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論　文　名　「Studies on BSS Method for Signal Recovery in Multiuser MIMO-OFDM Systems (BSS 手法を用いたマルチユーザ MIMO-OFDM システムにおける信号復元に関する研究)」

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論文要旨

In recent years, the growing demand of multimedia services and the growth of Internet related contents lead to increasing interest to high speed communications. The requirement for wide bandwidth and flexibility imposes the use of efficient transmission methods that would fit to the characteristics of wideband channel in wireless environment. A large amount of research has been performed to achieve very high data rate networks to support reliable transmission of video, data, and speech at high rates to many users. One way to increase the data rate in a wireless system is to use multiple transmitting and/or receiving antennas structure. Multiple antennas can be used at the transmitter and receiver, where an arrangement is called a multiple-input multiple-output(MIMO) system. An MIMO system takes advantage of the spatial diversity that is obtained by spatially separated antennas in a dense multipath scatter environment. In order to achieve the very high data rates that data-demanding applications require, MIMO systems will have to operate in much larger bandwidths . Clearly, the MIMO receivers of such systems will have to handle not only the problem of interuser interference(IUI) between different antenna elements but that of intersymbol interference(ISI) due to the channel's frequency selectivity. Combating ISI, MIMO receivers are faced with the challenge of more demanding channel estimation. This complicates further the receiver design and causes performance degradation but typically also requires the sacrifice of a fraction of available system resources.

For user detection, the most popular way is using a linear MIMO equalizer at the receiver. This involves finding a matrix that will cancel out the effect of the cross-channel terms in the MIMO channel, i.e., the elements off the main diagonal. This can be achieved by calculating the inverse matrix of the MIMO channel, also known as the zero- forcing (ZF) solution. The ZF is that it only counteracts the spatial dispersion or co-channel interference effects of the channel but takes no account of the noise introduced. When noise is considered, the minimum mean squared error (MMSE) method is better solution.

Orthogonal frequency division multiplexing(OFDM) is well-known to be effective against multipath distortion. It is a multicarrier communication scheme, in which the bandwidth of the channel is divided into subcarrier and data symbols are modulated and transmitted on each subcarrier simultaneously. Because of the frequency spacing selected, the sub-carriers are all mathematically orthogonal to each other. The signals of the different sub-channels are allowed to overlap, and the fact that they are kept orthogonal facilitates their separation in the receiver. In OFDM, ISI usually refers to interference of an OFDM symbol by previous OFDM symbols. Interference caused by data symbols on adjacent sub-carriers is referred as inter-carrier interference (ICI), since the carriers are no longer orthogonal to each other. To overcome these problems, the cyclic prefix(CP) is introduce. A CP is a copy of the last part of the OFDM symbol that is pre-pended to the transmitted symbol and removed at the receiver before the demodulation. The length of the CP should be made longer than the experienced impulse response to avoid ISI and ICI. Another key advantage of OFDM is that it dramatically reduces equalization complexity by using the fast Fourier transform(FFT) in the frequency domain.

The combination of MIMO and OFDM is very natural and beneficial since OFDM enables support of more antennas and larger bandwidths. The use of OFDM alleviates this problem by turning the frequency-selective MIMO channel into a set of parallel narrow-band MIMO channels, which will greatly simplify the equalization process. Only a constant matrix has to be inverted for each OFDM tone. The combination of MIMO and OFDM techniques forms the foundation needed for wireless communication systems to break the Gbps barrier in typical indoor environments, and the 100 Mbps barrier in outdoor mobile cellular environments. Though OFDM enables support of more antennas and larger bandwidths since it simplifies equalization dramatically in MIMO systems, the challenge is on what type of channel state information(CSI) can be made practically available to the transmitter in a wireless setting, where fading channels are randomly varying. Initially both SISO as well as MIMO systems assume perfect CSI at the transmitter. Then the training sequences and pilot tones for channel estimation were investigated.

