Joint Co-channel Interference Cancellation and Channel Shortening with Space-Time Processing

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Abstract

The mitigation of co-channel interference (CCI) and inter-symbol interference (ISI) has been a major area of focus of researchers in wireless communications. An approach of interest separates CCI cancellation and ISI equalization in a slow frequency-selective Rayleigh fading channel into two stages. A space-time filter reduces the CCI, followed by a Viterbi equalizer for ISI equalization. The complexity of the Viterbi equalizer can be reduced by using a filter for channel shortening. I am investigating various ways to design a space-time finite-impulse response (FIR) filter which would perform joint CCI cancellation and channel shortening, while maximizing a signal-to-interference-plus-noise-like objective function.

1 Introduction

Co-channel interference (CCI) is a problem inherent to all cellular wireless communication systems. It arises due to the basic frequency reuse scheme of cellular systems. This means that a number of cells in a given coverage area use the same set of frequencies. The interference between the signals from these cells is termed as co-channel interference. Inter-symbol interference (ISI) is a characteristic problem of frequency-selective fading channels. The multiple versions of the transmitted waveform, which travel over multiple reflective paths, arrive at slightly different times from the others. This leads to a spreading of the symbol in time (time dispersion). Some of these components arrive during the next symbol duration, causing ISI (commonly termed as channel-induced ISI to differentiate it from the ISI caused by filters). [1] and [2] are comprehensive tutorials on the characterization and mitigation of fading and its effects in mobile Rayleigh fading channels.

The mitigation of both CCI and ISI has been a major concern of researchers in wireless communications. The goal has been to demodulate the data symbols while maximizing the signal-to-interference-plus-noise ratio (SINR), using equalizers of acceptable complexity.

The area demands a trade-off between the SINR and the complexity of the receiver and the optimum solution still remains an open problem.

2 Background

Various approaches to deal with CCI and ISI equalization have been suggested over the years. A multi-user-maximum-likelihood-sequence-estimator (MLSE) [3] is the optimal solution for maximizing the signal-to-interference ratio (SIR). But it requires the channel information of the interferer along with that of the desired user and this can not be easily estimated.

While there have been subsequent sub-optimal solutions to the problem, one approach of interest has been presented by the authors in [4]. This paper is discussed in Section 3. It is basically a single user two-stage approach for separate CCI reduction and ISI equalization in a slow frequency-selective Rayleigh fading channel. A space-time filter is used for CCI cancellation in the first stage. A Viterbi equalizer performs ISI equalization in the second stage. The complexity of this equalizer is a function of the number of states in it, which in turn, is an exponential function of the length of the channel impulse response. In [4], the complexity of the equalizer is not addressed.

A helpful reference for equalizer design for cellular mobile radio channels is [5]. Here, the authors have presented a comprehensive theory for optimum diversity combining and equalization in digital data transmission over frequency-selective Rayleigh fading channels. Various combiner-equalizers, which minimize the mean-squared error, are determined.

A unified analysis of optimum space-time equalizers with linear filters on each antenna branch, followed by a decision feedback equalizer (DFE) or MLSE is provided in [6].

Channel shortening for discrete multi-tone (DMT) transceivers is a much-researched area and [7] explores various methods for determining the coefficients of a time-domain channel shortening filter. Various relevant references for channel shortening are explored in Section 4.

Channel memory truncation for reducing the complexity of the Viterbi decoder was suggested as early as 1973 in [8], [9] and 1978 in [10]. The different approaches to this problem are discussed and compared in Section 5.

3 CCI/ISI Reduction with Space-Time Processing

This paper presents a hybrid approach for separate CCI reduction and ISI equalization in a slow Rayleigh fading channel. The signal is received by an array of antennas, followed by a space-time filter as shown in Figure 1. The filter is designed to maximize the signal-to-interference-plus-noise ratio (SINR) by jointly optimizing the filters weight vector and the modified channel vector (effective channel impulse response). This channel vector is used by a Viterbi equalizer, that forms the next stage, to demodulate the data symbols with ISI equalization.

The space-time filter has the effect of temporally coloring the disturbance. The Viterbi algorithm performs optimally only when the input noise is white. So, a temporal whitening filter is included in the design of the Viterbi equalizer to take care of non-Gaussian residual CCI and noise.

The authors do not rely on the channel information of CCI. A training sequence is used by the joint optimizer to provide an eigenvector solution for the space-time filter and the Viterbi equalizer. As discussed in Section 2, the number of receiver operations per data symbol is an exponential function of the length of the channel impulse response, resulting in unacceptably large receiver complexity for a length greater than 4. The complexity can be reduced by using a channel shortening equalizer. This issue is not addressed in the paper.

