Performance Analysis of Linear Precoding in Downlink Based on Polynomial Expansion on Massive MIMO Systems

Sammaiah Thurpati¹, Mahesh Mudavath², and P. Muthuchidambaranathan³

¹ Research Scholar, Department of ECE, National Institute of Technology, Tiruchirappalli, India
² Department of ECE, Vaagdevi College of Engineering, Warangal (Telangana State), India
³ Corresponding author E-mail: sammaiah_404@yahoo.com, mahichauhan@gmail.com, muthuc@nitt.edu

Abstract: - The performance of linear precoding schemes in downlink Massive MIMO systems is dealt with in this paper. Linear precoding schemes are incorporated with zero-forcing (ZF) and maximum ratio transmission (MRT), truncated polynomial expansion (TPE), regularized zero force (RZF) in Downlink massive MIMO systems. Massive MIMO downlink output is evaluated with linear precoding included. This paper expresses the performance of achievable sum-rate linear precoding with variable signal-to-noise (SNR) ratio and achievable sum rate and several transmitter-receiver antennas, such as imperfect CSI, less complex processing, and inter-user interference. The transmitter has complete state information on the channel. The information narrates how a signal propagates to the receiver from the transmitter and reflects, for example, the cumulative effect of distance scattering, fading, and power decay. They show that the performance analysis of two linear precoding techniques, i.e., Maximum Ratio Transmission (MRT) and Zero Forcing (ZF) for downlink mMIMO output network over a perfect chain. The results show the improved ZF precoding achievable sum rate compared to the MRT precoding schemes and compared the average achievable rate RZF and TPE.

Index Terms— massive MIMO (mMIMO), precoding, zero-forcing, matched filter, truncated polynomial expansion, regularized zero-forcing, average achievable rate.

1. INTRODUCTION

Nowadays, the mobile communication network having several users is growing exponentially. Through mobile communications technology, users must have a more data rate low latency, and full mobility communications networks. Mobile communication technology needs to upgrade the infrastructure to satisfy the demands of the market. To reach a broader bandwidth, the mobile communications network is now moving into the 5th generation and working on the massive MIMO and millimeter wave spectrum [1].

However, the 5th generation organizes the recently developed subsystems on its network, one is an antenna subsystem and the other one is a beam-forming subsystem. A multi-input multi-output (MIMO) antenna subsystem is implemented by the latest mobile communications technology. When the massive MIMO there are many antennas. Therefore, one is a transmitter and the other one is a receiver. The massive MIMO has certain leads in terms of channel power, spectral efficiency, reducing interference [1]. Because of its ability to bit error rate, signal-to-noise ratio, feasible sum rate, and reduce interference, the mMIMO was a tropical research matter. The transmitter is fitted with large numbers of antennas assisting multiple users with single or multiplied receiver antennas. There will be a multipath between transmitter and
receiver, multiple users are served simultaneously. Interference under these conditions may theoretically occur.

mMIMO technology has been also recently called the huge Scale MIMO. This mMIMO technology is a huge base station (BS) transmitting antennas [6] and a small number of offering antennas are used by the user terminal (UE) for communication systems. The major interference of the suppression gains and the array gain from the mMIMO that allows the control consumer spectral efficiency and the cell total spectral efficiency have been significantly improved [2]. mMIMO technology is now attracting considerable academic and industrial attention. Most studies were considering the performance of uplinks. In this paper, we are researching a huge downlink framework from mMIMO with linear precoding schemes.

The mMIMO provides spectral efficiency increases in energy efficiency and radiation compared with the 4G wireless technologies. Hence, the massive MIMO technology is a forward-looking innovative 5G communication technology [2,3]. The high consumption of downlink overhead channels and feedback required to obtain the CSI of each user will eventually limit the number of BS antennas [4]. BS downlink transmission can effectively reduce the associated signaling overhead according to the uplink channel estimate.

Precoding is a part of the massive processing of MIMO signals. A precoding/beamforming module introduced would add massive enhancements to MIMO. Precoding is made up of two forms, one of which is non-linear and the other linear. Several earlier studies have expressed the efficiency of both. The authors in [3] proposed zero-forcing precoding efficiency and studied the relationship for precoding maximum ratio transmission between vector and matrix normalization.

Meanwhile, in the sense of MIMO’s huge downlink in [4], the author has studied the feasibility of maximum ratio transmission and zero-forcing. In [5] the authors discussed the success in downlink massive MIMO for non-linear precoding of the combination of statistical and imperfect channel state information (CSI). This concept explores the precoding techniques of zero-forcing and maximum transmission ratio as well as the regularized zero-forcing (RZF), truncated polynomial expansion (TPE) in downlink mMIMO.

This paper studies the linear precoding in downlink massive MIMO with a full channel state information transmitter (CSIT). Linear precoding involves maximum transmission ratio (MRT) and zero-forcing (ZF), regularized zero-forcing (RZF), truncated polynomial expansion (TPE). The paper is structured according to the following. Section I presents the introduction, previous plays, and the history of this study. The model of this work for the MIMO system is outlined in section II. Section III presents the achievable sum-rate for different techniques. Section IV and V give results and explanation of the precoding performance and Section VI conclude the work.

