PERFORMANCE ANALYSIS AND COMPARISON OF MULTIUSER MIMO BROADCAST PRECODING TECHNIQUES FOR 5G NETWORKS

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ABSTRACT

The fifth generation of mobile networks (5G) aims to meet the high demand for mobile data that will exist from the year 2021, product of the development of new technologies, applications and services. Its main requirements are to achieve high data transmission rates, massive user capacity, low power consumption, high communication reliability and low latency. We propose ZF Precoding and ZF-DPC precoders’ scheme and algorithms that employ multiple transmit processing and ordering strategies along with a selection scheme to mitigate interference in MU-MIMO systems. Both of the two proposed precoding algorithms can achieve a comparable sum-rate performance as, substantial bit error rate (BER) performance gains, and a simplified receiver structure, while requiring a much lower complexity.

Keywords: MU-MIMO, Precoding, BER, 5G Networks.

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1. INTRODUCTION

As of now future wireless networks will should address a sizable increase of data transmission due to some of rising applications that include gadget-to-machine communications and video streaming [1]- [4]. This very big amount of statistics alternate is anticipated to hold and upward thrust inside the subsequent decoder so, presenting a totally huge challenge to Designer’s of fifth-generation (5G) wireless communications systems [4].

This work focuses on the study and analysis of the performance of the most accepted linear precoding techniques on the downlink of the Massive MIMO systems. Specifically, minimum-square error (MMSE), Zero Forcing and Maximum Ratio Transmission (MRT) are compared in terms of attainable rate of transmission, Spectral efficiency and energy efficiency.

The main problems faced by present 5G wireless communication systems can be attributed to two major aspects, namely, the limited radio spectrum resource and the complicated wireless propagation environment. With the continued development of industry and business, there requirement for radio spectrum is increasingly strong, and thus the suitable radio spectrum is becoming scarcer and more expensive. Meanwhile, wireless systems are inevitably faced with a complicated propagation environment. The three impact factors are noise, fading and interference. For noise, communication systems usually use the matched filtering method to maximize the Signal-to-Noise-Ratio (SNR) [9]. The way to overcome the fading effects mainly relies on equalization and diversity techniques. The art of dealing with interference is closely related with multiple access techniques [10], such as Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), Space Division Multiple Access (SDMA), etc.

Because of its tremendous potential in addressing the limited spectrum resource and the system performance problems, Multiple-Input Multiple-Output (MIMO) technique have attracted intense research efforts in the wireless communications field. By producing multiple transmitting channels in space, the spectrum efficiency has been greatly increased without additional bandwidth or increased transmit power. MIMO systems have already been employed in the existing 802.11n [11] and 802.16e [12] standards, and are among the core techniques in the next generation wireless systems [13, 14]. The works in [15–17] pointed out that for the i.i.d Gaussian noise channel, the capacity of Single-User MIMO(SU-MIMO) systems can grow linearly with the number of transmit or receive antennas. For the capacity of Multiuser-MIMO (MU-MIMO) systems, it was showed that similar capacity scaling can be achieved by using Dirty Paper Coding (DPC) techniques [18].The vision for next generation cellular networks includes data rates approaching 100 Mb/s for highly mobile users and up to 1 Gb/s for low mobile or stationary users. This calls for efficient use of the existing spectrum and MU-MIMO systems are expected to play a key role in this context [19].

Some advantages of MU-MIMO systems can be obtained with the aid of precoding techniques. By precoding we mean all methods applied at the transmitter that facilitates detection at the receiver [20]. Although precoding is not a new concept and has been used in SU-MIMO systems as well, it was optional and used only to improve the SNR at the receiver [21]. However, in MU-MIMO systems precoding is essential to eliminate or minimize Multiuser Interference (MUI). Precoding is performed with the help of downlink Channel State Information (CSI). The requirement of CSI is not essential in SU-MIMO systems but is fundamental for MU-MIMO systems. The assumption that full CSI is available at the transmit side is valid in Time-Division Duplex (TDD) systems because the uplink and downlink share the same frequency band. For Frequency-Division Duplex (FDD) systems, however, the CSI needs to be estimated at the receiver and fed back to the transmitter. With precoding techniques employed at the transmit side, the required computational effort for each user’s receiver can be reduced and eventually the receiver structure can be simplified [22].
types of precoding techniques, linear and non-linear. Linear precoding is characterized by its simplicity since the data signal is linearly transformed at the transmitter and the received signal is only weighted with a scalar before quantization. The nonlinear precoding is named from its nonlinear processing, and a superior performance is achieved compared to the linear precoding algorithms. A number of different techniques to address the issue of MU-MIMO downlink transmission and reception have been proposed [2, 22].

