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Effect of Channel Estimation Error on EST System Performance

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Abstract: Energy Spreading Transform (EST) system can extend the energy of the signal to both the time domain and frequency domain. In the system which is not encoded, EST has been widely concerned because that it enables the system performance approach the matched filter limit. The existing literature mainly discussed EST iterative detection performance under the conditions of the ideal channel estimation, while it did not consider the possible impact of channel estimation error. Under the doubly selective channel conditions, this study took a theoretical analysis of the system demodulation algorithm in the presence of channel estimation error, and also verified the impact of channel estimation error in different channel environments using simulation.

Keywords: EST, channel estimation, doubly selective channel.

1. Introduction

The mobile communication is one of the most active and rapidly-developed fields among the communication fields. In wireless communication systems, due to the poor channel characteristic of the wireless channel, the communication is vulnerable to factors such as interference and fading. Multipath seriously affect reliability of the communication, and the channel will produce inter symbol interference[1],[2].

Energy Spreading Transform (EST) system is an iterative detection system based on energy's expansion and transformation. Using the EST expansion matrix, signal energy can be extended to the time domain and frequency domain at the same time.

Through the signal energy expansion, it can obtain frequency diversity in the frequency domain, and in the time domain it can significantly increase the reliability of the feedback signal, which can improve the signal detection performance1.

Based on EST iterative algorithm, data at the receiving end is iteratively detected, eliminating the Inter Carrier Interference (ICI) and inter-symbol interference (ISI). So it is able to get better performance.

EST technology can be combined with Single Input Single Output System (SISO) and Multiple Input Multiple Output Systems (MIMO), so it achieves good performance through iterations in the case of no channel coding. The EST system wireless communication has great significance in the research of wireless communication[3]-[6].

In the EST iterative detection technology, it often assumes ideally the channel is known. In order to assess the effect of channel estimation accuracy on the energy spreading transform iterative technique's performance, this study took a theoretical analysis and numeral simulation.

2. Overview of EST technology

The iterative technique based on the energy spreading Transform (Energy-Spreading Transform, EST) is one technology that uses energy spreading the transformation matrix at the same time to expand the energy in the time domain and frequency domain data and then get the time domain and frequency domain gain. The EST transformation is a normalized orthogonal transformation. After EST transformation, the energy of the data symbols can be extended to the time domain and frequency domain at the same time. The ideal matrix of EST has perfect spreading

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performance in the time domain and frequency domain. The ideal EST extended matrix amplitude as follows[7]-[8]:

$$|(\mathbf{E})_{l,n}| = |(\mathbf{FE})_{l,n}| = \frac{1}{\sqrt{N}} \quad (1)$$

In Eq. (1) , the EST matrix is a square matrix ,and $\mathbf{F}^H$ is the element of line l, list n in order N matrix $E(\mathbf{E} = \mathbf{F}^H)$. In EST matrix, the phase of $\mathbf{E} = \mathbf{PF}_D^H = \mathbf{P}diag\{\mathbf{F}^H$, ..., $\mathbf{F}^H\}$ is random and dual symmetric distribution in $\mathbf{E} \in C^{LN \times LN}$. $\mathbf{F}$ denotes the normalized Fourier matrix, and its l row, n column element is expressed as

$$(\mathbf{F})_{l,n} = \frac{1}{\sqrt{N}} e^{-j2\pi nl/N}, 0 \le l, n \le N-1 \quad (2)$$

EST matrix may be of the following ways:

$$\mathbf{E} = (\mathbf{P}_\mu)\mathbf{U}_\mu \mathbf{P}_{\mu-1}\mathbf{U}_{\mu-1}...\mathbf{P}_1\mathbf{U}_1 \quad (3)$$

In Eq.(3), $\mathbf{P}_l \in C^{N \times N}$ represents pseudo-random permutation matrix, where there is $\mathbf{E} = \mathbf{PF}_D^H$ and $L \times N$ is the number of Orthogonal matrix, and can take advantage of the interleaves to achieve the random permutation operation. N square matrix $\mathbf{E} = \mathbf{PF}_D^H$ is a normalized orthogonal matrix .In the composition process of EST matrix, matrix used are orthogonal matrix, which can guarantee EST matrix orthogonality. Because there is orthogonality, and low complexity and fast algorithm, the FFT matrix and the Hadamard matrix is a good choice $\varepsilon\{|h_{n,l}|^2\} = \{0.0992e^{-0.1l}\}$ at the matrix of the EST matrix.

EST is at the sending end. The source bit of information via modulation, S / P conversion gets the modulation symbol vector $\mathbf{x}$. A symbol $\mathbf{x} = \{x_0, x_1, ..., x_{N-1}\}^T$ is transmitted at the sending end. N is the size of the symbol block. After doing EST, the energy of each symbol maps to $\tilde{\mathbf{x}} = \{\tilde{x}_0, \tilde{x}_1, ..., \tilde{x}_{N-1}\}^T$.

$$\tilde{x}_k = \mathbf{Ex} = E(k,1)x(1) + E(k,2)x(2) + \cdots + E(k,N)x(N) \quad (4)$$

Where $E(k,i)$ means the k line, the j list element of matrix $\mathbf{E}$ and $x(i)$ is the symbol of Number I in vector $\mathbf{x}$, $(k, i = 1, 2, ..., N)$.It can be seen from the above equation that $\tilde{x}_k$ contains $\mathbf{x}$ all the energy of the symbol. In other words, x after the energy of all the symbols expanded, uniformly extends in the time domain and frequency domain to the symbols of vector $\tilde{\mathbf{x}}$. When through the channel, because the signal energy of each symbol is uniformly distributed in the whole symbol block, when disturbed, doing the symbol extending at the receiving end can get the diversity gain .In order to measure the extended effect of the data energy by EST extended matrix, the expansion coefficient of the time domain and frequency domain was separately defined in the time domain and frequency domain .In EST matrix, the n send data domain extended factor is expressed as[7]-[8]

$$\mathbf{s}_T(\mathbf{E}^H; n) = \sum_{l=0}^{N-1} (|(\mathbf{E}^H)_{l,n}|^2 - \frac{1}{N})^2 \quad (5)$$