2. SYSTEM MODEL

Here we consider the downlink of an mMIMO scheme to be a single cell, in which BS with M antennas transfers data in a single antenna to K user terminals (UTs). The channel has a Rayleigh fading channel with zero mean and variance of $\lambda_k$ (Fig. 1). This work employs a single-cell model. Fig 1 represents an mMIMO model of the single-cell downlink. For all users, the transmitter has perfect CSI. The Massive MIMO platform uses configuration Rayleigh channel [18]. The channel which has the transmitter and user coupling is shown in Fig.1 Furthermore, the precoding locality is also viewed in Fig.2. As illustrated in Fig.1, mMIMO device consisting of the BS equipped with M antennas and K(« N) UTs, each UT provided with one antenna. We assume in this paper that the BS supporting UTs over the Rayleigh fading channel will obtain perfect channel state information on a certain frequency or subcarrier. The signal vector is transmitted to the K users during the downlink transmission, where $M > K$ can be expressed as

$$r = \sqrt{\rho W_s}$$  (1)
Where \( W \in \mathbb{C}^{M \times K} \) is the linear precoding matrix \( S \in \mathbb{C}^{M \times 1} \) is the precoding source data, and \( \rho \) is the moderate transmission power of the BS. Here, both \( M \) and \( K \) are huge, and their ratio is supposed to be persistent \([24]\). The precoding matrix \( W \) is a justification of the channel matrix defines by \( H \in \mathbb{C}^{M \times K} \). The power of the original signal being transmitted is normalized, i.e., \( s^2 = 1 \).

![Fig. 1: massive MIMO system on a downlink](image1)

![Fig. 2: linear precoding system in massive mimo](image2)

Let ‘\( r \)’ is \( M \times 1 \) Precoded vector with a complex information symbol transmitted from the base station antenna. The signal that the \( y \in \mathbb{C}^{K \times 1} \) user antenna receives is then given as \([13]\).

\[
y = H^H r + n_s
\]

\[
r = \sqrt{\rho} H^H W_s + n_s
\]

Where \( H \) is the \( M \times K \) channel matrix between the \( M \) is an antenna at BS and the \( K \) is device terminals. \( n_s \in \mathbb{C}^{K \times 1} \) is the additive white Gaussian noise (AWGN) with zero mean and variance \( \sigma^2 = N_0 B \). Here the AWGN channel length and spectral power density denote by \( B \) (Hz) and \( N_0 \) (W/Hz) respectively.

\[
A_{ZF} = H^H (HH^H)^{-1}
\]

\[
A_{MRT} = H^H
\]

For \( K \) and many \( Z \), the \( k \)th user interference signal to noise ratio, ZF, and MRT precoding is prepared as follows.
2.1 Normalization method
The linear precoder with zero-forcing and maximum transmission is known as the normalization of the vector and the matrix. The normalized transmission of vectors or matrix beamforming vectors are given as the \( \frac{1}{\| \mathbf{a} \|} \) and \( \frac{1}{\| \mathbf{A} \|} \) respectively, the normalization of the vector applies equal power per downlink channel, whereas the matrix normalization relents various power streams.

2.1.1 vector normalization of ZF/MRT: The received signal at the \( k \)th UE can be expressed in the equation below

\[
y_k = \sqrt{p_d} h_k^T \frac{a_k}{\| \mathbf{a} \|} s_k + \sqrt{p_d} \sum_{i=1, i \neq k}^{K} \frac{h_i^T}{\| \mathbf{a} \|} a_i s_i + n_k
\]  

2.1.2 matrix normalization of ZF/MRT: The received signal can be written matrix normalization as in the equation below

\[
y_k = \sqrt{p_d} h_k^T \frac{a_k}{\| \mathbf{a} \|} s_k + \sqrt{p_d} \sum_{i=1, i \neq k}^{K} \frac{h_i^T}{\| \mathbf{a} \|} a_i s_i + n_k
\]

3. ACHIEVABLE SUM RATE
This The achievable sum rate of precoders ZF and MRT is argued in [12], Assuming full downlink power is set and divided uniformly among all users. The Shannon theorem acquires the achievable rate over the additive white Gaussian noise (AWGN) as a function of the signal-to-noise ratio (SNR) [12].

\[
D = \log_2 (1 + SNR)
\]

The SNR is the signal-to-noise ratio. The channel state information (CSI) is a very crucial matter in multiuser communication systems. Normally each user emits data streams of multiple transmitters periodically and systematically to the CSI [11]. All the transmitters receive the channel evaluation response from the receiver to the reverse path, so the transmitter acquires CSI. The transmitter, therefore, communicates with only the complete CSI with all receivers [9]. As can be seen in equation (2), additive noise and interference between the users themselves is the signal emitted to each unit. Therefore, in a single cell downlink mMIMO network the obtainable information rate per user is defined with perfect channel state information.

\[
D_k = \log_2 (1 + SNR_k)
\]

Where SINR of the \( k \)th user is \( \text{SINR}_k \). The achievable sum rate of ZF and MF precoders with optimal CSI for huge values of \( M \) and \( K \) [5].