2. SYSTEM ARCHITECTURE

Precoding and detection algorithms are fundamental approaches to mitigating interference at the transmitter and receiver of modern wireless communication systems. In 5G systems, the heterogeneity and architecture of networks and the increasing levels of interference pose challenges for the design precoding and detection algorithms.

We consider a single cell downlink channel with an $M$ antenna BS serving a total $N$ single antenna users. The set $U$ consists of the integer indices of all users in the system. At any given instant, the BS transmits data for a subset $A \subset U$ where $|A| = M$. $A$ is the active user set that consists of the indices of the multiplexed users at a given scheduling instant. $A$ selected by greedy scheduling where the norm of all user channels are calculated and $M$ users with highest norm are selected such that

$$\tau = \arg \max_{\forall \tau \in U \setminus A} ||h_{\tau}||^{2}$$  \hspace{1cm} (1)

We initialize the active user set as an empty set, $A = \{\phi\}$. The BS transmits to $M$ different active users through $M$ antennas at any time instant. However, the transmitted signals for different users interfere with each other and thus corrupt the signal designated to any particular user. Thus, the received signal for user $k$ can be expressed as

$$y_{k} = h_{k}^{H}x_{k} + \sum_{j \neq k} h_{j}^{H}x_{j} + n_{k}$$ \hspace{1cm} (2)

where $h_k \in \mathbb{C}^{M \times 1}$ is the channel vector between the BS and user $k$, $x_k \in \mathbb{C}^{M \times 1}$ is the transmitted signal for user $k$ and $n_k$ is zero mean Gaussian noise. The transmitted vector for user $k$ is obtained by multiplying the beam forming vector $w_k$ and symbol $u_k$ as

$$x_{k} = w_{k}u_{k}.$$ \hspace{1cm} (3)

The beam forming vector $w_k$ is applied to avoid the interference caused by other transmitted signals. We stack the channel vectors to form a channel matrix $H \in \mathbb{C}^{M \times M}$ and beam forming vectors to form the precoding matrix $W \in \mathbb{C}^{M \times M}$ and thus the input-output relation can be written as

$$y = HWu + n,$$ \hspace{1cm} (4)

where $u$ is a vector of the original symbols, $n$ is the noise vector and $y$ is the received signal vector. Typically, precoders are designed with respect to a total power constraint of the form

$$E||X||^{2} = Tr\{WW^{H}\} \leq P$$ \hspace{1cm} (5)

Where total power, $P > 0$. Total power constraint simplifies the design problem and leads to simple precoders.
In particular, precoding algorithms must have access to the channels of all users in the system in order to perform interference mitigation, which is often carried out with the help of signal processing transformations. Among the existing precoders are vector perturbation, Tomlinson-Harashima and linear techniques, which exhibit different performance complexity trade-offs. Key problems in the design of precoders for 5G networks include the limitation of existing signal processing algorithms which are not scalable, the hardware impairments, inaccurate channel state information across networks with small cells, network MIMO concepts and users with mobility. In our 5G lab, we look at innovative solutions to the problems encountered in the design of precoders, namely:

- Low-complexity precoding strategies
- Robust precoding algorithms
- RF-aware pre-coding designs
- Pilot contamination

