Energy Efficient Linear and Non-Linear Precoders for Massive MIMO Systems

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ABSTRACT

The term Massive MIMO means, Massive multiple input multiple output also known as (large-scale antenna system, very large MIMO). Massive Multiple-Input-MultipleOutput (MIMO) is the major key technique for the future Fifth Generation (5G) of mobile wireless communication network due to its characteristics, elements and advantages. Massive MIMO will be comprised of five major elements; antennas, electronic components, network architectures, protocols and signal processing. We realize that precoding technique is a processing technique that utilizes Channel State Information Technique (CSIT) by operating on the signals before transmitting them. This technique varies base on the type of CSIT and performance criterion. Precoding technique is the last digital processing block at the transmitting side. In this paper, linear and non-linear Precoding technique was reviewed and we proposed two techniques under each that is Minimum Mean Square Error (MMSE), Block Diagonalization (BD), Tomlinson-Harashima (TH) and Dirty paper coding (DPC). Four Precoding techniques: MMSE, BD, DPC and TH were used in the studies to power consumption, energy efficiency and area throughput for single-cell and multi-cell scenarios. In comparing the proposed techniques, in terms of energy efficiency and area throughput, reuse factor (Reuse 4) performs better than other techniques when there is an imperfect CSI is used.

Keywords: *Massive MIMO, Precoding, CSI, antennas, base station, signals, linear/non-linear precoders.*

1 INTRODUCTION

Wireless communication was introduced in the 19th century and wireless communication technology has developed over the last decade and it one of the most important mediums of transmission of information from one device to other. The term wireless is often used to describe all types of devices and technologies not connected by a wire. A garage door opener and a television remote control are some examples of wireless devices. Devices like notebook computers, tablets, digital still picture and video cameras, printers, portable digital music players, even refrigerators, washing and drying machines, and electricity meters are equipped with the ability to communicate without wires [1] [2].

Wireless communications are defined as the transmission of digital data without the use of wires, meaning devices that can be interconnected

using some kind of data networking technology. Digital data may include e-mail messages, spreadsheets, and messages transmitted to or from a digital cellular phone.

It can also be defined as, transmitting of information through the air without requiring any cable or wires or other electronic conductors, by using electromagnetic waves like IR (Infrared), RF, satellite, etc. [3]. Wireless communications affect almost everything we do on a daily basis, like using cellular phones

to making voice calls and accessing information, counting of inventory in large retail stores, buying public transit system tickets, locating hotspots for Internet access and wireless remote sensors installed in locations that are difficult to access, using credit and debit cards that just need to be placed near a device instead of swiped or inserted, etc. There should be no question in anyone's mind

that the use of wireless devices will continue to expand into virtually every aspect of our lives [4]. Wireless communication has the following advantages: To enhance information quickly to the consumers. Working professionals can work and access the Internet anywhere and anytime without carrying cables or wires wherever they go.

Fig. 1. Block Diagram of Wireless Communications System

This also helps to complete the work anywhere on time and improves the productivity [5]. Doctors, workers and other professionals working in remote areas can be in touch with medical centers through wireless communication. An urgent situation can be alerted through wireless communication. The affected regions can be provided help and support with the help of these alerts through wireless communication. Wireless networks are cheaper to install and maintain. We can be in touch with the digital resources we need, no matter where we may find ourselves [6]. Nearly everyone has experienced dramatic changes based on wireless technologies, to the extent that we don't even think about what we are doing, we just expect devices [7]. The key contributions made in this paper are next:

- Four Precoding techniques namely MMSE, BD, DPC and TH were used in the studies in terms of power consumption, energy efficiency and area throughput for single-cell and multi-cell scenarios.
- In comparing the proposed techniques, in terms of energy efficiency and area throughput, reuse factor (Reuse 4) performs better than other techniques when there is an imperfect CSI is used

The rest of the paper is structured as follows. Review of related work is described in Section II. The system model and the proposed approach for precoders MIMO systems is declared in Section III. Performance analysis with some existing

conventional approach is described in Section IV. To end with, we conclude in section V.

