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Receiver Design for Single Carrier Equalization in Fading Domain

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ABSTRACT

Single carrier frequency division multiple access (SCFDMA) is one well-known scheme, which has recently become a preferred choice for uplink channels. Due to the usage of single carrier, the performance of SC-FDMA systems degrades in deep frequency selective fading channels. In this paper, we propose a structure of equalizer based on frequency domain decision feedback which could be used for multi-user SC-FDMA systems. Specific parameters of the equalizer are analyzed as well. This algorithm is applicable to various carrier allocations in multi-user systems such as localized allocation, distributed allocation, and frequency- hopping (FH) allocation. To reduce the complexity, it is not necessary to derive the inversion of matrix, which is required in the traditional decision feedback equalizer for single carrier frequency domain equalization (SC-FDE-DFE). We present an efficient single carrier frequency domain equalization for Advanced Television Systems Committee (ATSC) digital television receiver. The proposed scheme employs iterative cyclic prefix reconstruction (CPR) combined with block-overlapping process to reduce inter-carrier interference (ICI) component caused by the absence of cyclic prefix in multipath fading channel. In addition, trellis decoder aided iterative decision feedback frequency domain equalizer is derived to further mitigate inter-symbol interference (ISI). Finally, low-complex iterative frequency domain channel estimation is proposed to predict and track the time-varying multipath fading channel coefficients**.**

Keywords: *Decision feedback equalizer (DFE), frequency domain, SC-FDMA, uplink. ATSC, ATSC-M/H, single-carrier frequency domain equalization (SC-FDE), inter-symbol interference (ISI), cyclic prefix reconstruction (CPR).*

INTRODUCTION

Digital terrestrial television broadcasting (DTTB) has been a very popular broadcasting transmission system in the world. Recently, the time domain synchronous orthogonal frequency division multiplex (TDS-OFDM) technique was adopted as the Chinese national DTTB standard, named as Digital terrestrial Television Multimedia Broadcasting (DTMB) system. Instead of using cyclic-prefix (CP), TDS-OFDM uses a short pseudo-random noise (PN) sequence
as the guard interval, which can also be used for synchronization and channel estimation? As an important addition of the DTTB system, interactive uplink channel can provide more user oriented services and expanded operations. The
European Telecommunications Standards Institute (ETSI) has launched the Digital Video Broadcasting - Return Channel through Terrestrial (DVB-RCT) as the uplink channel. The Advanced Television Systems Committee (ATSC) digital television (DTV) standard is designed to transmit broadband, high quality multimedia information and data to consumers over terrestrial networks, while another standard Called ATSC-Mobile/Handheld (ATSC-M/H), which is completely backward compatible to ATSC, is also proposed for mobile environments recently. Though additional channel coding mechanisms are introduced in ATSC-M/H systems to overcome the problems under mobile conditions, either ATSC or ATSC-M/H systems have poor performances in the present of multipath channel, especially under the long echo spread channel and time-varying multipath fading channel. The conventional approach is to employ time domain equalizer (TDE) to mitigate inter-symbol interference (ISI) in multipath channels. Nevertheless, TDE suffers from several drawbacks including convergence speed in multipath channel, high computational complexity for coping with long echo spread channel in single frequency network, and the tracking capability over time-varying multipath fading channel.

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Doubly Selective Channel (DSC)

Channel is a medium through which data is too sent out or signal is to pass from the source to destination. Some time a change in frequency & wavelength of a wave is defined by user moving w.r.t source of wave or some time it is defined by multipath factor. So in both case it take both concept of frequency as well as time selective. So the channel whose response is both time selective as well as frequency selective is known as doubly selective channel.