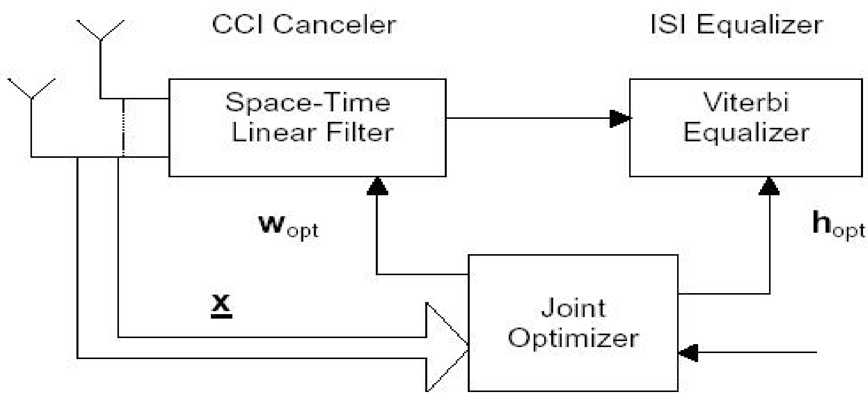

Figure 1: The block diagram of the hybrid approach. [4]

4 Channel Shortening

The design of time-domain equalizers (TEQ) for channel shortening for discrete multi-tone transceivers has received extensive attention in the literature. A key reference in the area is [7]. In this paper, the authors have developed various computationally efficient algorithms for reducing the effective length of the channel for DMT transceivers using a short time-domain FIR filter.

In the first method, the algorithm utilizes eigenvectors and eigenvalues to generate the coefficients of an optimal shortening filter, given the original impulse response, the desired length of the effective channel (ν) and the filter length. The objective function, which is maximized by this algorithm, is the shortening-signal-to-noise-ratio (SSNR), which is the ratio of the energy of the largest ν consecutive samples to the energy in the remaining samples. The energy in these remaining samples is minimized while the energy inside the window of interest is constrained to be unity.

This method can be incorporated into the approach in [4] to build an objective function that includes both the SINR and the SSNR. The solution to this joint optimization problem would give the coefficients of a space-time filter that can jointly tackle CCI reduction and channel shortening.

The design of MIMO equalizers for channel shortening has been investigated in recent literature [11] and [12]. In [11], the author derives finite length MIMO channel shortening equalizers using a minimum-mean-squared-error (MMSE) criterion (as opposed to the maximum SSNR approach of [7]). The designed equalizers also perform noise whitening and multi-channel matched filtering. [12] presents another approach to the same problem. The authors build up an objective function that includes a trade-off parameter between maximizing the SINR and the SSNR. An eigenvector solution is obtained for the optimum equalizer coefficients and the effective MIMO channel.

The solution in [12] requires knowledge of the autocorrelation sequence of the noise vector. In addition, there is no separate treatment of CCI and ISI.

5 Channel Shortening for MLSE

The specific problem of channel memory truncation for MLSE, implemented by the Viterbi algorithm, was addressed in a series on papers way back in the 1970's. In all these papers, the pre-equalizer was designed to minimize the noise variance seen by the Viterbi equalizer. They differed in the choice of the desired impulse response (DIR) of the channel that was used for MLSE by the Viterbi algorithm.

In [8], the DIR is chosen to be a truncated version of the original channel impulse response. In [9], Falconer and Magee used a unit energy constraint for the fixed length DIR to minimize the noise variance. In other words, they used the MMSE method for channel shortening.

The pre-equalizer colors the noise and no attempt is made to restrict the correlation of the noise in either of these papers. In [10], the author, Beare, defines an effective signal-to-noise ratio (SNR) that includes the effects of noise correlation on the Viterbi algorithm. He then proceeds to show that this effective SNR is maximized by choosing a DIR whose power spectrum closely matches that of the original response in the mean square error (MSE) sense.

In this paper, a comparison of the three choices of the DIR has been made on the basis of the effective SNR. This is shown in Figure 3. The Falconer and Magee channel model is used (Figure 2).