For single-user OFDM systems with multiple transmitting/receiving antenna, Multiple transmitting/receiving antennas in combination with coding are used to improve diversity and rate. This scheme is developed with the space time block codes(STBC). In this case, the channel matrix is non diagonal. In the approach of STBC, each information symbol is transmitted twice in two consecutive time intervals through two different antennas. For Multiuser OFDM systems with multiple transmitting/ receiving antenna, all users use all available subcarriers independently. Each user can employ one or more antenna. Inevitably, in this case there is multi-user interference and the channel matrix is non diagonal. The majority of the single-user OFDM channel estimation methods do not apply to this case. Although ISI can be avoided employing the CP in multiuser MIMO systems, the phase and gain of each sub-channel is needed for coherent symbol detection. In MIMO receivers, the channel state needs to be estimated for equalization, detection, and for feedback to the transmitter in case of adaptive modulation and coding.

Until now most of researches MIMO-OFDM systems concentrate on a single user, there are rarely researches that consider multiuser. The signal recovery in multiuser MIMO-OFDM systems with the natural gradient algorithm(NGA) in blind signal separation(BSS) has not been discussed yet. Our work focus is to resolve multiuser interference (MUI) and two indeterminacies nature of BSS algorithm. The basic idea is to apply existing BSS algorithm for mobile communication signals, which leads to efficient utilization of the bandwidth. Using BSS directly mobile communication signals can not be separated due to the existence of delayed multiple paths of the sources. The system considered here is that all of the subcarriers are assigned to all users without any time or frequency division multiple access scheme. The effect of the dispersive MIMO channel in such a system can be treated as a set of instantaneous mixtures from the frequency bin(FB) viewpoint, due to the CP and the IDFT/DFT modulation/ demodulation nature of OFDM signal. Therefore, the blind signal recovery in this MIMO-OFDM system can be split up into a set of BSS problems. Although BSS algorithm can successfully separate different user signals at FB level, the recomposition of them from the separated signals will suffer from the indeterminacies nature of BSS algorithm. Solving the indeterminacies in the large number of FBs is a very difficult problem. We use the second-order statistical(SOS), combination of blind and semi-blind, pre-coding and employing known partial CSI methods to resolve these problems. Along these lines, the main components of this thesis and the major results of the presented work can be summarized as follows:

Chapter 1 introduces the history of the signal recovery in MIMO-OFDM systems research and gives an overview of this thesis.

Chapter 2 describes the MIMO system, OFDM system, multiuser MIMO-OFDM system models and introduces BSS method.

Chapter 3 develops the statistic characteristics of the transmitted signals, the key is the computation of auto-correlation of separated user signals. Since the BSS algorithm runs at each FB individually, the permutation indeterminacy will result at the loss of user ownership information of the signal, and occur the complex uncertain scalings. We design a pre-filter for nonzero auto-correlation of transmitted signal. Through the computation of auto-correlation, the separated user signals belong to the same FB can be collected. As a result, a unknown phase distortion has the same outcome with the uncertain carrier phase in single carrier systems. With differential quadrature phase shift keying(DQPSK) signal restriction, it can be eliminated by noncoherent detection method. Finally, the user identification is simply based on the users ID information hidden in the user signals. The ID signal is shorter very much than the training signal. In the blind approach, using a few ID signals is permitted since ID signals have taken supplementary role only, are not major. Therefore, using ID signal is still belong to blind scope in our method. This scheme has better performances in the fast varying channel without using any training sequence. Computer simulation also demonstrated the validity of the proposed method.