In the case of detection algorithms, the receiver must perform synchronization, channel estimation prior interference mitigation, which is often carried out with the help of either lattice searches or receive filters. Among the most effective detection algorithms are maximum likelihood detectors, sphere decoders, lattice-reduction techniques, decision-feedback schemes, successive interference cancellation and linear techniques, which exhibit different performance complexity trade-offs.
Key problems in the design of detectors for 5G networks include the limitation of existing signal processing algorithms which are not scalable to large-scale systems, hardware impairments, inaccurate channel state information across networks with small cells, network MIMO concepts and users with mobility and decoding delay when iterative detection and decoding algorithms are employed. In our 5G lab, we look at innovative solutions to the problems in the design of detectors, namely:
- Low-complexity detection algorithms
- Low-delay iterative detection and decoding techniques
- RF-aware detection algorithms

3. PRECODING ALGORITHMS
The linear precoding techniques under study are presented below.

**ZF Precoding:**
The zero-forcing (ZF) precoding strategy completely eliminates the interference between users by projecting the signals to be transmitted over the orthogonal complement of the components causing the interference between users. Consider the $k^{th}$ columns of the channel matrix and the precoding matrix respectively. The precoding process must be such that ZF precoding matrix can be expressed as

$$W = H^H(HH^H)^{-1}.$$  \hfill (a)

**MMSE Precoding:**
The precoding technique by means of a minimum error of the mean square error (MMSE) assumes that there will be interference between users, so its strategy is to minimize the average power of the error signal, i.e. the difference between the signal transmitted by the base station and the Signal estimated by the user, with a minimum quadratic error criterion. The precoding matrix that fulfills this characteristic. We use a regularization of the pseudo inverse to compute the MMSE precoding matrix as

$$W = H^H(HH^H + \alpha^2 I)^{-1}.$$  \hfill (b)

where $\alpha^2$ is the regularization factor. A non-zero regularization factor can be used to allow a measured amount of multi-user interference.

**ZF-DPC Precoding:**
Dirty paper coding (DPC) is a highly nonlinear technique and its implementation is a very challenging problem [10]. Zero forcing dirty paper coding (ZF-DPC) is a reduced complexity suboptimal DPC scheme that was first proposed in [11]. The channel matrix is decomposed to a lower triangular matrix $E \in C^{M \times M}$ and a unitary matrix $Q \in C^{M \times M}$ to apply the ZF-DPC. It converts the symbol vector such a way that multiplying the symbol vector with $L$ creates a diagonal matrix [12]. Afterwards, the modified symbol vector is multiplied by Hermitian transpose of the unitary matrix, $QH$ and transmitted over the channel. A new symbol vector $\tilde{u}$ to convert the non-diagonals of $L$ to zero can be obtained as

$$\tilde{u} = u_i - \sum_{j=1}^{i-1} l_{ij} u_j$$  \hfill (c)

where $u$ is the original symbol vector. ZF-DPC pre-cancels the interference without any loss of information.
4. SIMULATION RESULTS
For a BS with $M = 4$ antennas that serves $M$ active users out of a total $N = 20$ users, they are scheduling, matrix decomposition, precoding and power constraint. A norm-based greedy scheduling and total power constraint is used in this work. MMSE precoding is the primary focus of this work, but the designed in such a way so that it can support ZF-DPC too. QR-decomposition is used for matrix decomposition as it is needed for both precoding algorithms. We present the bit error-rate (BER) performance of ZF, MMSE and ZF-DPC precoders for various SNR in Fig. 3 and Fig.4. An additive white Gaussian noise (AWGN) channel is used for QPSK modulation and the BER is averaged over 100 000 Monte-Carlo trials.

**Figure 3** BER versus average SNR performance for different precoders for 16 QAM

**Figure 4** BER versus average SNR performance for different precoders for 64QAM
5. CONCLUSION & FUTURE SCOPE

Interference is one of the obstacles for accomplishing reliable high-speed data transmission over wireless media. Dirty Paper Coding (DPC) is used to eliminate known interference at the transmitter side and Zero forcing Channel Inversion (CI) is used to remove ISI at receiver side. Dirty paper coding (DPC) is capacity achieving for the MIMO broadcast channel.

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