Blind Parameters Estimation Algorithm Based on SC-FDE Cyclic Autocorrelation

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Abstract: This paper analyzes properties of Single-Carrier Frequency Domain Equilibrium (SC-FDE) signal’s cyclic autocorrelation section. The relationship between cyclic autocorrelation, useful signal length, cyclic prefix length is studied. The blind estimation algorithm is proposed for the useful signal length and cyclic prefix length without prior information. According to zero point symmetry property and the relationship between cyclic prefix length and spectral line, the area of spectral peak search is limited. So that the length of cyclic prefix and the number of cyclic prefix symbols are estimated. Simulation results show that the algorithm can improve the estimation accuracy and have better estimation performance at low signal-to-noise ratio.

Key words: Orthogonal Frequency Division Multiplexing; Single-Carrier Frequency Domain Equilibrium (SC-FDE); Single Carrier-Frequency Domain; Cyclic Autocorrelation; Parameter Estimation; Cyclic Prefix; Block Transmission

1. Introduction

In the wireless digital communication system, in order to overcome the multi-path fading of the signal, orthogonal frequency Division multiplexing (Orthogonal Frequency Division Multiplexing, OFDM) and single-carrier frequency domain equilibrium (SC-FDE) equalization technique is proposed [1]. OFDM has the advantages of high spectrum efficiency, strong anti-multipath fading ability and simple equilibrium, and has been widely used in wired and wireless communication, but it is sensitive to carrier synchronization and high peak power ratio [2-3]. For OFDM problems, 802.16a incorporates SC-FDE-based transmission solutions into the wireless man standard [4]. The SC-FDE can overcome the shortcomings of the OFDM system and obtain approximate performance with the OFDM system while maintaining the same complexity [5]. Therefore, studying the application of OFDM and SC-FDE in various environments and comparing the performance between them has become a hot topic in recent years.

At present, there are few literatures on SC-FDE modulation identification and parameter estimation. The literature [6-7] deduced the cyclic autocorrelation expressions of SC-FDE signals in Gaussian white noise channel and fading multipath channel, respectively. Modulation identification of CP-OFDM, SC-FDE and conventional single-carrier signals; literature [8] uses the relevant properties of SCFDE cyclic autocorrelation to estimate the number of cyclic prefix symbols and the number of useful signal symbols. In this paper, the parameter estimation problem of SC-FDE signal based on cyclic prefix is studied. A method based on cyclic autocorrelation is proposed. The cyclic prefix length and useful signal length are blindly estimated, and the known symbol rate and useful signal symbol are known. Under the condition of number, the number of cyclic prefix symbols is estimated, which is compared with the estimation accuracy of the literature [8] algorithm.
2. System Model
Like OFDM, SC-FDE is a block-based transmission system that uses a cyclic prefix as the guard interval [9]. Figure 1 is a schematic diagram of the SC-FDE transmission symbol. The continuous time baseband expression for the SC-FDE signal is as follows [6]:

\[
s(t) = \sum_{k=-\infty}^{\infty} \sum_{l=0}^{L_u-1} d_{k,l} g(t - b(T_u + T_{cp}) - lT)
\]

(1)

Figure 1. SC-FDE Symbol Structure

where \(d_{k,l}\) represents the k-th block, PSK or QAM modulated data transmitted on the l-th symbol, and is assumed to obey independent and identical distribution; \(L_u\) is the number of useful signal symbols; \(L_{cp}\) is the number of cyclic prefix symbols; \(T\) is the symbol length; \(T_u\) is the useful signal length; \(T_{cp}\) is the cyclic prefix length; \(g(t)\) is the transmit pulse shaping filter.