Fig. 2. Wireless Communications Application

2 RELATED WORKS

MIMO (multiple input multiple output) is a method of increasing the performance of radio link using multiple transmit and receive antennas to achieve a multipath propagation [8]. It can also be the use of multiple antennas at the transmitter and the receiver or technique for sending and receiving more than one data signal simultaneously on the same radio channel by performing multipath propagation [9],[14]. It is an important element of wireless communication standards which includes IEEE 802.11n (Wi-Fi), IEEE 802.11ac (Wi-Fi), HSPA+ (3G), WiMAX (4G) and Long-Term Evolution (4G).

Fig. 3. Block diagram of MIMO Systems

Massive MIMO is a Multi-user MIMO (Mu-MIMO) with a large number of Base Station (BS) antennas and users and it has less number of transmitter terminals than the BS antennas [11]. This system uses antenna arrays with a very large number of antennas elements that makes use of service antennas over active terminal and Time Division Duplex (TDD) operation on a large scale [12],[23]. This technology is an upgrade of the current MIMO (Mu-MIMO) and extract all the

benefits of it but on a large scale. In this system, hundreds or thousands of BS antennas serves tens or hundreds of users simultaneously in the same time-frequency channel [13]. Massive MIMO is the next Generation network that is expected to be lunch across the globe by the year 2020 [15]. The concept of Mu-MIMO

System was proposed in 1991 by Richard Roy and Bjorn Ottersten [23]. Massive MIMO system components will have different ways of accessing higher frequency ranges and the motive of massive antenna setups are going to be direct-to device communication and ultra-dense deployments [24].

Fig. 4. Block diagram of MIMO Systems

Signal processing deals with the impairments of the physical medium and acquiring a low-cost effective tool for processing information is an extremely role for MIMO signal processing [16]. This signal processing needs a computational cost for transmitting and receive processing which grows as cubic or super-cubic functions of the number of antennas that is certainly not effective with a large number of antennas elements [17]. The need of simpler solutions for the transmit and receive processing task will need signal processing under Massive MIMO System will require novel signal processing to deal with all the problems like computational complexity and its scalability, RF impairment, coupling effects, pilot contamination, delay and calibration issues [18] [19].

This is a processing technique that utilizes CSIT by operating on the signals before transmitting them [20], [21]. This technique varies base on the type of CSIT and performance criterion [22] and it is the last digital processing block at the transmitting side as shown in Figure 7. Improvement of link performance and reduction of the corrupting effect of the communication channel are some of the main aims of this technique. In precoding technique, every transmits signals processing involves CSIT [25].

Fig. 5: Massive MIMO System Antenna Configurations

Fig. 6. The structure of Precoding System

3 APPROACH TO LINEAR AND NON-LINEAR PRECODING TECHNIQUES

A. System Model

Consider the Massive MIMO broadcast channel with, N_t transmit antennas at the base station (BS), N_i receive antennas at i 'th user equipment, K number of users equipment and N number of receive antennas per user. The total number of receive antennas can be represented as [23]:

$$N_r = \sum_{i=1}^k N_i \quad (1)$$

The received signal is represented by y , for the i 'th user equipment, the received signal is represented as:

$$y_i = H_i x + n_i \quad (2)$$

Which is also represented by independent and identical distribution matrix:

$$\begin{bmatrix} y_1 \\ \vdots \\ y_i \end{bmatrix} = \begin{bmatrix} H_1 & 0 & 0 \\ \vdots & \vdots & \vdots \\ 0 & 0 & H_i \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_i \end{bmatrix} + \begin{bmatrix} n_1 \\ \vdots \\ n_i \end{bmatrix} \quad (3)$$

Where H_i is the i th users channel gain matrix, x is the transmitted symbol of the user and $n_i C$ ($N_r 1$) represents the i th users AWGN noise symbol vector of the user i having the size of ($N_r 1$) for the information transmitted signals. P precoding matrix. At the base station, the perfect Channel State Information (CSI) receive as a channel gain matrix H . Whiles imperfect CSI is given by a noisy channel matrix.

$$H_e = H + E \quad (4)$$

$$H = [H_1^T \dots H_k^T]^T \in C^{N_r \times N_t} \quad (5)$$

$$P = [P_1 \dots P_k]^T \in C^{N_r \times N_t} \quad (6)$$

Where $H(i)C(N_i N_i)$ is the i th users channel matrix. The quantity $P(i)C(N_i N_i)$ is the i th users precoding matrix.

