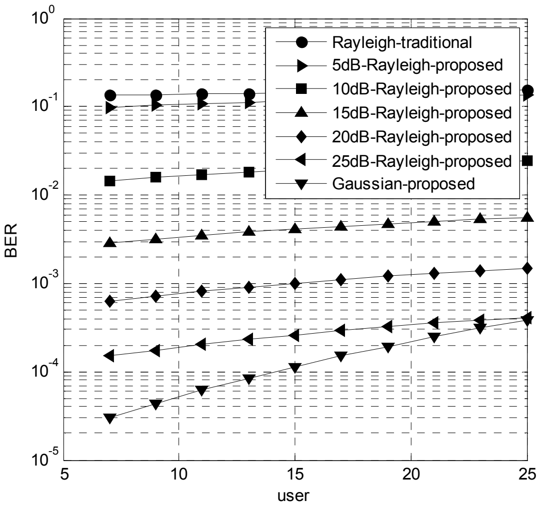

**Fig. 4.** BER vs. User.

## 5. Conclusions

The combination of STC and OFDM technology is widely used in broadband wireless communication system. It not only alleviates drawbacks of each other, but also improves the performance of high speed transmission which has two inherent fundamental impairments, multi-path fading and ISI. The given algorithm based on the combination of pilot CFR recovery and SIC algorithm can further inhibit the CCI, and the BER performance of the system has improved to some extent.

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