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Channel Equalization and Estimation for SC FDE systems

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Abstract: Single Carrier Frequency-Domain Equalization is one of the emerging technologies in broadband wireless systems. It requires reliable channel estimates to maintain an acceptable bit error rate performance. A two-dimensional MMSE channel estimation (2D-MMSE) algorithm along with blind channel equalization based on improved channel estimation is proposed in this paper. This method can ensure improved spectral efficiency, robustness and spectrally-efficient transmission in Single Carrier Frequency Domain Equalization systems over time- varying channels. The Unique Word (UW) is used as the cyclic prefix and this UW is not needed to delete in receiver section, which reduces the overhead of the system. The 2D-MMSE estimation is simplified as an MMSE interpolation in the frequency domain cascaded by an MMSE filter in the time domain. The noise variance is estimated by UW. Finally, the results show that the proposed algorithm has better performance than previous algorithms and is simple also.

Keywords: MMSE; LS estimation; two-dimensional channel estimation; UW; Single Carrier Frequency Domain Equalization (SC-FDE) system;

I. INTRODUCTION

The next generation wireless systems will use flexible combinations of frequency domain block transmission methods such as orthogonal frequency domain multiple access (OFDMA) and single carrier with frequency domain equalization (FDE). The single carrier may be preferred for the uplink of cellular systems because of its low peak to average power ratio (PAPR) and the resulting power amplifier efficiency in the user terminal. The ever increasing demand of high transmission rates in broadband wireless systems poses major design challenges especially due to the severe time dispersion occurring in the radio channel. Emergent radio systems often resort to block transmission techniques with frequency domain equalization (FDE) methods in order to sustain the envisioned data rates.

The channel estimation is an important section in the receiver in order to compensate for the loss of received data. Channel estimation based on pilot insertion method is used extensively. Pilot symbols are inserted in transmission data symbols with a certain interval at the transmitter. In all most all the cases, the UW should need to delete at the receiver side. But here the UW is used as the cyclic prefix and also as the pilot to reduce the overhead of system. SC equalizers are often designed for the perfect channel estimation case and, even if the performance of a channel estimator is known, namely the estimator' bias and error variance, this knowledge is not used by the equalizer.

To perform channel estimation without a corresponding loss in spectral efficiency, one can use blind techniques which allow the channel to be estimated while transmitting data that is not known to the receiver. In this paper we propose the use of two dimensional MMSE estimation technique along with the blind equalization.

II. SYSTEM DESCRIPTION

The binary information is being generated from uniformly distributed random integers with equal probability of either 0 or 1. The SC-FDE system uses the single-carrier modulation technique at the transmitter and the Cyclic Prefix (CP) is inserted into the mapped signals. Then the signals are sent to the multipath channel where it gets added with the noise. At the receiver, first the signal is converted into serial to parallel and then removes the cyclic prefix which is added at the transmitter. Then the FFT technique is used to transform the received signal from time domain into frequency domain. After that the channel estimation and the equalization algorithm in frequency domain is used to eliminate the influence of multipath channel. To transform the equalized signals from frequency domain back to time domain, IFFT technique is used and then the subsequent processing such as channel decoding and making decision are done. The basic block diagram of the SC-FDE system is shown in Fig. 1.

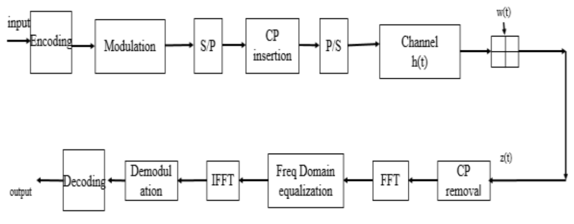

Fig.1 SC FDE

We denote the UW as $\{ul\}_{l=0}^{M-1}$, and the data block for frame as $\{dm\}_{m=0}^{N-1}$. The total length of a frame is N=L+M. So we can derive the transmitted symbols as Equation (1).

