A Robust Turbo Coder Design for Channel Maximization in MIMO OFDM with Cognitive Radio System

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Abstract—In this paper, we study the turbo coder design problem for MIMO-OFDM systems with insufficient cyclic prefix (CP) using statistical channel state information (CSI) at the transmitter. In our previously proposed channel independent turbo coder scheme, an interference nulling based turbo coder structure is studied, which can assist to either cancel inter-block interference (IBI) or separate the subspace engaged by IBI from the subspace used for information symbols. In this work, we consider a robust turbo coder design which combines statistical CSI at the transmitter and the interference nulling based turbo coder arrangement to gain a better performance compared to the channel independent turbo coder scheme. OFDM (Orthogonal Frequency Division Multiplexing) has been chosen as the air interface technique for LTE (Long Term Evolution) standard. However, OFDM system is sensitive to synchronization errors generated by multipath delay, Doppler shift and oscillator instability. In this paper, we address the synchronization problem between the transmitter and the receiver is done. Time-domain synchronous orthogonal frequency division multiplexing (OFDM) has advantages in spectral efficiency and synchronization. However, its iterative interference cancellation algorithm will suffer from performance loss especially under severely fading channels with long delays and has difficulty supporting high-order modulations like 256 QAM, which may not accommodate the emerging ultra-high definition television service.

Key words: Orthogonal Frequency Division Multiplexing (OFDM), Long Term Evolution, Channel State Information, Cyclic Prefix

I. INTRODUCTION

Ever-Increasing data rate demands are the motive force for wireless research. In the past decades, it has been witnessed that there are a lot of successes in wireless research and technique homogeny. There is no doubt that two of the most representative technologies are Orthogonal Frequency Division Multiplexing (OFDM) and Multiple-Input Multiple-Output (MIMO). In order to gain the benefits of both MIMO and OFDM, MIMO-OFDM is a promising technology to support the wireless communications with high data rate requirements[1]. Along with the evolution of wireless systems, MIMO-OFDM becomes to be a key ingredient of wireless ports. In order to achieve the great possible performance improvement, the research on MIMO-OFDM has attracted lots of attention and there exists a rich body of literature work. Due to space limitation, a detailed list of the excellent papers on this topic is not given here[3]. In the existing work, in a common sense, exploiting channel state information (CSI) can enhance the MIMO-OFDM system performance greatly[4]. Unfortunately imperfect CSI will degrade the system performance. In order to reduce the negative effect of channel errors and simultaneously enhance the system performance, robust designs are of great importance[6]. In this paper, we investigate robust linear transceiver designs for MIMO-OFDM systems with numerical channel uncertainties. In our work, only channel estimation errors are considered[8]. For this class of channel errors, both transmitter and receiver have the same CSI. Inspired by the fact that for point-to-point MIMO systems various performance metrics for linear transceiver designs can be combined to a weighted MSE minimization problem,[11] in this paper our attention is focused on the objective function of weighted MSE minimization. This paper, we study the turbo coder design problem for MIMO-OFDM systems with insufficient cyclic prefix (CP) using statistical channel state information (CSI) at the transmitter. In this work, we consider a robust turbo coder design which combines statistical CSI at the transmitter and the interference nulling based turbo coder structure to gain a better performance compared to the channel independent turbo coder scheme. In this paper, a robust linear turbo coder design is proposed based on the statistical CSI at the transmitter for a MIMO OFDM system with insufficient CP. To clearly compare this work and our previous work[15], the following major distinctions should be noticed: The work in is mainly to prove the feasibility of a turbo coder that is able to separate IBI into a disjoint subspace with the minimum dimension from the signal subspace, but the simple turbo coder example does not guarantee a good performance. In the present work, one of the main goals is to enhance the performance of our turbo coder. The channel independent turbo coding scheme in indicates that no CSI is literally needed for the turbo coding. However, in this current turbo coding scheme, channel statistics serves as a necessity to improve the performance.