B. Linear Precoders Strategy

In this section, the minimum square error (MMSE) and block diagonalization algorithm procedure is described briefly as follows. In linear precoding, we employed the technique of MMSE to reduce throughput to avoid constantly presence of zero-forcing precoding. To minimize the presences of MSE (mean squared error), the precoding is given by:

$$\min_p \sum_{i=1}^k \left| x_i - y_i / E^{(i,i)} \right|^2 \quad (7)$$

Where $E(i; i)$ signifies the i th diagonal element of the matrix. Again, the precoding matrix of MMSE is given as:

$$P_i = H_i^H (H_i H_i^H + \beta I_i)^{-1} \quad (8)$$

Where P_i indicates the precoding matrix for the user i th with size of ($N(i)N$), I is the identity matrix and β represents the normalization factor, which is given as:

$$\beta_i = \frac{N_t}{SNR_i} \quad (9)$$

We discuss the Block Diagonalization (BD) algorithm and the procedure to obtain the precoding matrix P . In BD algorithms, the first precoding filter is used to transform a Massive MIMO channel into a block channel. The

reduced channel matrix for the i th user is defined as

$$\bar{H}_i = [H_1^T \dots H_{i+1}^T \dots H_K^T]^T \in C^{\bar{N}_i \times \bar{N}_i} \quad (10)$$

Where $N_i = N_r - N_i$. The first precoding matrix is given as:

$$P_i^\alpha = \bar{V}_i^{(\alpha)} \quad (11)$$

Where, $V_{(i(0))(N_i(N_i - R_i))}$ is obtained by performing the SVD decomposition of H_i . R_i is the rank of the channel gain matrix H_i . The combined precoding matrix is given by,

$$P_i = P_i^\alpha P_i^\beta \quad (12)$$

Where, $P_{ia}(N_i L_i)$ and $P_{ib}(L_i N_i)$. The parameter L_i is dependent on the specific choice of the precoding algorithm.

C. Non-Linear Precoders Approach

Algorithms for Tomlinson-Harashima and Dirty Paper Coding of non-linear Precoding are as follows with the same system model as the linear Precoding. Where F is the $N_r K N$ feedforward matrix obtained by an LQ decomposition of the channel matrix H and the input is computed element by the element. Where b_{lq} are the elements of the $K N K N$ lower triangular matrix.

$$x[i] = F \tilde{x}[i] \quad (13)$$

$$\tilde{x}[i] = \text{mod} \{ s_l[i] - \sum_{q=1}^{l-1} b_{lq} x_q[i] \}, l = 1 \quad (14)$$

This technique of interference transmission can be known by subtracting the potential interference before transmission.

It is very important to know the channel gain completing at the transmitter side before implementing DPC. These Precoding techniques are implemented when the channel gains are completely known on the transmitter side. If $K=3$ user, the received signal is given as:

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} H_1^{DL} \\ H_2^{DL} \\ H_3^{DL} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix} + \begin{bmatrix} Z_1 \\ Z_2 \\ Z_3 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix} \quad (15)$$

The channel matrix H_{DL} can be LQ -decomposed as:

$$H^{DL} = \begin{bmatrix} l_{11} & 0 & 0 \\ l_{21} & l_{22} & 0 \\ l_{31} & l_{32} & l_{33} \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix} \quad (16)$$

$H^{DL}(13)$ is the channel matrix between BS and i th user. The received signal for the first user is given as:

$$y_1 = l_{11}x_1 + z_1 + n_1 \quad (17)$$

$$x_1 = \overline{X_1} \quad (18)$$

Received signal for $K = 3$ user,

$$y_3 = l_{31}x_1 + l_{32}x_2 + l_{33}x_3 + z_3 + n_3 \quad (19)$$

Combining equations, P is the precoding signals expression:

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = P \begin{bmatrix} \tilde{x}_1 \\ \tilde{x}_2 \\ \tilde{x}_3 \end{bmatrix} \quad (20)$$

The equation can be re-write as;

