OPTIMIZING PERFORMANCE OF MULTIUSER MIMO OFDM SYSTEMS WITH FEEDBACK DELAY, ERROR, AND INTER-CARRIER INTERFERENCE (ICI)

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Abstract

The availability of Channel State Information (CSI) at the transmitter in Multiuser Multiple-Input Multiple-Output (MU-MIMO) systems is an extremely important factor in determining whether or not the system will perform at its absolute best. Typically, this is accomplished through the use of feedback systems. Within the context of orthogonal frequency division multiplexing (OFDM), this study analyzes how the availability of CSI and feedback faults affect the performance of broadcast multiuser MIMO systems. In the analysis, channel-dependent scheduling, beamforming techniques, and the impacts of feedback latency and error are all taken into account. When determining the ergodic capacity and the Bit Error Rate (BER), various elements, including the noise variance, the modulation order, the number of users, and the number of antennas, are taken into consideration. The findings highlight the importance of CSI as well as the adverse impact that feedback errors and inter-carrier interference (ICI) have on the performance of the system. These findings provide useful insights that may be applied to the design and optimization of multiuser MIMO OFDM systems in real-world circumstances.

Keywords: multiuser MIMO OFDM, CSI, BER, Capacity, ICI.

1. INTRODUCTION

In broadcast multiuser MIMO systems, the transmitter can operate at its best when it has access to Channel State Information (CSI) through feedback [1]-[2]. Channel state information is abbreviated as [CSI]. For canceling or reducing interference during simultaneous broadcast to several customers, "known channel properties," or CSI, is a must [2]. The abbreviation "CSI" stands for "channel state information." The Zero-Forcing (ZF) beamforming technique is used in the research by [3] to create a beam pointing in the desired direction. The impact of channel-dependent scheduling and a common Base Station (BS) that is aware of the current channel quality at any given time are also taken into consideration in [4].

The concept of mean feedback is put out for usage with flat-fading multiantenna channels in reference number [5]. The ability of most communication systems to adjust the signal that is being transmitted across numerous users can be used to achieve an additional degree of freedom. But as more people use the channel, the bare minimum of channel expertise required also rises. Practical system implementations face challenging obstacles in the form of problems when the transmitter lacks a priori channel information [6].

The working theory is that each Mobile Station (MS) will be able to determine its own channel state vector because the Base Station (BS) will broadcast downlink pilot symbols. The MSs exchange their responses to this prediction via an uplink, a Channel State Information (CSIT) feedback channel.

The majority of previous studies on restricted feedback beamforming were predicated on the idea that there was no delay in the feedback channel. However, [7]-[9] have examined the impact of CSI feedback delay on Bit Error Rate (BER) or capacity in MIMO communication systems. The References section contains references like these. In [10], the CSI feedback delay is used to establish the CSI source bit rate and an upper bound on the feedback throughput gain for limited feedback beamforming systems over temporally correlated channels. For limited feedback beamforming systems, this is done. In order to consume less transmission power, [11] also describes an adaptive Orthogonal Frequency Division Multiplexing (OFDM) subcarrier distribution scheme. Several performance measurements are derived from the premise that Inter-Carrier Interference (ICI) results from feedback error in [12]. This assumption is the last one.

The remainder of the paper is into the following sections: where, the system's model is displayed. We will go over how to develop performance measurements for a multiuser MIMO OFDM system while accounting for feedback delay and error in the section that follows. The results of the numerical analysis are presented in the sections labeled "Results in Numbers" and "Conclusions," respectively.

2. MULTIUSER MIMO OFDM SYSTEM ARCHITECUREANDOPERATION

The basic system model for a multiuser MIMO OFDM network with U users and K receivers is given by,as in Eq. (1)

$$y_k = \sum_{i=1}^{U} \mathbf{H}_{ki}\mathbf{x}_i + \mathbf{n}_k \qquad (1)$$

Where $\mathbf{y}k$ *is the N×1 received signal vector at receiver k,* $\mathbf{H}ki$ is the N×M channel matrix between transmitter i and receiver k, $\mathbf{x}_i$ is the M×1 transmitted signal vector from transmitter i, and $\mathbf{n}_k$ is the N×1 additive white Gaussian noise (AWGN) vector at receiver k.