Equalization in Carrier Transmission

Equalization is the process of adjusting the strength of number of frequencies within a signal. The basic & main use of equalization is in recording of sound and reproduction but still there are many other applications in electronics and telecommunications. The equipment used to achieve equalization is called an equalizer. These devices strengthen (boost) or weaken (cut) the energy of specific frequency bands. In telecommunications, equalizers are used to occupy the frequency response—for instance of a telephone line—flat from end-to-end. In sound reproduction, equalization has come to mean the adjustment of frequency responses for aesthetic reasons, which usually produces a response that is not flat.

Why Channel Estimation

There are various reasons to estimate the channel in which some are as below:-
It allows the receiver to calculate the impulse response. It is used to observe the behavior of the channel. Diversity techniques (for e.g. the IS-95 Rake receiver) utilize the channel estimate to implement a matched filter such that the receiver is optimally matched to the received signal instead of the transmitted one. One of the most important benefits of channel estimation is that it allows the implementation of coherent demodulation.

SYSTEM DESCRIPTION

In this paper, we design novel frequency domain decision feedback equalization (DFE) structure that has the united form for all three kinds of subcarrier distributions namely localized allocation, distributed allocation and frequency hopping (FH) allocation for multi-user SC-FDMA system in the first time. This strategy reduces the complexity by replacing the operation to get the inversion of matrix in SC-FDE-DFE with simple DFT transform. Simulations in multi-user uplink systems illustrate

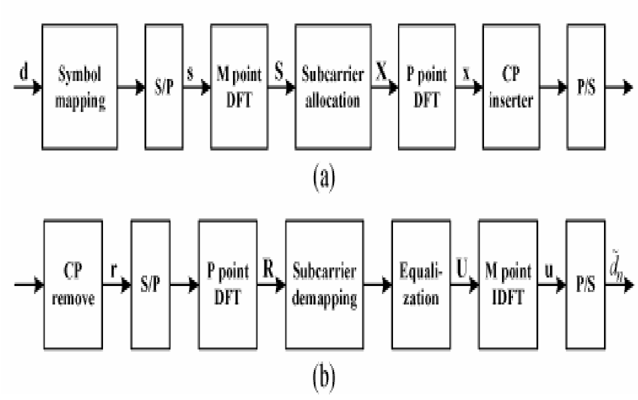

Fig. 1 Block diagram of SC-FDMA system.

that the performance of this approach is effective under various resource distribution methods. This paper is organized as follows. In Section II, both transmitter and receiver of SC-FDMA systems are described and analyzed according to three different resource allocation methods. The multi-user frequency domain DFE is proposed in Section III, and the parameters are defined based on minimum mean square error (MMSE) rule in both ideal feedback and actual case when decision feedback errors are considered. And in simulation results are presented to verify the benefits of the proposed algorithm.

The Proposed Iterative Frequency Domain Equalization

For ATSC receivers, equalizer design is essential to system performance in multipath channel. In this section we present IFDE with block-overlapping process and CPR for ATSC receivers. We assume that the channel state information (CSI) is known, and channel estimation will discuss in the next section. As shown in Fig. 2, the received ATSC data are divided into N-length blocks and then fed into IBI cancellation to remove IBI by subtracting the third term, where x_{m-1} can be obtained from trellis decoder output of previous block as shown as:-

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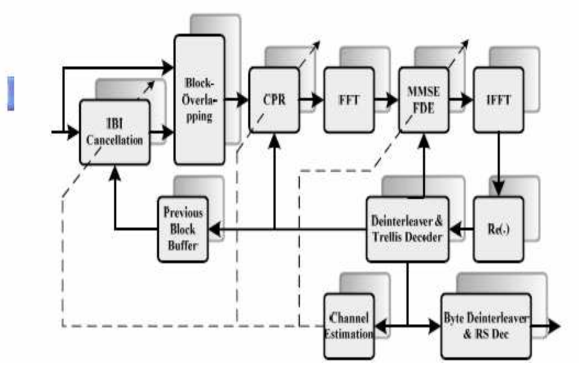

