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Review of Single Carrier FDE Performance Enhancement Techniques

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***Abstract*—Single-carrier (SC) block transmission with cyclic prefix (CP) has several advantages that has been seen in this paper. The aim of this paper to improved the performance of SC-FDE multi-antenna SC-FDE by using cyclic-delay diversity (CDD) and Alamouti signaling.**

Analysis characterizes the diversity, it shows that diversity depends on the antenna configuration, channel memory, data block length and data transmission rate. Full diversity is available to both CDD and Alamouti signaling below a certain rate threshold, while at higher rates their diversity diminishes.

This paper shows that at high data rates the Alamouti signaling provides twice the diversity of SISO SC-FDE, while CDD diversity degenerates to the diversity of the SISO SC-FDE.

Index Terms— **SCFDE, CDD, Alamouti signaling**

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has many advantages such as bandwidth efficiency, spectral efficiency better than FDM (frequency division multiplexing), high data rate transmission, etc. Because of this advantages it has been considered as a strong candidate for next generation wireless communication systems. But OFDM systems suffer from larger PAPR. SCFDE gives better performance in multipath fading channels and lower peak to average power ratio (PAPR) than OFDM system

In this paper, either cyclic delay diversity (CDD) or Alamouti signaling are used to improved the performance of SC-FDE, which characterize the diversity as a function of transmission-block length, data rate, channel memory and number of antennas.

If data rates is high, the CDD diversity degenerates to the diversity of the SISO SC-FDE, while Alamouti signaling provides twice the diversity of SISO SCFDE. If diversity is reduced due to a certain rate threshold, it can be recovered by increasing the FFT block length.

Cyclic delay diversity (CDD) is more widely used for single carrier and multicarrier applications. Because CDD can be applied to any number of transmit antennas without any rate loss or change in the receiver structure [3]–[16]. In this paper, we show that linear MMSE receivers can achieve the maximal diversity for that purpose equalizer and the cyclic delay are properly designed.

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II. SINGLE CARRIER FREQUENCY DOMAIN EQUALISATION (SCFDE)

In broadband wireless communications, highly dispersive channels is improved by Single-carrier modulation technique using frequency domain equalization (SC-FDE)[1].

Single carrier frequency domain equalization (SC-FDE) transmission performs single carrier modulation at the transmitter and frequency domain equalization at the receiver. SC-FDE technique is similar to OFDM, equalization is performed in the frequency domain, but SCFDE gives low PAPR and this is important in the uplink communications, where transmit power efficiency and manufacturing cost are greatly benefits the mobile terminal,

By combining single-carrier (SC) modulation with frequency domain equalization (FDE) ISI has beem mitigated. In recent years, for the next-generation broadband wireless networks, SC-FDE has become a powerful and an attractive link access method.

Transmit diversity technique such as antenna delay diversity, which can take the form of time delay, cyclic delay and phase delay [2], [3] are used for single carrier and multicarrier systems. From that, cyclic delay diversity (CDD) is more widely adopted for single carrier and multicarrier applications because CDD can be applied to any number of transmit antennas without any rate loss or change in the receiver structure [3]–[4].

Below Figure 1 shows the Single-carrier and multicarrier MISO system with transmitter sided CDD scheme and proposed MMSE receiver. In that, input data sequence is given to the single carrier or multicarrier modulation system.

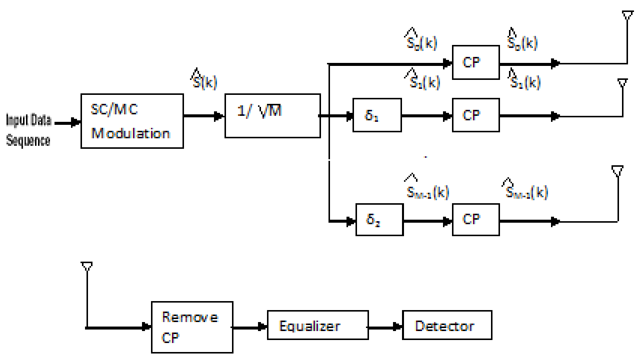

Fig.1.Single-carrier and multicarrier MISO system with transmitter sided CDD scheme and proposed MMSE receiver

Where a MISO system with *M* transmit antennas and a block fading channel are model. After modulation cyclic prefix is added. In that channel remains unchanged during the block transmission. Figure 1 shows that input data sequence is transmitted by using multiple antennas and input data is received at receiver side using a single antenna.

At receiver, first step is to remove cyclic prefix and then that data is given to equalizer. Equalizer predict if there is any interference is present or not, if it is present then it automatically remove that interference. Then this equalizer output is passed through the detector to get the original input data sequence.

III. TECHNIQUES TO ACHIEVE MAXIMUM DIVERSITY GAIN

A. SC-FDE

In frequency selective channels, the diversity gain achieved by single-carrier frequency-domain equalizers (SC-FDE)[7]. SC-FDE is similar with OFDM, but SC-FDE decisions are made in the time domain, while OFDM decisions are made in the frequency domain.