Where H denotes the Hermitian transpose. Equally, the n-th frequency domain extended coefficient of EST matrix can be defined as:

$$\mathbf{s}_F(\mathbf{E}; n) = \mathbf{s}_T(\mathbf{FE}; n) = \sum_{l=0}^{N-1} (|(\mathbf{FE})_{l,n}|^2 - \frac{1}{N})^2 \quad (6)$$

It can be seen from the above Eq. (5) and (6) that when $\mathbf{s}_T(\mathbf{E}^H; n) = 0$ for all the $n \in [0, N-1]$ was founded, $\mathbf{E}$ Matrix can perfectly extend data energy in the time domain. Equally, when for all $n \in [0, N-1]$, there is $\mathbf{s}_F(\mathbf{E}; n) = 0$, $\mathbf{E}$ Matrix can perfectly extend data energy in the frequency domain .

It can be seen by the EST matrix structure ,that when EST matrix represent the unit matrix and have no iteration , the EST system can degenerate into the SC system ; when EST matrix represent the IFFT matrix and have no iteration , the EST system can degenerate into the OFDM system.

Literature [7] and [8] studied the optimal filter design based on the ideal channel estimation in the doubly selective channel. The equivalent model as follows:

In Fig. 1, $\dot{\mathbf{A}}_D^{(i)}$ and $\dot{\mathbf{B}}^{(i)}$ represent to the forward direction filter and the feedback filter respectively. $\dot{\mathbf{A}}_D^{(i)}$ is a diagonal matrix, which compensates the data on the receiving end, making the output SINR is maximized. $\dot{\mathbf{B}}^{(i)}$ can be divided into diagonal matrix $\dot{\mathbf{B}}_D^{(i)}$ and off-diagonal matrix $\dot{\mathbf{B}}_O^{(i)}$ in which the diagonal elements have been removed. $\dot{\mathbf{B}}_D^{(i)}$ is used to eliminate the ISI caused by the channel frequency selectivity, and $\dot{\mathbf{B}}_O^{(i)}$ is used to eliminate ICI caused by time-varying channel.

Considering the equivalent model in Fig. 1, the definition of the error of the ith iteration posterior detection is :

$$d_n^{(i)} = x_n - \hat{x}_n^{(i)} \quad (7)$$

in which $\hat{x}_n^{(i)}$ is the i th ruling symbol. Thus, after the i th iterations, the judgment vector is expressed as:

$$\mathbf{z}^{(i)} = \underbrace{g_0^{(i)}\mathbf{x}}_{\text{signal}} + \underbrace{\mathbf{E}^H\mathbf{F}^H\dot{\mathbf{B}}_D^{(i)}\mathbf{FEd}^{(i-1)}}_{\text{ISI}} + \underbrace{\mathbf{E}^H\mathbf{F}^H\dot{\mathbf{B}}_O^{(i)}\mathbf{FEd}^{(i-1)}}_{\text{ICI}} + \underbrace{\mathbf{E}^H\mathbf{F}^H\dot{\mathbf{A}}_D^{(i)}\mathbf{Fw}}_{\text{noise}} \quad (8)$$

where

$$\mathbf{d}^{(i)} = [d_0^{(i)}, d_1^{(i)}, ..., d_{N-1}^{(i)}]^T \quad (9)$$

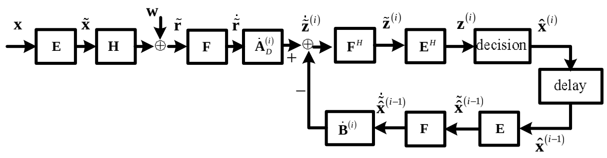

Figure 1 The equivalent model of doubly selective channel

$$g_0^{(i)} = \frac{1}{N}\sum_{k=0}^{N-1}(\dot{\mathbf{G}}_D^{(i)})_{k,k} \tag{10}$$

and

$$\dot{\mathbf{G}}_D^{(i)} = \dot{\mathbf{A}}_D^{(i)}\dot{\mathbf{H}}_D \tag{11}$$

In Eq.(8), using $\dot{\mathbf{B}}_D^{(i)}$ and $\dot{\mathbf{B}}_O^{(i)}$ to eliminate the residual ISI and ICI respectively, in which:

$$\dot{\mathbf{B}}_D^{(i)} = \dot{\mathbf{G}}_D^{(i)} - g_0^{(i)}\mathbf{I} \tag{12}$$

$$\dot{\mathbf{B}}_O^{(i)} = \dot{\mathbf{A}}_D^{(i)}\dot{\mathbf{H}}_O \tag{13}$$

where $\mathbf{I}$ represents the unit matrix.

Design the forward filter to make the output SINR is maximized.

$$SINR = \frac{P_{si}}{P_{ISI}+P_{ICI}+P_{no}} \tag{14}$$

Through the analysis above, the expression of the forward filter is formula[10]-[11]:

$$(\dot{\mathbf{A}}_D^{(i)})_{k,k} = \frac{\alpha(\dot{\mathbf{H}})^*_{k,k}}{(\sigma_d^{(i-1)})^2\sum_{l=0}^{N-1}|(\dot{\mathbf{H}})_{k,l}|^2+\sigma_w^2} \tag{15}$$

The α in Eq. (13) is used to normalize $g_0^{(i)}$ to 1.