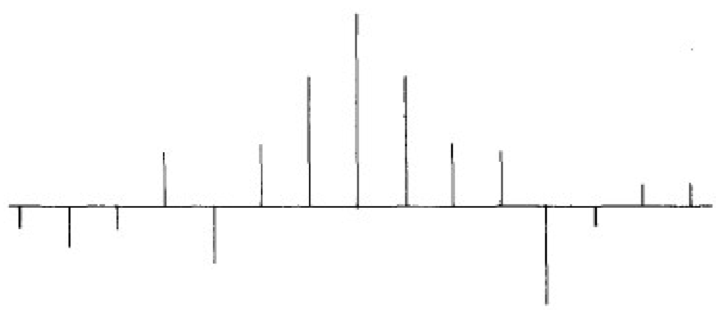

Figure 2: Falconer and Magee discrete time channel A. [9]

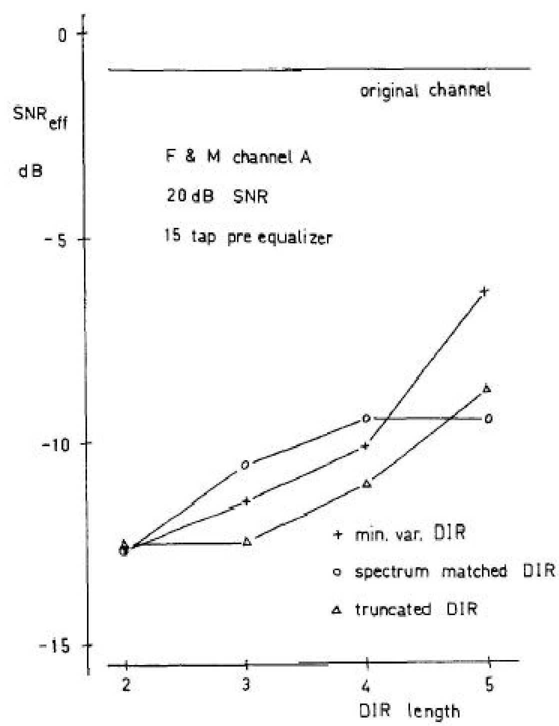

Figure 3: Effective SNR for various DIR schemes. [10]

It is observed that for DIRs of up to length 4, the Beare scheme achieves the best results. In practice, a DIR of length 2 or 3 is usually all that is feasible because of the increase in the complexity of the Viterbi detector.

6 Relevant Simulation Results

The approach that is closest to my proposed idea is the one undertaken in [12]. The simulation results are presented in Figures 4 and 5. Two different metrics have been used to compare the method with the MMSE method of [11], namely, the energy compaction ratio, which is an indication of the channel shortening achieved and the overall SNR. α is the trade-off parameter between the SINR and the SSNR, mentioned in Section 4.

I will be comparing the performance of my method with the simulation results of this paper.

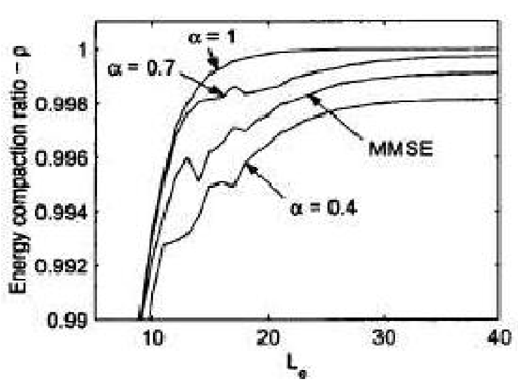

Figure 4: Energy compaction as a function of equalizer length. [12]

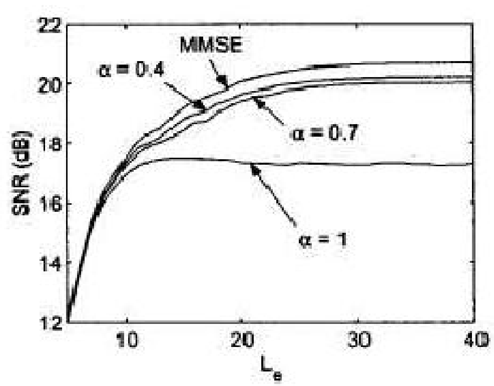

Figure 5: Overall SNR as a function of equalizer length. [12]

7 Conclusion

CCI reduction and ISI equalization for cellular mobile radio channels, characterized by slow Rayleigh fading channels, has been an active area of research. In [2], the authors introduced a novel two-stage approach to this problem wherein they designed a space-time filter for CCI cancellation, which was followed by a Viterbi equalizer for ISI mitigation. Shortening the effective channel impulse response can reduce the complexity of the Viterbi equalizer. Given a fixed number of stages in the Viterbi equalizer, space-time filters can be designed to jointly tackle CCI reduction and the appropriate channel shortening while maximizing the SINR. The multiple antennas in the receiver bring this problem into the realm of multi-dimensional digital signal processing. I plan to investigate this joint optimization problem and come up with various ways to design the filter. I will be exploring the issue in the time-domain for the single-input-multiple-output (SIMO) channel where the space-time filter will be multi-input-single-output. The simulations would be performed using the MATLAB Communications and Signal Processing toolboxes.

If time permits, I will try to extend the same to the frequency domain to deal with multiple-input-multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM) systems.

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