In particular SC-FDE is not susceptible to the peak-to-average ratio (PAR) problem. SC-FDE has been used to reduced sensitivity to carrier frequency errors, and confines the frequency-domain processing to the receiver.

B. MIMO system

A brief survey of related literature is as follows. We know that SC-FDE is a single antenna(SISO) system which displays a diversity having a function of transmission block length and data rate[5]. SC-FDE has been analyzed by multi-stream MIMO system. In that diversity multiplexing tradeoff is obtained[6].

C. Uncoded OFDM

When the frequency selective channel has nulls on the DFT grid, *Uncoded* OFDM is vulnerable to weak symbol detection and because of that, the full diversity of the inter-symbol interference (ISI) channel may not be capture by uncoded OFDM. For that reason various coded- OFDM schemes have been considered to mitigate this effect.

D. Complex field coded (CFC)-OFDM

In this section, full diversity has been achieve by C*omplex field coded (CFC)*-OFDM which introduced without error-control coding, where it is shown to achieve full diversity with maximum likelihood (ML) detection. CFC-OFDM achieves its diversity similar to signal space diversity by sending linear combinations of the uncoded symbols to each subcarrier therefore, by deploying *ML detection*, they also achieve full diversity.

E. Linearly Precoded OFDM

Orthogonal Frequency Division Multiplexing (OFDM) facilitates equalization by converting a dispersive channel into parallel subchannels [8]. Maximum Multipath Diversity With Linear Equalization in Precoded OFDM Systems proposed paper in[5]. Tepedelenlioglu [9] showed that maximum multipath diversity is achieved by linearly precoded OFDM systems. Transmitted symbols can be decoded by Complex maximum-likelihood (ML) method and take advantage of the full multipath diversity that the channel has to offer.

F. ZF equalizer

ZF equalizer is used to achieve full diversity in the zero-padded SC system with linear equalization was analyzed in [10]. In this survey, the zero-padded transmissions or precoded OFDM is studied for the performance of linear equalizers for block transmission systems.

G. Coded OFDM (COFDM) with ML decoding

Coded OFDM (COFDM) schemes were considered in [12], where ML decoding has been used to achieves the maximum channel diversity. It was shown that COFDM in [12] are having a zero-padded and cyclic-prefix single-carrier system which achieve the maximum diversity with ML.

H. Precoded OFDM

Precoded OFDM systems and zero-padded block transmissions used the diversity properties of linear equalizers for block transmission systems. Muquet *et al.* [11] compared the performance of ZP-OFDM and CPOFDM.

In that, both systems Zero padding (ZP) and cyclic prefix (CP) are compared in terms of transmitter nonlinearities and required power back off. Both systems are tested for channel estimation and tracking capabilities, two equalizers are derived for bit error rate (BER) performance for extra savings in complexity.

I. Alamouti Signaling

The Alamouti method of space-time signaling is also a transmit diversity scheme. Unlike the CDD system, Alamouti signaling preserves the transmit diversity and thus provides a larger diversity gain compared with the CDD scheme above a rate threshold.

J. MMSE SC-FDE

MMSE SC-FDE can achieve full diversity for certain values of block length and operating rate R b/s/Hz[5]. Theoretical Reliability of MMSE Linear Diversity is explained by combining Rayleigh-Fading Additive Interference Channels[13]. In this, the exact distribution of the output signal to interference ratio (SINR) has been derived by using linear MMSE diversity combiner which operated in a Rayleigh-fading additive interference channel.

K. MULTI-ANTENNA SCHEMES FOR SCFDE

Multiple antennas are used to improve the performance of wireless systems. A system with multiple transmit and receive antennas (MIMO channel) is widely adopted because the spectral efficiency is much higher than that of the conventional single antenna channels. Research on multiple antenna channels which includes the study of channel capacity [14], [15] and the design of communication schemes [16], demonstrates a great improvement of performance.

Diversity has been increase by using multiple antennas. Each pair of transmit and receive antennas provides a signal path from the transmitter to the receiver. Transmitter sends the signals that carry the same information through different paths, multiple independently faded replicas of the data symbol can be obtained at the receiver end; hence more reliable reception is achieved.

This paper analyzes the single-carrier frequency domain equalizer (SC-FDE) for cyclic delay diversity (CDD) and Alamouti signaling. We improved the diversity for both schemes at all spectral efficiencies. In the process, threshold rate is obtained as a function of data-block length, channel memory, and number of antennas below which the full diversity is achieved. This paper shows that at high data rates the CDD achieve the diversity which is same as that of the diversity of the SISO SCFDE, while Alamouti signaling provides twice the diversity of SISO SC-FDE.

IV. CONCLUSION

This paper analyzes the single-carrier frequency domain equalizer (SC-FDE) for cyclic delay diversity (CDD) as well as Alamouti signaling. We achieved the full diversity for both schemes at all spectral efficiencies. In this, threshold rate is obtained by used of number of multiple antennas below which the full diversity is achieved. If it is possible to increased diversity in SCFDE via MIMO then this method will be convenient for High speed aerial vehicle communication.

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