3. Effect of Channel Estimation Error

3.1. The effect of The EST system PAPR characteristics on the channel estimation

In the EST system, EST matrix is alternately multiplied by the matrix $\mathbf{P}$ and the matrix $\mathbf{F}$. It can be seen from Eq.(4), that after the EST transformation of the data, the data obtained $\tilde{x}(k)$ is superimposed by the data .The formula can also be written as :

$$(\tilde{x})_l = \sum_{k=1}^{N} E_{l,k}\times x_k \tag{16}$$

As can be seen by the Eq.(16), data after EST is superimposed by the data before transformation, so that the EST system can be seen as a multi carrier system .According to the definition of the PAPR of the multicarrier, Similar to the OFDM system, the definition of the PAPR of the EST system can be written as:

$$PAPR_{EST} = \frac{\max_n\{|\tilde{x}_n|^2\}}{E\{|\tilde{x}_n|^2\}} \tag{17}$$

The construction methods of EST matrix is as shown in Eq. (3). And it is widely varied. For studying PAPR in EST, for example in $\mathbf{E}=\mathbf{F}^H\mathbf{P}\mathbf{F}^H$, the $\mathbf{E}$ matrix's elements can be expressed as:

$$\begin{aligned}(\mathbf{E})_{m,n} &= \frac{1}{N}\sum_{l_1=0}^{N-1}\sum_{l_2=0}^{N-1}P_{l_1,l_2}e^{\frac{j2\pi ml_1}{N}}e^{\frac{j2\pi nl_2}{N}}\\ &= \frac{1}{\sqrt{N}}\sum_{l_1=0}^{N-1}e^{\frac{j2\pi(ml_1+nl_2)}{N}}\end{aligned} \tag{18}$$

As $\mathbf{P}$ is a random permutation matrix, so there is: $\sum_{k=0}^{N-1} P_{k,n}=1$,$\sum_{l=0}^{N-1}P_{l,n}=1$ .And l_2 expresses the position of the first one in the l_1-th line of $\mathbf{P}$ matrix. So the data obtained after the EST extended can be expressed as:

$$(\tilde{s})_m = \sum_{n=1}^{N}E_{m,n}\times s_n = \frac{1}{\sqrt{N}}\sum_{n=0}^{N-1}\sum_{l_1=0}^{N-1}e^{\frac{j2\pi(ml_1+nl_2)}{N}}\times s_n \tag{19}$$

In EST matrix structure, when random permutation matrix is under certain circumstances, because in random permutation matrix, each row and each column have an element 1, and the other remains 0, the expression above can be simplified as:

$$(\tilde{s})_m = \frac{1}{\sqrt{N}}\sum_{n=0}^{N-1}\sum_{(l_1,l_2)\in o(P)}e^{\frac{j2\pi(ml_1+nl_2)}{N}}\times S_n \tag{20}$$

Where $o(P)\triangleq\{(l_1,l_2)|(P)_{l_1,l_2=1}\}$ represents a position of 1 in random permutation matrix.

After PSK or QAM modulation, $E\{|x_n|^2\}=1$, the maximum data after EST can be obtained by the formula:

$$\begin{aligned}A_{max}^2 &= \max_k\{|\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1}\sum_{l_1=0}^{N-1}\sum_{l_2=0}^{N-1}P_{l_1,l_2}e^{\frac{j2\pi ml_1}{N}}e^{\frac{j2\pi nl_2}{N}}\times s_n|^2\}\\ &= \frac{1}{N}\max_k\{|\sum_{n=0}^{N-1}\sum_{(l_1,l_2)\in 0(P)}e^{\frac{j2\pi(ml_1+nl_2)}{N}}\times s_n|^2\}\\ &\le \frac{1}{N}[\sum_{n=0}^{N-1}|s_n|]^2 = N\end{aligned} \tag{21}$$

Where $E\{|\tilde{x}_n|^2\}$ denote the average of $|\tilde{x}_n|^2$. The instantaneous power of the signal after transformation is

$$P = \tilde{x}_n \times \tilde{x}_n^* \tag{22}$$

The average power can be expressed as

$$\begin{aligned} P_{av} &= E\{\tilde{x}_m \times \tilde{x}_m^*\} \\ &= \frac{1}{N} E\{(\sum_{n=0}^{N-1}\sum_{l_1=0}^{N-1}\sum_{l_2=0}^{N-1} P_{l_1,l_2} e^{\frac{j2\pi m l_1}{N}} e^{\frac{j2\pi n l_2}{N}} e^{\frac{-j2\pi m l_1}{N}} e^{\frac{-j2\pi n l_2}{N}} \\ &\qquad \times x_n \times x_n^*)\} \\ &= \frac{1}{N}\sum_{n=0}^{N-1} E\{|x_n|^2\} \\ &= 1 \end{aligned} \tag{23}$$

It can be seen from the above Eq.(17), (21) and (23) that the maximum crest factor of s after EST transform by the Eq. (17) as

$$PAPR^{EST} = \frac{\max_n\{|\tilde{s}_n|^2\}}{E\{|\tilde{s}_n|^2\}} \leq N \tag{24}$$

It can be seen from the above equation that there are still the PAPR peak based on EST system, and the largest peak is the size N of the expanding transformation matrix.

It can be seen from Fig.2 that although in EST system ,the iterative technique based on EST can get higher iterative gain ,and characteristics close to the matched filter ,the EST system still exists the problem of high PAPR .We can see from the numerical analysis method that the PAPR based on EST extend matrix's matrix system with the change of the size of the data block and the increase of the length of the frame, the PAPR threshold is increasing .So the impact of PAPR on device still have to take into account in the implementation of EST system, and the PAPR must be suppressed in the implementation process. And to some extent it will impact channel estimation of guided sequence, but for simplicity, you can see it as the loss of signal to noise ratio [9] .