The transmitter architecture consists of MIMO encoding and OFDM modulation blocks. In MIMO encoding, the input bit stream for each user is encoded into multiple data streams to be transmitted from multiple antennas for spatial multiplexing. [13] This increases the spectral efficiency of the system compared to single antenna transmission. The encoded streams then go through OFDM modulation where the data is modulated onto N parallel subcarriers using an Inverse Fast Fourier Transform (IFFT) operation. This converts the frequency domain data into time domain samples to be transmitted.

Mathematically, the OFDM modulation can be expressed as in Eq. (2)

$$x(n) = \sum_{k=0}^{N-1} X(k)\exp(j2\pi kn/N) \qquad (2)$$

for n = 0,1,...,N-1

Where x(n) is the transmitted time domain signal, X(k) is the frequency domain input symbol on subcarrier k, N is the number of subcarriers, and n is the time index.

The receiver architecture consists of OFDM demodulation followed by MIMO decoding. The received time domain signal is first transformed back into frequency domain by applying an FFT operation across the N subcarriers, as in Eq. (3)

$$Y(k) = \sum_{n=0}^{N-1} y(n)\exp(-j2kn/N) \qquad (3)$$

for k = 0,1,...,N-1

Where Y(k) is the frequency domain received symbol on subcarrier k.

After OFDM demodulation, the MIMO decoder separates and decodes the signals transmitted from multiple transmit antennas to the user's receive antennas. Popular MIMO decoding methods include Zero Forcing (ZF), Minimum Mean Square Error (MMSE) and Successive Interference Cancellation (SIC). This finally recovers the original input bit streams for each user.

To support multiple simultaneous users in the system, orthogonal sequences can be allocated to different users to suppress multiuser interference. For example, orthogonal Walsh codes can be assigned to separate users when transmitting in the code domain. Similarly, different time, frequency or spatial signatures can be allocated to separate user signals in the time, frequency and spatial domains respectively.

The advantages of multiuser MIMO OFDM include increased spectral efficiency and link reliability from MIMO processing as well as robustness against frequency selective fading from OFDM. However, there is increased complexity in transceiver design and signal processing compared to single antenna systems.[14] Overall, this architecture provides an efficient technique to deliver high data rates to multiple users in wireless systems.

3. PERFORMANCEEVALUATION

The analysis of Bit Error Rate and to performance of Capacity Evaluation under the Multiuser MIMO-OFDM Systems with Feedback Fault.

3.1 BIT ERROR RATE ANALYSIS

The bit error rate (BER) is an important performance metric that quantifies the reliability of data transmission in communication systems. For MIMO OFDM systems, the BER depends on the signal to interference and noise ratio (SINR) across all data streams and subcarriers, which varies dynamically depending on channel fading, power allocation, spatial multiplexing and interference conditions.[15]

Assuming ideal channel state information and MIMO processing at the receiver front-end, the post-processing SINR for user i on data stream l and subcarrier k can be derived as in Eq. (4)

$$SINR^{i}_{k,l} = \frac{\rho^{i}_{k,l}|h^{i,i}_{k,l}|^2}{\sum_{j=1}^{U}\sum_{j\neq i}\sum_{n=1}^{d_j}\rho^{j}_{k,n}|h^{j,i}_{k,n}|^2 + 1} \quad (4)$$

Where $\rho^{i}_{k,l}$ = transmit PSD from user i's transmitter for symbol on stream l, subcarrier k. $h^{j,i}_{k,l}$ = Channel frequency response from transmitter j stream l to receiver i subcarrier k.By modeling SINR across subcarriers as independent Gaussian random variables for a fixed channel realization, the average BER can be computed by integrating the conditional BER with AWGN (given by the Q-function) over the probability distribution function of SINR, expressed in Eq. (5)

$$P_b = \int_0^{\infty} Q(\sqrt{SINR})\ f(SINR)\ dSINR \quad (5)$$

Where $Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} \exp(-t^2/2)dt$

This can be numerically evaluated for different channel models like Rayleigh fading. As an example, under uncorrelated Rayleigh fading with maximal ratio combining at receiver, the BER simplifies, as in Eq. (6)

$$P_b = \frac{1}{2}(1 - \sqrt{\frac{SNR}{1+SNR}}) \quad (6)$$

to transmit diversity order 1.

Here SNR denotes the average post-processing signal to noise ratio across data streams. We observe that at high SNR, increased fading diversity from extra transmit/receive antennas (achievable through MIMO processing) helps mitigate BER deterioration.

However, in practical systems, imperfect CSI and interference affect actual SINR and BER. Quantifying these degradations helps design robust modulation, coding and signal processing schemes.