$$S=[s_0, K, s_{N-1}]^T=[d_0, K, d_{M-1}, u_0, K, u_{L-1}]^T \quad (1)$$

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The nth block of transmitted symbols is defined S[n, k] after through the channel and convert to frequency domain by FFT, and the nth block of received base-band signal is given by

$$R[n,k] = H[n,k]S[n,k] + W[n,k] \quad K = 0, K, N-1 \quad (2)$$

Where k is the numbers of K^{th} sub-channel, W[n.k] is the Additive White Gaussian Noise, H[n,k] is the channel impulse response. We take Equation (2) to be the transmission model for the SC-FDE system, so the sub-channel received signal in pilot position is

$$Y[n,k] = X[n,k]H[n,k] + W[n,k] \quad K = 0, K, N-1 \quad (3)$$

Where X[n,k] is the transmit signal in pilot position Y[n,k] is the received signal in pilot position, then it can be rewrite to matrix form as

$$Y[n] = X[n]H[n] + W[n] \quad (4)$$

III. LS CHANNEL ESTIMATION ALGORITHM

Least Square (LS) algorithm derives from curve fitting method of Mathematical Statistics, the frequency domain LS channel estimation can be done as follow:

$$\hat{H}_{LS}[n] = X^{-1}[n]Y[n] = X^{-1}[n](X[n]H[n] + W[n]) = H[n] + X^{-1}[n]W[n] \quad (5)$$

The LS algorithm is a simple channel estimation method and its complexity is very low. But it has a high Mean Square Error because of not using any knowledge of the statistics of the channels and the performance of algorithm can be easy influenced by noise.

I. MMSE CHANNEL ESTIMATION ALGORITHM

Making use of frequency domain correlation of the channel, we can get MMSE channel estimation. Let us assume the estimation value of kth sub-channel is $\hat{H}[n,k] = c_k^H[n]Y[n], c_k[n]$ is n dimensional column vector, $c_k^H[n]$ is the weighted value of Y[n]. Here uses the linear combinations of received signals to estimate channel state. The cost function of MMSE is given by

$$\text{e[n.k]} = E\{\| c_k^H[n]Y[n] - \hat{H}[n,k] \|^2\} \quad (6)$$

By the orthogonal principle,

$$E\{Y[n](c_k^H[n]Y[n] - \hat{H}[n,k])^*\} = 0$$

We can obtain MMSE channel estimation, which is given by,

$$\hat{H}_{MMSE}[n] = R_{HH}(R_{HH} + \sigma^2(X^H[n]X[n])^{-1})^{-1}\hat{H}_{LS}[n] \quad (7)$$

We can find that the result of LS make a Winer filtering is to be the MMSE. For the Winer filtering considering effect of noise, the MMSE estimation has good performance of anti- noise.

IV. 2 DIMENSIONAL MMSE AND BLIND EQUALIZATION

The two-dimensional MMSE (2D-MMSE) estimation can be simplified as an MMSE interpolation in the frequency domain cascaded by an MMSE filter in the time domain with the separation property of mobile wireless channels. The coarse estimation by LS algorithm is made in the system receiver at first, and the result of coarse estimation will be used for noise variance estimation. We use the knowledge of the coarse estimation and noise variance estimation to obtain 2D-MMSE. The estimation algorithm in this paper is suboptimum, but its performance is basically equivalent to the optimal 2-D MMSE estimation, and easy to realize. The two- dimensional parameters of pilot meet Nyquist sampling theorem, and the estimation value for nth block in kth sub- channel can be defined as follow:

$$\hat{H}(n,k) = \sum_{(\acute{n},\acute{k})\in\delta} w_{n,k}(\acute{n},\acute{k}) H_p(\acute{n},\acute{k})_{LS} \quad (8)$$

Hp is the gain of frequency domain channel estimation in pilot position, δ is the two-dimension position of the pilot. The mean square error of estimation is given as follow:

$$MSE = E[\,|H(n,k) - \hat{H}(n,k)|^2] \quad (9)$$

Minimizing MSE by orthogonal projection, we get

$$E\left[\left(H(n,k) - \hat{H}(n,k)\right) H_p^{"}(n^{"},k^{"})_{LS}\right] = 0 \quad (10)$$

Thus,

$$H_P(n',k')_{LS} = H_P(n',k') + W_P(n',k')_{LS} \quad (11)$$

Then we get the MMSE estimation of channel impulse response in frequency domain as follow:

$$\hat{H}_{MMSE}(n,k) = \sum_{(n',k'\in\delta)} w_{n,kMMSE}(n',k')\, H_p(\acute{n},\acute{k})_{LS} \quad (12)$$

The Equation (12) can be simplified as an MMSE interpolation in the frequency domain cascaded by an MMSE filter in the time domain, as follow

$$\hat{H}_{1dMMSE}(n) = R_{HH_P}\left(R_{H_PH_P} + \sigma_n^2 I\right)^{-1} \widehat{H_P}(n)_{LS} \quad (13)$$

$$\hat{H}_{2dMMSE}(n) = R'_{HH}(R'_{HH} + \sigma_k^2 I)^{-1} \hat{H}(K)_{1dMMSE} \quad (14)$$

In order to reduce the complexity of MMSE algorithm and the estimation accuracy is not loss, $(X^H[n]X[n])^{-1}$ can be rewritten as new form by the theory of diagonal matrix as

$$X = P\Delta_x P^{-1} \quad (15)$$

Channel equalization is the process of reducing amplitude, frequency and phase distortion in a channel with the intent of improving transmission performance. The basic operation of channel equalization is to inverse the effect of the channel.