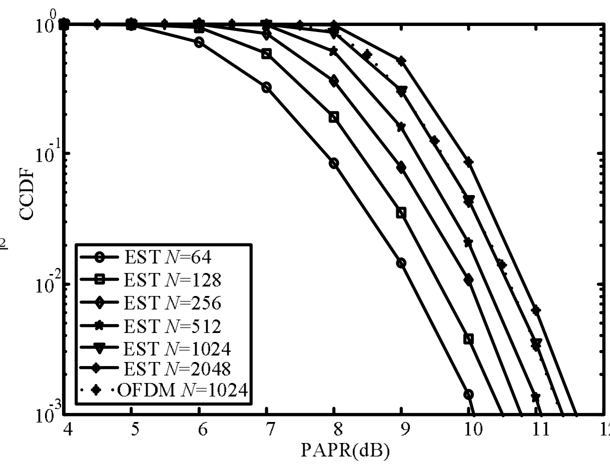

Figure 2 PAPR of EST system

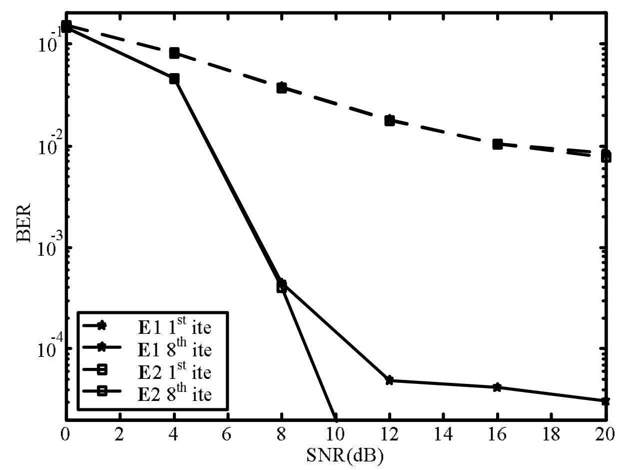

Figure 3 $\mathbf{E_1}$ and $\mathbf{E_2}$ in EST matrix extended performance comparison

3.2. EST extended matrix and the extended length selection

3.2.1. Extension matrix performance

In practical application, it is to hard to find that in time domain and frequency domain of signal energy for the perfect extended EST matrix simultaneously. Transform matrix and Hadamard matrix because of the presence of a fast algorithm, can be used to construct an EST matrix, but the two matrices are not able to meet the ideal EST matrix condition. In practical application, we must according to the channel information, according to the frequency selectivity and time selective strength to choose channel extended matrix, makes the EST system performance optimization.

In Table 1, according to the Eq.(3) constructed by several different EST extension matrix, and the use of Eq.(5) and (6) defined in the time domain and frequency domain spreading factor expansion factor of structure matrix analysis, the calculation of matrix extension properties, and use simulation comparison. Where the matrix $\mathbf{F}$ stands for the Fourier matrix, and the matrix $\mathbf{T}$ stands for Hadamard matrix.

The table can be seen, $\mathbf{E}_1$, $\mathbf{E}_2$ by normalized Fourier matrix is constructed by, $\mathbf{E}_3$, $\mathbf{E}_4$ and $\mathbf{E}_5$ normalized Hadamard matrix, $\mathbf{E}_6$ is composed by $\mathbf{E}_1$ and $\mathbf{T}$ As can be seen from the table, $\mathbf{E}_1$, $\mathbf{E}_3$ and $\mathbf{E}_4$ has perfect time performance, $\mathbf{E}_2$ and $\mathbf{E}_5$ has perfect frequency domain extension performance. So, when the channel frequency selectivity caused severe fading, can select $\mathbf{E}_2$ and $\mathbf{E}_5$ as an extension of data matrix energy expansion.

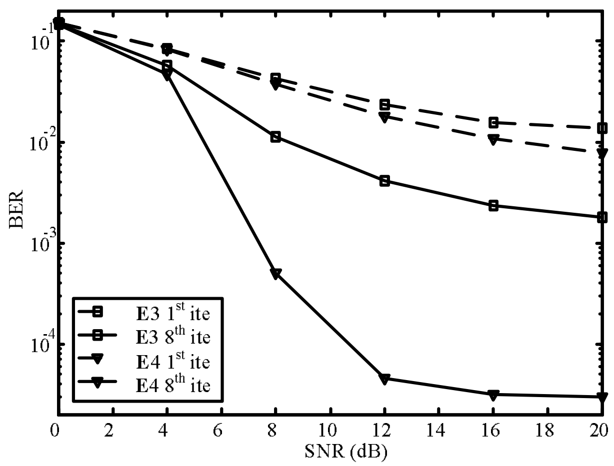

Figure 4 Scalability Comparison between $\mathbf{E_3}$ and $\mathbf{E_4}$ in EST matrix