3.2 CAPACITY EVALUATIONWITH FEEDBACK FAULTS

For frequency selective fading MIMO channels, the Ergodic channel capacity considering statistical averaging over small scale fading (for a fixed channel realization) is given, as in Eq. (7)

$$C = \mathbb{E}\left[\log_2 \det\left(\mathbf{I}_{NR} + \frac{P}{N_t M}\mathbf{H}\mathbf{H}^H\right)\right] \text{bits/s/Hz (7)}$$

Where $\mathbf{H}$ = NR × NT channel matrix
P = Total transmit power
N_R, N_T = Number of receive and transmit antennas

This capacity bound assumes optimal spatial multiplexing transmission and Gaussian signaling across transmit antennas and subcarriers.

Practical systems employ quantized CSI feedback mechanisms from receiver to transmitter to leverage channel knowledge for scheduling subcarrier assignment and adaptive power allocation. However, feedback channel errors can degrade capacity.With scalar quantization and noisy feedback, channel uncertainty increases with Feedback Error Variance (FEV) σ_e^2. For simplified analysis under spatially uncorrelated Rayleigh fading, the Ergodic MIMO channel capacity gets limited, as in Eq. (8)

$$C = \mathbb{E}\left[\log_2 \det\left(\mathbf{I}NR + \frac{P}{\sigma e^2 + N_t M}\mathbf{\Omega}\right)\right] \text{bits/s/Hz (8)}$$

for $\mathbf{\Omega}$ = Effective channel covariance matrix after feedback errors.

Thus, CSI uncertainty from limited feedback impacts the multiuser channel gain and spatial multiplexing capability, reflected via the degraded channel covariance matrix post errors. This reduces capacity, especially for higher order MIMO configurations. Designing optimal feedback and tracking mechanisms helps minimize such overheads and capacity loss while enabling robust transmission to dynamic multi user fading channels [16].

The capacity with feedback error is given by equation. In this equation, 0(1()) max,)0(] [S SnNEosu u−+= represents a specific term, and Lk n−m(λ) is the associated Laguerre polynomial of order k.

When the frequency offset (FO) is less than the thermal noise, the effect of inter-carrier interference (ICI) is minimal. However, increasing signal power with a big FO result in performance loss from ICI.

The Bit Error Rate (BER) graphs for various noise variances with feedback error are displayed in Figure 1(a). The BER increases along with the noise power. This illustrates how noise can affect a system's sensitivity, with higher noise levels resulting in higher mistake rates.

The BER graphs for various modulation orders in a closed-loop MU MIMO OFDM system with feedback error maintaining an average BER requires an additional 4-5 dB of Signal-to-Noise Ratio (SNR) to achieve an additional bit per dimension.The capacity versus gain curves for a Rayleigh fading channel with feedback delay are shown in Figure 1(b).

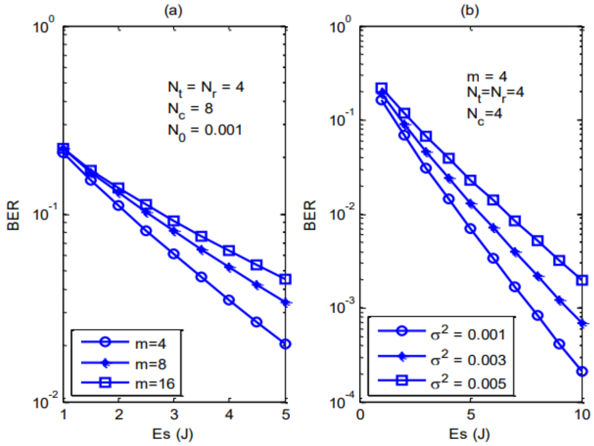

Figure 1. BER with feedback error for (a) different modulation order, and (b) different noise variances [7]

The capacity reduces as the number of users rises. This suggests that increasing the number of users in a system reduces individual capacity due to increased interference and constrained resources.