V. SIMULATION RESULTS

This section discusses the results of the simulation that were performed based on the information and mathematics discussed in the Section III, IV & V respectively.

For the simulation of basic SC FDE system, we used the following parameters as shown in Table I.

Table 1: Simulation parameters for SC FE systems

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Parameters	Values
Data modulation	QPSK
System bandwidth	5 MHz
Doppler frequency	5 Hz
Transmitter IFFT size	512
UW size	64
Noise model	Independent AWGN
Number of iteration	10^5

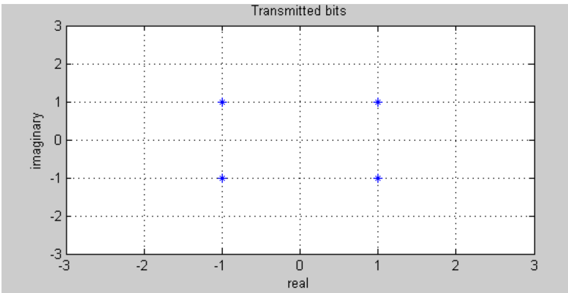

Fig. 2 : Transmitted bits

Fig. 2 shows the QPSK modulated transmitted bits constallation diagram. The received bits after passing through the channel before equalization is given in Fig. 3

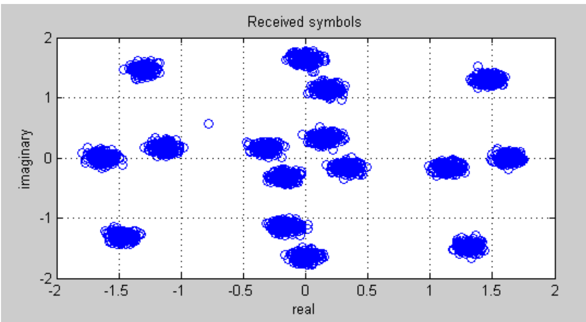

Fig. 3: Received symbols

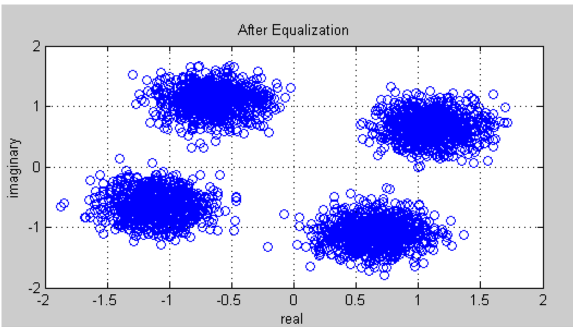

Fig. 4 : After equalization

Similarly if we want to make sure that frequency domain equalization is performed correctly, the constellation is plotted the equalized data and it shows that for QPSK the equalization was performed correctly as shown in the Fig. 4.

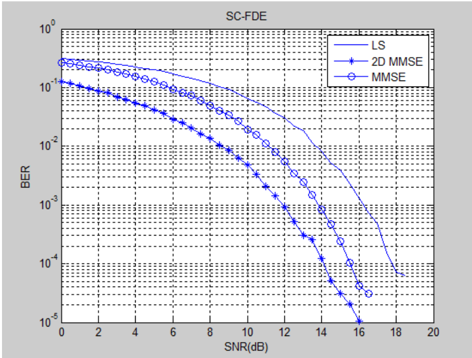

Fig. 5 : LS , MMSE & 2DMMSE estimation

Fig. 5 shows the BER performance of the LS, MMSE and 2D MMSE methods. 2D MMSE method has better result than the LS and MMSE methods.

VI. CONCLUSION

In this paper, we give a novel time-frequency two-dimensional MMSE channel estimation algorithm and blind equalization technique in order to defy frequency selective fading and improve the spectral efficiency in SC-FDE systems. This method simplify the 2D- MMSE in to two 1D-MMSE. By use the UW, the overhead of system can be reduced. The simulation results show that the performance 2D MMSE is better than traditional LS and MMSE estimation.

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