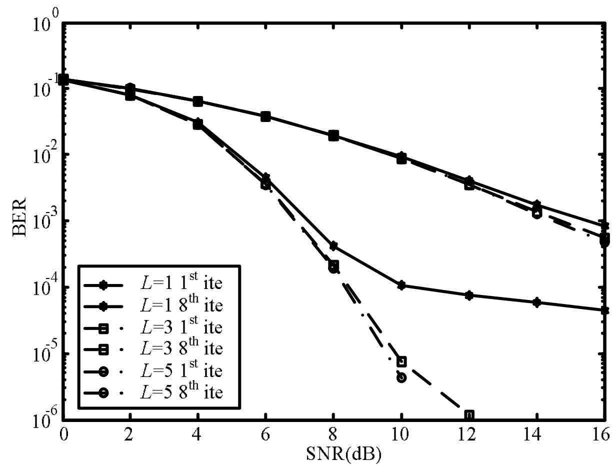

Figure 6 EST extension performance

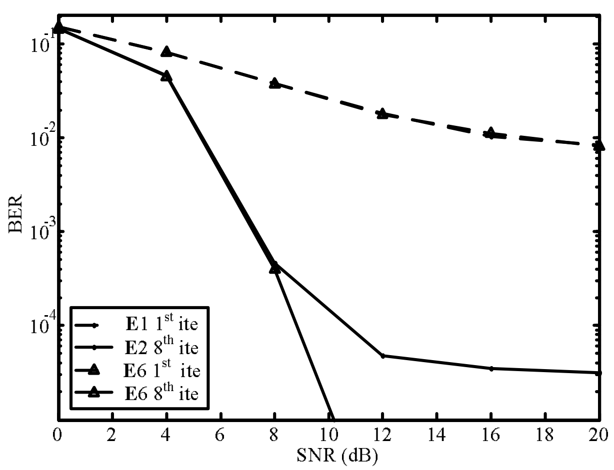

Figure 5 Extension performance comparison between$\mathbf{E_1}$ and $\mathbf{E_6}$ in Energy extension transformation

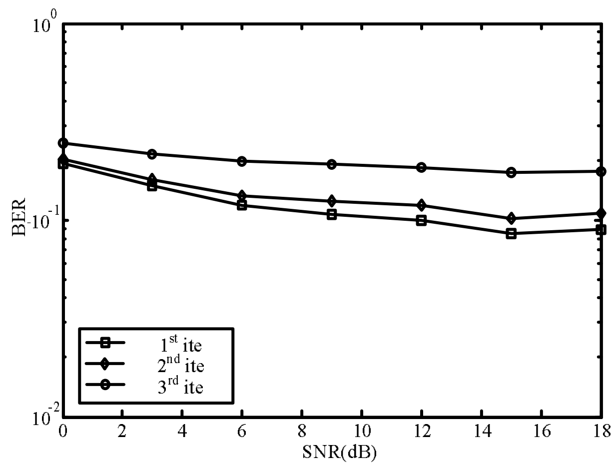

Figure 7 System performance with MSE = 0.1(single path Rayleigh channel)

Table 1 Some of the EST matrix expansion properties, $1 \leq N, N = 512$

$\mathbf{E}$	$\varepsilon_d = \{s_T(\mathbf{E}_i^H; n)\}$	$v_d = \{s_T(\mathbf{E}_i^H; n)\}$
$\mathbf{E}_1 = \mathbf{PF}^H$	0	0
$\mathbf{E}_2 = \mathbf{F}^H\mathbf{PF}^H$	2×10^{-3}	2.98×10^{-8}
$\mathbf{E}_3 = \mathbf{T}$	0	0
$\mathbf{E}_4 = \mathbf{PT}$	0	0
$\mathbf{E}_5 = \mathbf{F}^H\mathbf{PT}$	2×10^{-3}	3.78×10^{-8}
$\mathbf{E}_6 = \mathbf{TPT}$	9.82×10^{-2}	9.3×10^{-3}

$\mathbf{E}$	$\varepsilon_d = \{s_F(\mathbf{E}_i; n)\}$	$v_d = \{s_F(\mathbf{E}_i; n)\}$
$\mathbf{E}_1 = \mathbf{PF}^H$	2×10^{-3}	2.97×10^{-8}
$\mathbf{E}_2 = \mathbf{F}^H\mathbf{PF}^H$	0	0
$\mathbf{E}_3 = \mathbf{T}$	9.64×10^{-2}	7.5×10^{-3}
$\mathbf{E}_4 = \mathbf{PT}$	2×10^{-3}	5.93×10^{-8}
$\mathbf{E}_5 = \mathbf{F}^H\mathbf{PT}$	0	0
$\mathbf{E}_6 = \mathbf{TPT}$	1.8×10^{-3}	5×10^{-8}

Below in a doubly selective channel is simulated to compare the various extensions of matrix performance. Among them $N = 512$, a channel using a Rayleigh channel $l = 32$ sizes, each size for energy: $\varepsilon\{|h_{n,l}|^2\} = \{0.0992\ e^{-0.1l}\}$.

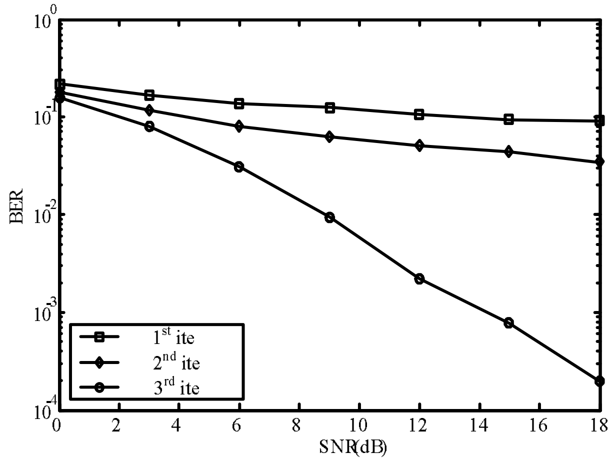

Figure 8 System performance with MSE = 0.0005 (single path Rayleigh channel)