Specifically, we include the statistical optimization technique in our linear turbo coding scheme in, which can separate and eliminate IBI when used in combination with a projection operation at the receiver. The turbo coder fulfills the role of the minimum maximal MSE turbo coder when MMSE equalization is adopted for signal detection. For the explicitness of this paper, the main distinctive contributions are highlighted in the following:

- The optimization over all the spatial and frequency dimensions easily takes the inter carrier interference into account, which greatly simplifies our problem formulation and solution. The optimized turbo coding scheme for MIMO-OFDM is designed in a carrier cooperative way. This scheme can potentially gain a better performance than the carrier non cooperative scheme.
- At the transmitter only the covariance matrix of the equivalent channel matrix is required as the
statistical CSI. The cost to feedback this statistical CSI is fairly acceptable, since the covariance matrix evolves rather slowly compared to the instant values of the equivalent channel matrix. Once computed and feedback, this covariance information can be valid through many transmission blocks.

II. MIMO-OFDM MODEL

In radio, multiple-input and multiple-output, is the use of multiple antennas at both the transmitter and receiver to improve communication performance. It is one of several forms of smart antenna technology. MIMO can be subdivided into three main categories, turbo coding, spatial multiplexing or SM, and diversity coding. Turbo coding is multi-stream beam forming, in the narrowest definition. In more general terms, it is considered to be all spatial processing that occurs at the transmitter. In (single-layer) beam forming, the same signal is emitted from each of the transmit antennas with appropriate phase (and sometimes gain) weighting such that the signal power is maximized at the receiver input. When the receiver has multiple antennas, the transmit beam forming cannot simultaneously maximize the signal level at all of the receive antennas, and turbo coding with multiple streams is used. Note that turbo coding requires knowledge of channel state information (CSI) at the transmitter. Spatial multiplexing requires MIMO antenna configuration. In spatial multiplexing, a high rate signal is split into multiple lower rate streams and each stream is transmitted from a different transmit antenna in the same frequency channel. Spatial multiplexing is a very powerful technique for increasing channel capacity at higher signal-to-noise ratios (SNR). The maximum number of spatial streams is limited by the lesser in the number of antennas at the transmitter or receiver. Spatial multiplexing can also be used for simultaneous transmission to multiple receivers, known as space-division multiple accesses.

These techniques are used when there is no channel knowledge at the transmitter. In diversity methods, a single stream (unlike multiple streams in spatial multiplexing) is transmitted, but the signal is coded using techniques called space-time coding. The signal is emitted from each of the transmit antennas with full or near orthogonal coding. Diversity coding exploits the independent fading in the multiple antenna links to enhance signal diversity. Spatial multiplexing can also be combined with turbo-coding when the channel is known at the transmitter or combined with diversity coding when decoding reliability is in trade-off.

At each transmit antenna, an insufficient CP of length v (v < L) is added to the input signal block and propagates via a multipath channel \( h_{ij}(0), h_{ij}(1), \ldots, h_{ij}(L) \) between the \( i \)th receive antenna and the \( j \)th transmit antenna, where we assume that all the entries of \( h_{ij} \) are complex Gaussian random variables with 0 mean and the channel length, \( L+1 \), is identical for all the channels. We now define \( nr \times nt \) channel matrices \( H(l), l = 0, 1, \ldots, L, \) as

\[
H(l) = \begin{bmatrix}
    h_{11}(l) & \cdots & h_{1n}(l) \\
    \vdots & \ddots & \vdots \\
    h_{nr}(l) & \cdots & h_{nt}(l)
\end{bmatrix}
\]  

III. TURBOCODER DESIGN AND RECEIVER STRUCTURE

A. Turbo Coder Design:

In this section, we first discuss the processing at the receiver and then a design criterion depends on what the receiver is used.