Chapter 4 focuses on decreasing the large auto-correlation computation at FB. We design a convolutional pre-filter, where converts user signals into transmitted signals which possess a correlation structure. The separation work is at only two FB. Then we employ semi-blind method, a few pilot symbols insert the first FB in order to overcome BSS indeterminacies. The separated signals at the second FB are use as some reference signals for Wiener filter processing. The combination blind/semi-blind and Wiener filter through a cost function. Therefore, beside blind/semi-blind separation at the first and second FBs, the signal recovery at the other FB uses Wiener filter. We compared with the joint detection(JD) method. Although both the proposed method and the JD method employ pilots, the pilots in our method are used only for resolving the indeterminacies of the BSS. In the simulations, our method used 2 and 3 pilot symbols in each user signal respectively, but the JD method used 128 pilot symbols in each user signal.

Chapter 5 investigates the pre-filter at transmitter, a simple preprocessing is performed at each user signal. It introduces neither redundancy nor changing the data to the transmitted data, which makes the approach bandwidth efficient, and maintains zero-mean of the signal transmitted on each subcarrier. Also it introduces a correlation structure in signals transmitted over different subcarriers. Therefore we do not require signal correlation computation at only two FB. As a result, decrease the error of computation in FB and FB. Then using Wiener filter separate the other FB received signals. We used a cost function to impose that overall matrices in the FBs be the same in order to guarantee that all the coded symbols have the same amplitude in all the FBs. Thus, BSS indeterminacies can be removed.

Chapter 6 discusses the signal recovery with known partial CSI. From the view point of FB, the channel in multiuser MIMO-OFDM systems can be treated as a set of instantaneous mixtures. This advantage can be utilized for signal recovery with known partial CSI. When a new user joins in the current system, the new interferences are introduced which result an expanding mixture. The expanding mixture includes known partial CSI. From known partial CSI, employing the second order statistics and BSS, we design a new separation matrix. The result of separation, the permutation and scaling indeterminacies do not arise in whole separation processing since the known partial CSI is employed. However the new joined user`s signals still retain a phase distortion. Similarly this phase distortion can easily be eliminated by noncoherent detection.

Chapter 7 concludes this thesis and gives some topics for future research.

審査結果の要旨

本論文は、無線通信システムの送受信側に複数のアンテナ素子を設けたマルチユーザ多入力多出力 OFDM（Multi-Iput Multi-Output Orthogonal Frequency Division Multiplexing: MIMO-OFDM）通信システムモデルを対象とした BSS (Blind Source Separation)手法による信号復元に関する一連の研究を纏めたものである。得られた主な結果は、以下の項目に要約できる。

（１）マルチパス通信路におけるマルチユーザ MIMO-OFDM 通信システムの周波数領域モデルの信号復元問題は、OFDM のキャリア数からなる BSS 問題として記述することができる。しかしながら、BSS 問題にはスケーリングとパーミュテーションの曖昧さが存在する。提案手法では、送信信号の２次統計量を利用することにより、BSS 問題におけるスケーリングとパーミュテーションの曖昧さを無くし、マルチユーザの信号復元を可能にしている。

（２）BSS 問題におけるスケーリングとパーミュテーションの曖昧さを無くする一手法として、既知の部分情報を利用するセミブラインド分離の方法が知られている。提案手

法では、セミブラインド分離の観点に立ち、OFDM 信号の第 1 番目と第２番目のキャリアに既知パイロット信号を導入し、スケーリングとパーミュテーションの曖昧さを無くすことができる新たな方法を提案している。

（３）マルチユーザ MIMO-OFDM 通信システムにおいて、新たなユーザが通信に加わる際の信号復元問題を、新たなユーザが加わる前のチャネル情報を既知情報として利用するセミブラインド分離の観点より解決している。提案手法は、既知チャネル情報の利用により、スケーリングとパーミュテーションの曖昧さが生じない有効な手法であることが示されている。

以上の諸成果は、マルチユーザ MIMO-OFDM 通信システムにおける信号復元技術の基礎的な知見や基盤を与えるものであり、この分野の技術の発展に貢献するところ大である。また、申請者が自立して研究活動を行うに十分な能力と学識を有することを証したものである。学位論文審査委員会は、本論文の審査ならびに最終試験の結果から、博士（工学）の学位を授与することを適当と認める。