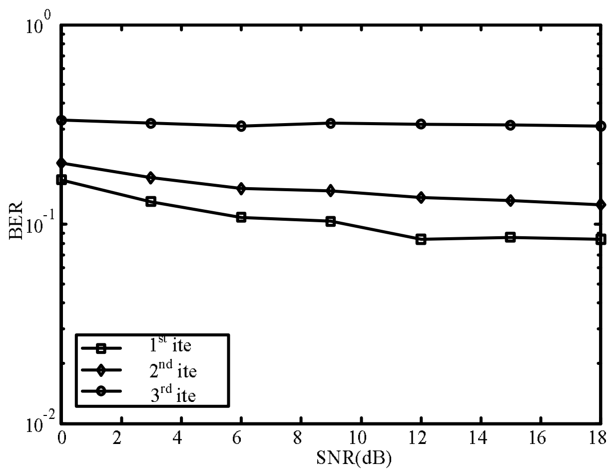

Figure 9 System performance with MSE = 0.1 (multipath Rayleigh channel without ICI)

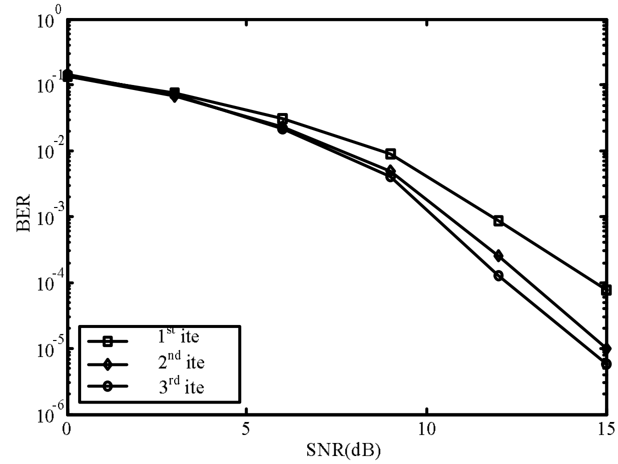

Figure 10 System performance with MSE = 0.0005 (multipath Rayleigh channel without ICI)

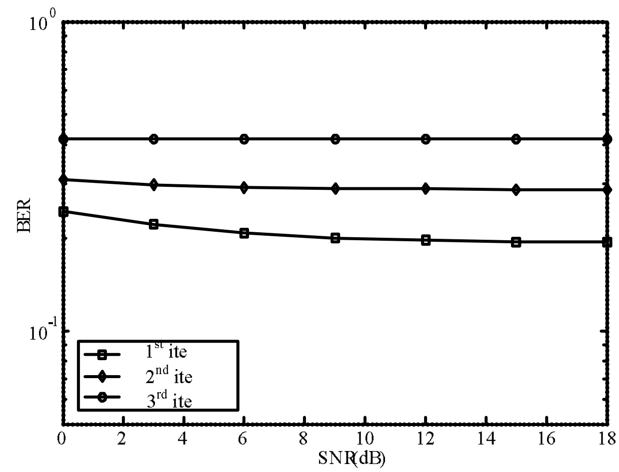

Figure 11 System performance with MSE = 0.1 (Doubly-selected channel)

In Figure 3, a dual channel under extended matrix $\mathbf{E}_1$ and $\mathbf{E}_2$ makes simulation analysis. Can see the first iteration $\mathbf{E}_1$ and $\mathbf{E}_2$ have similar properties, SNR=20dB, the extended performance of $\mathbf{E}_2$ is better than $\mathbf{E}_1$. When BER$= 10^{-4}$, the eighth iterative function performance of $\mathbf{E}_2$ is improved by 1.8dB than $\mathbf{E}_1$. So, in frequency selective channels, the frequency domain of $\mathbf{E}_2$ is perfect extended and has better performance than $\mathbf{E}_1$, it is consistent with the this analysis in Table1.

In Fig. 4, in double choose channel, the scalability of $\mathbf{E}_3$ and $\mathbf{E}_4$ is compared .Channel parameters used is the same as above. As can be seen from the figure, in the first iteration, when BER$= 1 \times 10^{-2}$, the performance of $\mathbf{E}_4$ is better than the performance of $\mathbf{E}_3$ 2dB. And after 8 iterations, in BER$= 1 \times 10^{-3}$, the made performance of $\mathbf{E}_4$ is better than the performance of $\mathbf{E}_3$ 11dB. The results obtained by simulation and data analysis form the expansion factor in Table 1 is consistent, which means that $\mathbf{E}_4$ has better scalability in the frequency domain .

Extension performance analysis of $\mathbf{E}_1$, $\mathbf{E}_2$ and $\mathbf{E}_3$, $\mathbf{E}_4$ in Table 1 and simulation result of Fig.3 and Fig. 4 states that the scalability calculated by the expansion factor can reflect the actual performance of the matrix to some extent. That is to say the performance got by the matrix in the actual channel is predicted by extending the matrix to extend performance calculations, which is of great significance to EST application.