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} l_{11} & 0 & 0 \\ 0 & l_{22} & 0 \\ 0 & 0 & l_{33} \end{bmatrix} \begin{bmatrix} \overline{x_1} \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix} \quad (21)$$

Base on the above formulations, the channel gain matrix can be obtained by considering the scaled inverse matrix of the lower triangular matrix.

$$P = \begin{bmatrix} l_{11} & 0 & 0 \\ l_{21} & l_{22} & 0 \\ l_{31} & l_{32} & l_{33} \end{bmatrix}^{-1} \begin{bmatrix} l_{11} & 0 & 0 \\ 0 & l_{22} & 0 \\ 0 & 0 & l_{33} \end{bmatrix} \quad (22)$$

4 SIMULATION RESULT AND PERFORMANCE ANALYSIS

Simulation of energy efficiency, average power, radio frequency power and radiated power per BS for number of antennas and the number of users were conducted together with all the proposed Precoding techniques that are MMSE, BD, DPC and TH. MATLAB was the software for the simulation. Figure 7, shows the flowchart of the simulation process.

Fig. 7. A Flow Chart of the Simulation Process.

We have demonstrated in Figure 8.0 the probably achieved energy efficiency values with proposed techniques in perfect CSI for diverse K and N_t values. This provides an optimal energy efficiency that is resilient to rapid changes in distributed network system.

Table 1: Simulation Parameters

Parameter used	Value
No. of base station antenna(BS)	200
Energy efficiency	35
No. of active users	150
Cell radius: $d_{\max}$	250m
Distance between Users and base station	35m
Average power	$10^{-2} - 10^2$
Area throughput	0-9
Coverage area (area Single cell)	$\pi (d_{\max}/1000)^2$
Coverage area (area multi cell)	$4 * (d_{\max}/1000)^2$
Regulate channel attenuation at minimum distance	$10^{-3.53}$
Path- loss exponent	3.76
Transmission bandwidth	20 MHz

Channel coherence bandwidth	180kHz
Channel coherence time	10ms
Total noise power	-96dBm
Fraction of downlink transmission	0.4
Fraction of uplink transmission	0.5
Power required to run the circuit components at BS	1W
Power required to run the circuit components at Users	0.1W
Power required for coding of data signal signals	0.1W/(Gbit/s)
Power required for decoding of data signal signals	0.8W/(Gbit/s)

Simulation was conducted for MMSE and BD for energy efficiency and average power and below are the results: Simulation was conducted for TH and DPC for area throughput and below is the result. From figure 9 and 10, linear precoding method was used to verify the appropriate techniques. Similarly, Figure 11 as nonlinear precoding techniques, verified the same approachable techniques. For the cases of multi-cell scenarios in Figures 9 to 11, similar conclusions are achieved as in single-cell scenarios using few antennas. Therefore, there is reduction in transmit power consumption and area throughput which affects the energy efficiency in the network. We observed that the highest reuse factors (Reuse 4) yields better area throughput and maximum energy efficiency.

5 CONCLUSION AND FUTURE WORK

Massive MIMO using Precoding techniques have proved to improve signal transmission from the transmitter through the cooperative relays to the receiver. Multiple antennas are used at both at both transmit and receive side. Four Precoding techniques: MMSE, BD, DPC and TH were used in the studies to power consumption, energy efficiency and area throughput for single-cell and multi-cell scenarios. In comparing the proposed techniques in terms of energy efficiency and area throughput in reuse factor (Reuse 4) performs better than other techniques when there is an imperfect CSI is used. We also realize that energy efficiency

increases as the number of users are increasing, more antennas are needed for signal transmission from sorts to destination and when the number of users' increases with less number of antennas there will be more power and energy consumption. In future, we hope to apply the precoding techniques based on reuse perfect CSI in signal transmission.

Fig. 8. A plot of energy efficiency with precoding techniques in the single-cell

Fig. 9. A plot of energy efficiency in the multi-cell scenario for different number of precoding antennas and different pilot factors.

Fig. 10. A plot of average power in maximizing energy efficiency for multi-cell scenario, using different precoding antennas different reuse factors.

Fig. 11. A plot of area throughput in maximizing energy efficiency for multi-cell.

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