A Turbo code based on OFDM (Orthogonal Frequency Division Multiplexing) is proposed in this paper. Orthogonal Frequency Division Multiplexing (OFDM) has become a popular modulation method in high speed wireless communications. By partitioning a wideband fading channel into flat narrowband channels, OFDM is able to mitigate the detrimental effects of multipath fading using a simple one-tap equalizer. There is a growing need to quickly transmit information wirelessly and accurately. OFDM is a suitable candidate for high data rate transmission with forward error correction (FEC) methods over wireless channels. In this project the system throughput of a working OFDM system has been enhanced by adding turbo coding. The use of turbo coding and power allocation in OFDM is useful to the desired performance at higher data rates.

Simulation is to be done over additive white Gaussian noise (AWGN) and impulsive noise (which is produced in broadband transmission) channels. In this paper Bit Error Rate performance of OFDM, QPSK, 16-QAM System over Rayleigh fading channel is analysed. OFDM is orthogonal frequency division multiplexing to reduce inter-symbol interference problem. The equalization algorithm is Normalized LMMSE equalizer. Finally simulations of OFDM signals are carried with Rayleigh faded signals to understand the effect of channel fading and to obtain optimum value of Bit Error Rate (BER) and Signal to noise ratio (SNR). The zero-forcing is first performed over the received signal to suppress all the residual IBI. A linear MMSE equalizer is concatenated to extract the desired signal symbols from the zero-forcing output.

Fig. 1: Multi Antenna Types
The transmitted signal can be written as

\[ s(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j 2\pi f_k t}, \quad -\Delta < t < N T. \] (3)

The signal then passes through a channel, modelled by a finite-length impulse response limited to the interval \( [0, \Delta] \). If the length of the cyclic prefix is chosen such that the received OFDM symbol evaluated on the interval \( [0, N T] \), ignoring any noise effects, becomes

\[ r(t) = s(t) * h(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} H_k X_k e^{j 2\pi f_k t}, \quad 0 < t < N T. \] (4)

Where

\[ H_k = \frac{\Delta}{\sqrt{N}} \int_{0}^{\Delta} f(t) e^{j 2\pi f_k t} dt \] (5)

is the Fourier transform of \( h(t) \) evaluated at the frequency \( f_k \). Note that within this interval the received signal is similar to the original signal except that \( H_k X_k \) modulates the \( k \)th subcarrier instead of \( X_k \). In this way the cyclic prefix preserves the orthogonality of the subcarriers. The received data in Equation (5) can be recovered with \( N \) parallel one-tap equalizers. This simple channel equalization motivates the use of a cyclic prefix and often the use of OFDM itself. Because we ignore the signal within the cyclic prefix this prefix also acts as the above mentioned silent guard period preventing ISI between successive OFDM symbols. In a fading channel the channel variations affect the performance of the OFDM system. For a fixed sampling period, the OFDM symbol length increases with the number of subcarriers and so do its sensitivity to channel variations. To illustrate the effects, consider an OFDM system in a flat-fading channel, a channel with a time-varying one-tap impulse response \( \alpha(t) \). The transmitted OFDM signal is multiplied with this time-varying scalar which yields the received

\[ r(t) = \alpha(t) s(t). \]

The multiplications appears as a convolution in the frequency domain causing spreading of the subcarriers and, consequently, ICI. The sampled signal after the DFT is of the form

\[ y_l = \sum_{k=0}^{N-1} x_k \alpha(k-l), \] (6)

where

\[ x_k \]

is the DFT of the now time-varying channel tap.
In some cases the above spreading may be desirable as it is a way to introduce diversity. A frequency domain channel equalizer can exploit such diversity. Other systems requiring orthogonality between subcarriers may suffer from the spreading. For a fixed sampling time the ICI due to the Doppler spreading increases with the number of carriers. Using a central limit theorem argument, characterizes the effect of the ICI as an additive Gaussian noise with a variance that increases with the number of subcarriers and with the maximum Doppler frequency. This noise is correlated in time, but white across subcarriers. The ICI leads to an error floor which may be unacceptable. Antenna diversity or coding are suggested to reduce this error floor. The receiver basically does the reverse operation to the transmitter. The guard period is removed. The FFT of each symbol is then taken to find the original transmitted spectrum. The phase angle of each transmission carrier is then evaluated and converted back to the data word by demodulating the received phase. The data words are then combined back to the same word size as the original data.