In Fig. 5, in double choose channel, the scalability of $\mathbf{E}_1$ and $\mathbf{E}_6$ is compared. Channel parameters used is the same as above. From table 1 it can be seen that expansion

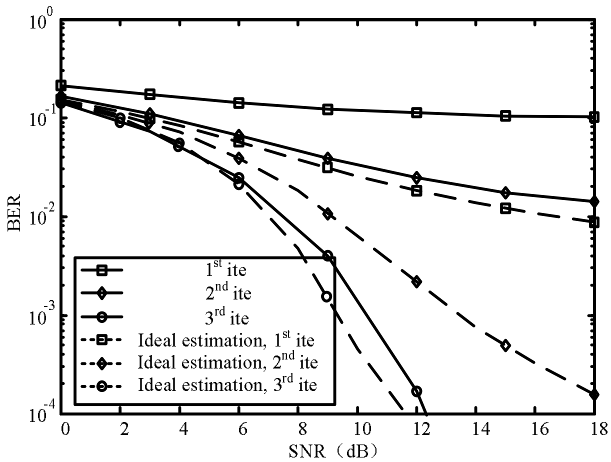

Figure 12 System performance with MSE = 0.00005 (Doubly-selected channel)

performance of $\mathbf{E}_6$ in the frequency domain is the same as $\mathbf{E}_1$,and that of $\mathbf{E}_6$ in the time domain is worse than $\mathbf{E}_1$. But form the result of simulation we can see, when BER$= 1 \times 10^{-4}$, after 8 iterations, probability of error of $\mathbf{E}_6$ is improved higher 1.8dB than $\mathbf{E}_1$. This results is inconsistent with the analysis in Table 1, which accounts for that the expansion factor mentioned above used to measure EST matrix does not apply in $\mathbf{E}_6$.

From the above analysis it can be seen that the performance of extension matrix can be done numerical quantization by a certain formula or other criteria, and Matrix in practice would be predicted to a certain extent, which is very important for EST matrix in practical applications. In section 2 the definition criteria for the expansion factor is not suitable for the degree of expansion of all the matrix to quantify .In the future study, we must find better expansion criteria that is able to measure all or most of the extended matrix scalability ,which have very far-reaching significance for the EST system in practical applications.

3.2.2. EST multi-symbol extension

According to the study of the previous section EST matrix $\mathbf{E} = \mathbf{PF}^H$ is used for analysis , and through analysis of its structure it can be found that the role of multiplication of the data and matrix $\mathbf{F}^H$ is sub-carrier mapping on data , so when $\mathbf{E} = \mathbf{F}^H$ and there is no iteration, EST will be equivalent OFDM system. But permutation matrices $\mathbf{P}$ play a role of interleaving data. That is to say it disrupts the transmission order of symbols in the symbol block, thereby reducing the correlation between symbols. As the interleaving depth increasing, the bit error performance will be better. So considering the multi-symbol EST matrix to construct a multi-symbol EST matrix as follows:

$$\mathbf{E} = \mathbf{PF}_D^H = \mathbf{P}diag\{\mathbf{F}^H, ..., \mathbf{F}^H\} \tag{24}$$

In this formula, EST matrix interleave for L symbol block. The size of the symbol block is N. And EST matrix $\mathbf{E} \in C^{LN\times LN}$, permutation matrix $\mathbf{P} \in C^{LN\times LN}$, piece of diagonal matrix $\mathbf{F}_D^H \in C^{LN\times LN}$, Fourier matrix $\mathbf{F}^H \in C^{N\times N}$.

It can be seen from the EST matrix structure that when dealing with data by $\mathbf{E} = \mathbf{PF}_D^H$, equivalently after each symbol sub-carrier mapping , then permutation matrix $\mathbf{P}$ is made in the L symbol block, which is to say that interleaving within $L \times N$ Symbol length . Compared to a single EST matrix interleaving within Single symbol, $\mathbf{E} = \mathbf{PF}_D^H$ expanded the energy of each symbol in more than one symbol block, which is called much sign extension. Because of multi-symbol extensions increasing the symbol interleaving depth, its theoretical performance improved compared with the initial matrix.

Next, the performance of multi-symbol extension matrix is simulated. In the double choose channel, a single symbol block length N is 512. modulation mode of the QPSK, Channel adopts Rayleigh channel $l = 32$ diameter. Energy of each path is $\varepsilon\{|h_{n,l}|^2\} = \{0.0992e^{-0.1l}\}$. The simulation derived is shown in Fig. 6:

If $L = 1$ is established, EST matrix is only extension of the single symbol matrix, which is $\mathbf{E} = \mathbf{PF}^H$. As shown in the performance curve of the Fig. 6, if BER$= 10^{-3}$ is established, in the 1st iterative process, $L = 3$ and $L = 5$ scalability is better than the single-symbol extension performance 1dB. After the 8th iteration, when BER$= 10^{-4}$ is established, the expansion performance of $L = 3$ and $L = 5$ improves 1.6dB than $L = 1$, and when BER$= 10^{-5}$ is established the error rate performance of $L = 5$ improves 0.2dB than $L = 3$. By simulation analysis, compared with the scalability of the single symbol, adopting the multi-symbol extension can increased inter-symbol interleaving depth to improve the EST system performance through. But its operation is no essential difference.

In summary, adopt the EST matrix $\mathbf{E} = \mathbf{PF}^H$ and the single sign extension to analyze the following performance.

3.3. Channel estimation error model and its impact

In the EST system, the channel time-domain impulse response estimate $\hat{\mathbf{h}}$ get through channel estimation algorithm can be expressed as:

$$\hat{\mathbf{h}} = \mathbf{h} + \Delta(\mathbf{h}) \tag{24}$$

Among them, $\mathbf{h}$ is the ideal channel time domain impulse response, $\Delta(\mathbf{h})$ is the error between the channel estimation value and the ideal channel value. If channel $\hat{\mathbf{h}}$ is written in the form of channel loop matrix $(\hat{\mathbf{H}})$, it can also be written as:

$$\hat{\mathbf{H}} = \mathbf{H} + \Delta(\mathbf{H}) \tag{24}$$

Transforming channel matrix into the frequency domain, it can get:

$$\begin{aligned}\dot{\hat{\mathbf{H}}} &= \mathbf{F}\hat{\mathbf{H}}\mathbf{F}^H \\ &= \mathbf{F}(\mathbf{H} + \Delta(\mathbf{H}))\mathbf{F}^H \\ &= \underbrace{\dot{\mathbf{H}}}_{\text{ideal}} + \underbrace{\Delta(\dot{\mathbf{H}})}_{\text{error}}\end{aligned}$$