Fig. 2 Diagram of the proposed iterative decision feedback FDE with DDCE

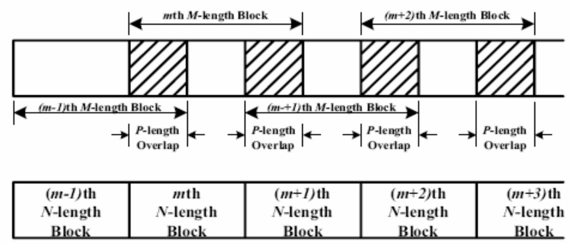

Fig. 3 Diagram of block partition with overlapping for the received data

In order to further eliminate ICI, iterative CPR scheme is utilized to recovery CP. The procedure of iterative CPR scheme with block-overlapping becomes:

1) Frequency domain *M*-length block data with overlapping data is fed into one-tap MMSE FDE to eliminate the effect of multipath channel.

2) After IFFT process, the real part of the time domain data are fed into the denier leaver and trellis decoder to reduce the error propagation, as shown in Fig. 2.

3) According to the *N*-length output of trellis decoder, ICI component ˆ(*i*) *m Qx* is calculated for the *m*th block data *m r*p , and then CP reconstruction can be achieved by adding ˆ(*i*) *m Qx* .

4) After CP recovery, decision feedback MMSE FDE is employed to further mitigate ISI of the *N*-length block data.

5) Repeat Step 2)-4) until symbol error rate (SER) approach the system requirement.

Complexity Analysis

In this section, we will analyze the computational complexity of the proposed iterative decision feedback FDE (IDF-FDE) and frequency domain DDCE. It will shows the complexity comparison of the symbol detection algorithms including the proposed IDF-FDE, iterative FDE with linear equalization (IL-FDE) and the conventional real-valued TDE. The numbers of real multiplications required per iteration to yield *N*-length time domain symbols are reported. For fair comparison, it is assumed that the conventional TDE employs *N*-tap filters with respect to *N* length block process in FDE. Note that for the first iteration of IDF-FDE, due to the process of overlapping data, the required

Real multiplications is $4M\log2(M)+4N\log2(N)+4M$. From this conclusion it can be seen that the implementation of equalization in IDF-FDE scheme requires much lower complexity than TDE, and the similar complexity with IL-FDE. For the coefficients calculation, TDE still requires the highest computational complexity, while the proposed IDF-FDE needs several resources to calculate the correlation and feedback coefficients compared with IL-FDE.

For the CE algorithms, others reports the numbers of real multiplications used in the proposed DDCE, frequency domain LMS channel estimation (LMS-CE) and AFDCE. In this comparison, the *N*-length channel coefficients are estimated, and *W*-length taps Wiener filter is used in DDCE. In AFDCE, *M* denotes AR-model order. AFDCE requires the highest computational complexity, while compared with LMS-CE, DDCE employs D filter to improve the accuracy of CFR and by decreasing tap number of filters the computational complexity of DDCE can be reduced.

Simulation Results

Based on the above analyses, simulations are performed to evaluate the performance of the proposed frequency domain decision feedback equalization algorithms in multiuser SC-FDMA systems. The number of subcarriers is and the length of CP is P/8=128. The number of users in this system is K=8 ,then P=128 subcarriers can be allocated to each user. Quaternary Phase Shift Key (QPSK) constellation is selected and the comparison is conducted between coded and non-coded systems. Figs. 4 and 5 show the performance of the algorithm under different subcarrier allocations. Since the channel conditions for every user are varying, 6-path channel model is chosen where the delay of the 6 paths distributes uniformly between 0 to 127 taps and the path power spectrum has exponential distribution. During the simulations, channel estimation and synchronization are assumed ideal. The bit error rate (BER) performance of non-coded system is shown in Fig. 4. From Fig. 4 it is clear that for the three subcarrier allocation methods, the performance of the

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non-ideal FD-DFE is around 3 dB better than FD-LE at BER=1.0e-3 .When localized or distributed allocation scheme is adopted, the performance difference between non-ideal FD-DFE and ideal FD-DFE is about 1.0 dB at BER=1.0e-3 . However in the FH allocation, this loss is much lower compared with the other allocation methods due to the random subcarrier allocation. For each equalizer, the performance of FH allocation is better than that of the localized and distributed allocation. Fig. 4 shows BER performances of the coded SC-FDMA system under various equalization schemes. A 1/2-rate convolution encode (133,171) is used at the transmitter and a soft-decision Viterbi decoder is used in the receiver. The same curves are provided in this figure.