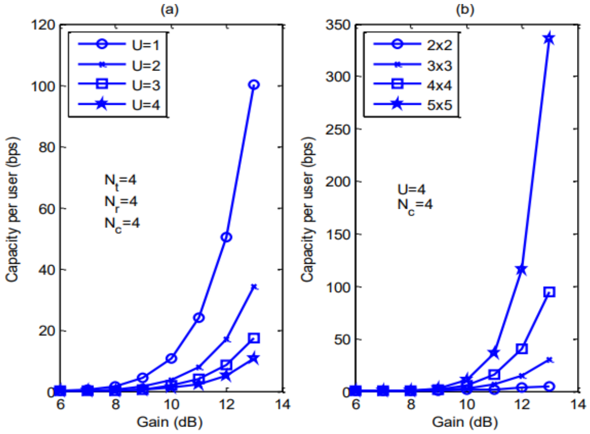

Figure 2. Capacity with feedback delay for (a) different number of users and (b) different antenna configurations

The capacity with feedback delay for various antenna counts is shown in Figure (2). It is evident that as the number of antennas rises,so does the capacity. This demonstrates the advantage of adding antennas to improve system performance and boost capacity.

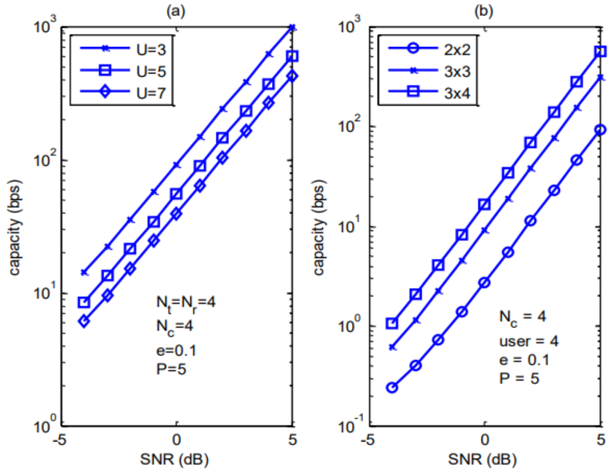

Figure 3. Capacity with ICI due to feedback error for (a) different number of users and (b) different antenna configurations.

A Multiuser Multiple-Input Multiple-Output (MU-MIMO) Orthogonal Frequency Division Multiplexing (OFDM) system's capacity with Inter-Carrier Interference (ICI) brought on by feedback channel faults is shown in Figures 3(a) and 3(b). The capacity is assessed for various user and antenna counts. [17]

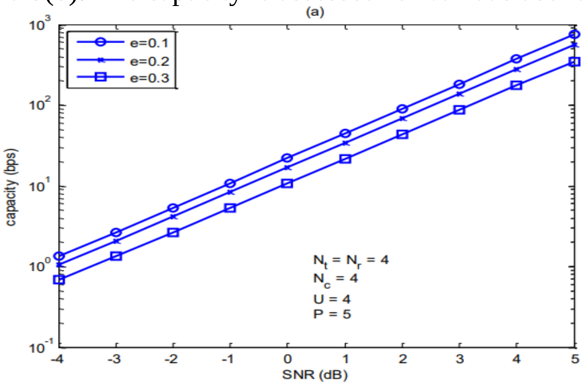

Figure 4. Capacity with feedback error for various FOs of a MU MIMO OFDM system.

The findings shown in Figure (4) indicate the important influence of transmit power and user density on system capacity.Additionally, Figure (4) shows how feedback error affects the MIMO OFDM system's capacity. It has been noted that as the Frequency Offset (FO) rises, the level of ICI rises as well, reducing the system's capability. This demonstrates the negative effects of feedback errors on the MIMO OFDM system's performance, particularly in terms of capacity.

4. CONCLUSION

In conclusion, this work has explored how feedback delay and feedback error can cause a decline in performance in Multiuser Multiple-Input Multiple-Output (MU MIMO) Orthogonal Frequency Division Multiplexing (OFDM) systems. The effect that feedback latency has on system capacity has been analyzed, and numerical findings for a variety of system parameters have been published. When the feedback is not updatedin the appropriate manner, it has been observed that the capacity of the system declines.

The Inter-Carrier Interference (ICI) that is brought on by feedback mistakes has also been taken into consideration in this research. Both the performance and capacity with feedback error for the Bit Error Rate (BER) have been analyzed and plotted for a variety of different system characteristics. The findings of the analysis make it abundantly evident that the performance of the system deteriorates with increasing feedback delay and increasing feedback inaccuracy.

These findings highlight how important it is for MU MIMO OFDM systems to have feedback that is precise and timely in order to keep their performance at their peak. Research in the future might concentrate on developing effective feedback mechanisms and error-mitigation approaches, with the goal of minimizing the negative impact that feedback delay and error have on the overall performance of the system.

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