Figure 2. 3D-graph of SC-FDE cyclic autocorrelation amplitude

Figure 3. \(\alpha = 0\) time section
3. SC-FDE cycle autocorrelation feature and parameter estimation

In [6], the SC-FDE cyclic autocorrelation function expression is derived by using the signal reception model and the definition and correlation of the cyclic autocorrelation:

\[
c(\alpha, \tau)_{2,1} = \begin{cases}
  c_{s,2,1} T^{-1} \sum_{n=-\infty}^{\infty} g(n)g^*(n + \tau) e^{-j2\pi\alpha u} & \tau = 0, \alpha = m T^{-1} \\
  c_{s,2,1} [T_u + \tau_c]^{-1} \sum_{n=0}^{\infty} \sum_{n=-\infty}^{\infty} g(u - nT)g^*(u - nT \pm \tau_c T + \tau) e^{-j2\pi\alpha u} & \tau = \pm T_u, \alpha = n(T_u + \tau_c)\end{cases} 
\]

(2)

where \(c_{s,2,1}\) is the cumulative amount of the subcarrier modulation constellation of the signal. The following can be derived for the nature of the SC-FDE cyclic autocorrelation amplitude \(|c(\alpha, \tau)_{2,1}|\):

i. On the \(\tau\) section of \(\alpha = 0\), there is a line at the position of \(\tau = 0\) or \(\pm T_u\).

ii. On the cross section of \(\tau = \pm T_u\), the cyclic frequency is an integer multiple of the block length, and a discrete spectral line exists at \(\alpha = n(T_u + \tau_c)^{-1}\), \(n\) as an integer position.

According to (1) and property (2), the useful signal length and cyclic prefix length of the SC-FDE signal can be blindly estimated, the number of useful signal symbols, number of cyclic prefix symbols can be calculated., when the symbol rate is known:

Here (1) is used for signal length estimation, according to the property (1), since the line appears at the \(\tau = 0\) or \(\pm T_u\) on the \(\tau\) section, the useful signal length can be obtained by searching for the next largest value:

\[
\hat{T}_u = \text{arg max}_{\tau} \{|c(0, \tau)_{2,1}|, \tau \in (\tau_1, \tau_2)\}
\]

(3)

where \(\tau_1\) is greater than 0; \(\tau_2\) is greater than \(T_u\).

where (2) is used to estimate the cyclic prefix length, the second largest value of \(|c(\alpha, T_u)_{2,1}|\) may not appear on \(n = \pm 1\) due to factors such as limited signal length or noise. However, it can be seen from equation (2) that it decreases with \(|\alpha|\) in \(\alpha \in \left(-\frac{1}{2T}, \frac{1}{2T}\right)\), and the energy is mainly concentrated near \(\alpha = 0\), so the next largest value appears in \(\alpha = 0\). The probability nearby is the biggest. In this paper, the search interval is extended to \(n \in \{\pm 1, \pm 2, \pm 3\}\); in addition, the cyclic prefix length ranges from, greater than 0 and less than the useful signal length. The spectral line appears on the integer frequency of the reciprocal of the block length, and the search interval is limited to \(\pm (\alpha_1, \alpha_2)\), where \(\alpha_1 = \frac{1}{T_u}, \alpha_2 = \frac{2}{T_u}\) corresponding to the second largest peak Cycle frequency \(\hat{\alpha}\):

\[
\hat{\alpha} = \text{arg max}_{\alpha} \{|c(\alpha, T_u)_{2,1}|, \alpha \in (\pm \alpha_1, \alpha_2)\}
\]

(4)

where

\[
T_{cp} = \frac{n}{\hat{\alpha}} - T_u, n \in \{\pm 1, \pm 2, \pm 3\}
\]

(5)

when \(\hat{\alpha}\) is greater than 0, the corresponding \(T_{cp}\) value in \(n \in \{1, 2, 3\}\) is calculated in turn; when \(\hat{\alpha}\) is less than 0, the corresponding \(T_{cp}\) value in \(n \in \{-1, -2, -3\}\) is calculated in turn. The first value that is not 0 is the cyclic prefix length \(\hat{T}_{cp}\) to be...
iii. According to the relationship between $T_u$, $T_{cp}$, $L_u$, $L_{cp}$ and $T$, $\hat{L}_u = \text{round}\left(\frac{T_u}{T}\right)$ = $\text{round}\left(\frac{T_{cp}}{T}\right)$. $\hat{L}_u$ and $\hat{L}_{cp}$ can be calculated.