Among them, $\mathbf{F}$ and $\mathbf{F}^H$ represent the FFT matrix and IFFT matrix. Then because the matrix $\hat{\mathbf{H}}$ can be expressed as follows:

$$\dot{\hat{\mathbf{H}}} = \dot{\hat{\mathbf{H}}}_D + \dot{\hat{\mathbf{H}}}_O \quad (24)$$

$$\begin{aligned}&\hat{\mathbf{H}} = \mathbf{H} + \Delta(\mathbf{H}) \\ &= \mathbf{F}\dot{\mathbf{H}}_D\mathbf{F}^H + \mathbf{F}\dot{\mathbf{H}}_O\mathbf{F}^H + \mathbf{F}\Delta(\dot{\mathbf{H}})_D\mathbf{F}^H + \mathbf{F}\Delta(\dot{\mathbf{H}})_O\mathbf{F}^H\end{aligned}$$

When there is channel estimation, the optimal filter obtained by the Eq. (13)can be updated as follows:

$$(\dot{\hat{A}}_D^{(i)})_{k,k} = \frac{\alpha(\dot{H})^*_{k,k} + \alpha(\Delta\dot{H})^*_{k,k}}{(\sigma_d^{(i-1)})^2 \sum_{l=0}^{N-1} |(\dot{H} + \Delta\dot{H})_{k,l}|^2 + \sigma_w^2} \quad (24)$$

$$\dot{\hat{G}}_D^{(i)} = \dot{\hat{A}}_D^{(i)}(\dot{H}_D^H + \Delta(\dot{H})_D^H) = \dot{\hat{A}}_D^{(i)}\dot{H}_D^H + \dot{\hat{A}}_D^{(i)}O(\dot{H})_D^H \quad (24)$$

$$\hat{g}_0^{(i)} = \frac{1}{N}\sum_{k=0}^{N-1}(\dot{\hat{G}}_D^{(i)})_{k,k} \quad (24)$$

In Eq.(8), the feedback matrix is the diagonal matrix and off-diagonal matrix, which are used to eliminate the ISI and ICI respectively, in which:

$$\dot{\hat{B}}_D^{(i)} = \dot{\hat{G}}_D^{(i)} - \hat{g}_0^{(i)}I \quad (24)$$

$$\dot{\hat{B}}_O^{(i)} = \dot{\hat{A}}_D^{(i)}\dot{\hat{H}}_O \quad (24)$$

Then, considered the channel estimation error, Eq.(8) can be written as:

$$\begin{aligned}z^{(i)} &= \underbrace{\hat{g}_0^{(i)}x}_{\text{Si}} + \underbrace{E^H F^H(\dot{\hat{G}}_D^{(i)} - \hat{g}_0^{(i)}I)FEd^{(i-1)}}_{\text{ISI}} \\ &+ \underbrace{E^H F^H \dot{\hat{A}}_D^{(i)}\dot{\hat{H}}_O FEd^{(i-1)}}_{\text{ICI}} + \underbrace{E^H F^H \dot{\hat{A}}_D^{(i)} Fw}_{\text{Noise}} \\ &+ \underbrace{E^H F^H \dot{\hat{A}}_D^{(i)}\Delta(\dot{H})_D FEx + E^H F^H \dot{\hat{A}}_D^{(i)}\Delta(\dot{H})_O FEx}_{\text{error}}\end{aligned}$$

Then calculated the signal power, noise power, the energy of the ISI and ICI, and then calculated the bit error rate[10]-[11].

4. SIMULATION RESULTS AND ANALYSIS

In the EST system, without the effect of the ISI, this paper studied the influence of channel estimation error for the system performance. The simulation process used single-track, the data length is $N = 512$, $f_d = 10$.

Simulation is shown in Fig. 7. When MSE=0.1, SNR = 16dB, in the first iteration BER=0.15. Because the channel estimation accuracy is very low, with the increase in the number of iterations, the performance of the system is getting worse.

Shown in Fig. 8, when MSE=0.0005, the channel estimation has been very precise, and with the increase of the number of iterations, the performance is getting better. When SNR=9dB, with the increase of iterations, after three iterations the bit error rate can be achieved 10^{-2} .

Without the effect of the ICI, this paper studied the influence of channel estimation error for the system performance. The simulation process using the multi-path channel, $L = 32$, the data length is $N = 512$, $f_d = 0.001$.

Contrast Fig. 7 with Fig. 9, Fig. 8 with Fig. 10, we can see under the influence of non-ISI and ICI, in the EST system, the channel estimation error MSE has a significant impact on the EST system performance.

Then this paper studied in doubly-selected channel, the influence of channel estimation on system performance. In which, $N = 512$, $f_d = 10$, and the channel multipath number is 32 drive sharp channel(32 paths Rayleigh channel).

As can be seen in Fig. 12, when it is the double-selected channel, when the channel estimation MSE=5×10^{-5}, with the increase in the number of iterations, the iterative performance of the system will get better, but is worse than the ideal channel estimation.

In the simulation above in Fig.7, 10 and 12, it can be seen that in the EST system, in the feedback process there should be the time domain impulse response in the channel, so the demand of the accuracy of channel estimation is very high, and the worse the channel conditions are, the higher the channel quality should be.

5. CONCLUSIONS

The iterative process of EST system needs to know the channel information, so in this paper, the impact of the EST system channel estimation accuracy on system performance was studied. The theoretical analysis and simulation results show that the EST system requires a higher accuracy of channel estimation, and channel conditions are harsher, the required channel estimation accuracy is higher.

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