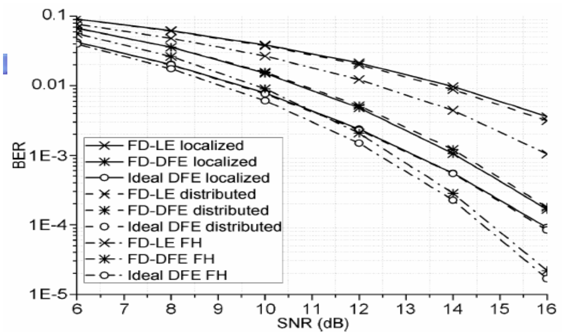

Fig. 4. BER performance of non-coded system.

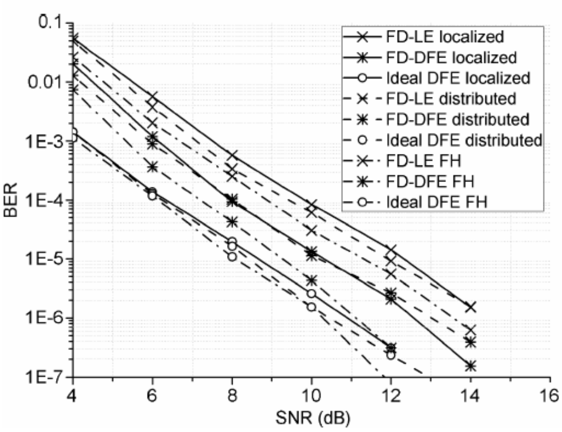

Fig. 5 BER performance of coded system.

In order to investigate the performance of the proposed scheme under mobile environment, TU6 channels with 10Hz and 70Hz Doppler shift, which are realized with Jacks' model, are utilized in the simulation. It give the SER comparison versus SNR for TU6 channel with 10Hz and 70Hz Doppler shift respectively. From Fig.4 and Fig 5, it can be seen that the conventional TDE and IDF-FDE with LMS-CE cannot track time-varying Rayleigh fading channel, which result in poor performance.

CONCLUSION

In this paper, an efficient and low-complex IDF-FDE with DDCE is proposed for ATSC receivers. The proposed scheme employs iterative CPR with block-overlapping to mitigate ICI component. Meanwhile, a trellis decoder aided iterative decision feedback FDE is utilized to further eliminate the effect of multipath channel. Finally, low-complex adaptive frequency domain DDCE is proposed to predict and track the time-varying multipath fading channel coefficient. The computer simulation results show that with respect to the previous TDE and FDE, the proposed IDF-FDE with DDCE can reduce the error floor at low SNR in static multipath channel and has a significant performance improvement in the time-varying multipath channel. A frequency domain decision feedback equalizer suitable for multi-user SC-FDMA systems has been proposed. Based on the MMSE criterion, the forward and feedback filter coefficients are derived theoretically. The parameters for ideal feedback and actual case with decision errors are considered respectively. The proposed FD-DFE can be used for the three subcarrier allocation methods with the same DFE structure and parameter calculation method. Compared with traditional SC-FDE-DFE, since there is no matrix inversion and solving equations in this scheme, the computation complexity is low. Simulations show that the proposed FD-DFE can improve the performance of the multi-user SC-FDMA system significantly when channel is in deep frequency selective fading. This FD-DFE can be used in the broadcasting uplink channel combined with SC-FDMA scheme.

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