![Performance Estimation curve $\hat{L}_{cp}$ under Gaussian white noise channel](image)

**Figure 5.** Performance Estimation curve $\hat{L}_{cp}$ under Gaussian white noise channel

### 4. Simulation Results

Experiment 1: The cyclic autocorrelation properties of the SC-FDE signal were verified by simulation experiments. The single carrier modulation mode is selected from the set {BPSK, QPSK, 8PSK, 16PSK, 16QAM, 64QAM}, the number of useful symbols is $L_u = 32$, the number of cyclic prefix symbols is $L_{cp} = 8$, the symbol rate $R_s = 2kHz$, the sampling rate $f_s = 16 kHz$, carrier frequency $f_c = 4 kHz$. The proposed method is formed by rms raised cosine pulse, and the observation length is 50 [10]. The simulation results are shown in Figure 2 to Figure 4.

Figure 2 to Figure 4 is SC-FDE cyclic autocorrelation amplitudes $|c(\alpha, \tau)_{2,1}|$, normalized 3D map, $|c(0, \tau)_{2,1}|$ and $|c(\alpha, T_u)_{2,1}|$ cyclic view. It can be seen from Figure 2 that the characteristics of the SC-FDE cyclic autocorrelation are obvious; as can be seen from Figure 3, the delay value corresponding to second largest peak of $|c(0, \tau)_{2,1}|$ is length of useful signal. So, the search for next largest value can estimate useful signal length of SC-FDE; as can be seen from Figure 4, the line spacing is reciprocal of block length, and the signal can be estimated based on the relationship between cycle frequency, block length, and cyclic prefix length.

Experiment 2 discusses the effect of different SNR on number of cyclic prefix symbols $\hat{L}_{cp}$ estimation error under Gaussian white noise channel and compares it with estimated performance of [8]. The symbol rate and useful signal length are assumed here. Performance evaluation index is normalized root mean square error, and other simulation conditions are same as experiment 1. The simulation results are shown in Figure 5.

It can be seen from Figure 5 that the estimation error of $\hat{L}_{cp}$ decreases with increase of signal-to-noise ratio, and the error-free estimation can be realized when signal-to-noise ratio is ~6 dB. In addition, this simulation also proves that it is low. Under signal-to-noise ratio, the algorithm is more accurate than the literature [8].
Figure 6: Performance Estimated curve $\hat{T}_u$ under Gaussian white noise channel

Figure 7: Performance Estimation curve $\hat{T}_{cp}$ under Gaussian white noise channel

Figure 8: Performance Estimated curve changes for different cyclic prefix lengths $\hat{L}_u$
Figure 9: Performance Estimated curve changes for different cyclic prefix lengths $\hat{L}_{cp}$

Experiment 3 discusses the effects of different observation lengths of different signal-to-noise ratios under Gaussian white noise channels on estimation errors of length of useful signals $T_u$ and the length of cyclic prefix $T_{cp}$. The observation length is 50 blocks and 75 blocks, and the performance evaluation index is normalized mean square root error, and other simulation conditions are the same as experiment 1. The simulation results are shown in Figure 6 and Figure 7. Since the data of estimated signal cyclic autocorrelation is limited, the length of signal observation directly affects the estimation accuracy of cyclic autocorrelation, and also affects estimation accuracy of proposed algorithm. It can be seen from Figure 6 and Figure 7 that the improvement of observation length can bring about an improvement in estimated performance, which is consistent with the theory.

Experiment 4 discusses the effect of different cyclic prefix lengths of different signal-to-noise ratios under Gaussian white noise channel on the estimated error of useful symbol length $T_u$ and cyclic prefix length $T_{cp}$. The number of cyclic prefix symbols is 4, 8, 16, the performance evaluation index is normalized mean square root error, other simulation conditions such as experiment 1, and simulation results are shown in Figure 8, Figure 9.

When the useful signal length is same, longer the cyclic prefix length, the better the algorithm’s estimated performance. This is because the peak on $\alpha = 0, \tau = T_u$ is caused by cyclic prefix, and longer the cyclic prefix is, the larger the peak value is, which is more conducive to spectral peak search.

5. Conclusion

In this paper, the estimation of signal parameters is studied by using cyclic stationary properties of SC-FDE signal, and the blind estimation of SC-FDE signal parameters is realized. Compared with the existing algorithm, this algorithm improves estimation accuracy. Because the noise does not have cyclic stability, the algorithm can also have better estimation performance when the signal-to-noise ratio is low. In addition, through theoretical analysis and simulation research, it is concluded that the noise, signal observation length and cyclic prefix length will have an impact on the estimation error of parameters.

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