IV. COMPARISON OF MIMO OFDM WITH QPSK AND QAM

Orthogonal frequency-division multiplexing is a multicarrier digital modulation system that has been employed as a modulation system for terrestrial digital broadcasting. Compared with single-carrier digital modulation, OFDM can lengthen the symbol period while maintaining the same error-rate characteristics and band efficiency. It can also add a redundant signal period called a guard interval. For these reasons, OFDM features little deterioration of transmission characteristics with respect to multipath distortion, the main type of disturbance on a terrestrial transmission path. The OFDM signal multiplexes multiple digitally modulated waves that are mutually orthogonal in a certain signal.

This operation is none other than OFDM demodulation. Digital modulation of individual carriers is normally performed using QPSK or QAM, and particular modulation systems are referred to as QPSK-OFDM, 64QAM-OFDM, etc. The QPSK-OFDM and 16QAM-OFDM systems are used on transmission paths characterized by severe disturbances such as in mobile communications where automobiles and other objects come into play. On the other hand, for fixed reception by an antenna installed on a roof as in ordinary television reception, 64QAM OFDM is used so that as much data as possible can be transmitted within a limited frequency bandwidth. Transmit symbols in OFDM consist of effective symbols and guard intervals. Data allocated to the carriers are transformed collectively by an inverse discrete Fourier transform into symbols each within the effective symbol period \( T_u \). A guard interval is formed for each effective symbol period by taking a section of waveform data from the end of the symbol in question and simply attaching it to the front of the symbol, as shown in Figure 2. Transmit symbols of period \( T_u + T_g \) are obtained in this way.

V. SIMULATION RESULTS

The transmission BER is the number of detected bits that are incorrect, divided by the total number of transferred bit. The information BER, approximately equal to the decoding error probability, is the number of decoded bits that remain incorrect after the error correction, divided by the total number of decoded bits (the useful information). Normally, the transmission BER value is larger than that of information BER. The information BER is affected by the strength of the forward error correction code. In this paper we tried to improve BER with M-QAM.

Fig. 3: Channel Estimation for OFDM with SISO Antenna System

The performance of a data transmission system is usually analyzed and measured in terms of the probability of error at given bit rate and SNR. The parameter \( \frac{E_b}{N_0} \), where \( E_b \) is bit energy and \( N_0 \) is noise energy, is adjusted every time by changing noise in the designed channel. For particular \( \frac{E_b}{N_0} \) value, system is simulated and corresponding probability of error is noted. The proposed design is simulated with necessary parameter changes for QPSK and QAM.

Fig. 4: Comparison between MIMO OFDM with QPSK and QAM Modulations with Sufficient Cyclic Prefix

As shown in Fig. 5, if we go on increasing the \( \frac{E_b}{N_0} \) value, BER reduces. In comparison of BER performance for M-PSK, it is observed that use of a higher M-ary constellation is better for high capacity transmission but the drawback is that the points on Performance Comparison of MIMO-OFDM Transceiver Wireless Communication System using QAM and QPSK Modulation Schemes constellation are closer which makes the transmission less robust to errors with high SNR. The MIMO-OFDM with QAM simulation are analyzed for BER performance. The Iterative Joint LMMSE equalizer is applied to improve the channel gain.
This work presented a new transmitter-based turbo coder to combat insufficient-cyclic-prefix distortion in multicarrier systems. A problem formulation that determines the optimal target distortion level to maximize the data-rate was introduced and shown to be a convex optimization problem that could be solved very efficiently. Low-complexity transmitter and joint transmitter-receiver processing were explored and shown to perform well. This design retains the property of IBI separation as what we have discussed in the channel independent precoding. Combined with the IBI zero forcing operation at the receiver, more data symbols are transmitted in the MIMO OFDM system, and thus higher spectral efficiency is achieved. Substantial gains compared to the unoptimized channel independent turbo coding can be seen from the simulation results.

VI. CONCLUSION

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