The achievable sum rate of \( K \) users as formulated as:

\[
SINR_{ZF}^k = \frac{p_d (Z - K)}{K} \\
SINR_{MRT}^k = \frac{-p_d (Z)}{K(p_d + 1)}
\]
\[ D_{\text{sum}} = K \log_2 (1 + \text{SNR}_k) \]  

3.1 achievable sum rate with ZF

The formula (12) has been applied in zero-forcing; the following are described [7] [8].

\[ D_{\text{sum}}^{ZF} = K \log_2 (1 + \text{SNR}_k^{ZF}) \]  

Substituting (6) into (13) gives

\[ D_{\text{sum}}^{ZF} = K \log_2 \left[ 1 + \frac{p_d(Z - K)}{K} \right] \]  

The zero-forcing using vector normalization/matrix normalization methods are given in the following equation

\[ D_{ZF_{vec}}^{ZF_{mat}} = D_{ZF_{mat}}^{ZF_{vec}} = K \log_2 \left[ 1 + \frac{p_d(Z - K)}{K} \right] \]  

3.2 Achievable sum Rate with MRT

The MRT of the achievable sum-rate is also deductible from (12) as

\[ D_{\text{sum}}^{MRT} = K \log_2 (1 + \text{SINR}_k^{MRT}) \]  

Substituting (7) into (16) gives

\[ D_{\text{sum}}^{MRT} = K \log_2 \left[ 1 + \frac{p_d(Z)}{K(p_d + 1)} \right] \]  

MRT is using methods of vector normalization/matrix normalization is given by below

\[ D_{MRT_{vec}}^{MRT_{mat}} = D_{MRT_{mat}}^{MRT_{vec}} = K \log_2 \left[ 1 + \frac{p_d(Z)}{K(p_d + 1)} \right] \]  

As the number of transmitting antennas hikes with \( Z >> K \), Equations (14) and (17) indicate that the same downlink transmits power available and a rigid number of mobile users. ZF reaches data rates higher than MRT.

3.3 regularized zero forcing precoding

The BS is armed with M antennas and supports K User Terminal with a single antenna. The complex baseband signal obtained represents the collection of complex numbers per C

\[ y_k = h_k^H X + n_k \quad k=1,\ldots,K \]
where $X \in \mathbb{C}^{M \times 1}$ is transmitted signal and $h_k$ represent a specific variable to the BS channels and the $k$th UT. The spatially linear additive Gaussian noise $k$th UT is expressed by the $n_k \sim \mathcal{CN}(0,\sigma^2)$ for $k=1,\ldots,K$, where $\sigma^2$ is the noise variance. The BS utilizes Gaussian code and precoding. In light of this suspicion, the transmitted signal in (19) can be communicated as

$$X = \sum_{n=1}^{K} u_n v_n = Uv$$

The matrix representation is defined by charter $U=[u_1,\ldots,u_K] \in \mathbb{C}^{M \times K}$ be matrix of the precoding and $v = [v_1,\ldots,v_K] \sim \mathcal{CN}(0_{K \times 1},I_K)$ is the vector that carries all symbols of UT data.

So, the signal received (19) can be indicated as

$$y_k = h_k^H u_k v_k + \sum_{n=1, n \neq k}^{K} h_n^H u_n v_n + n_k$$

The signal-to-interference noise ratio (SINR) at the $k$th UT [17] changes

$$\text{SINR} = \frac{h_k^H u_k u_k^H h_k}{h_k^H U_k U_k^H h_k + \sigma^2}$$

By taking that each perfect instantaneous CSI has UT, the achievable rates in the UTs are

$$r_k = \log_2 (1 + \text{SINR}_k) \quad k=1,\ldots,K$$

Regularized zero-forcing (RZF) precoder was known as a linear precoder for mMIMO wireless communication systems due to its ability to trade compensation for MRT and ZF precoders [13],[14],[15],[16].

**Assume the total power constraints**

$$\frac{1}{K} \text{tr}(UU^H) = P$$

we specify the scaling factor $1/K$ counteracts the channel variance scaling, and $\text{tr}(.)$ is the trace function. We density the total power $P$ is set, though we allow antennas number $M$ and UTs $K$ to grow large.

Like that to [22], we specify the ZRF precoding as

$$U_{ZRF} = \gamma (\hat{H}^H \hat{H} + \varsigma I_k)^{-1} = \gamma \hat{H}(\hat{H}\hat{H}^H + \varsigma I_M)^{-1} \hat{H}$$

(25)
Where the variable for power normalization $\gamma$ is set so that $U_{ZRF}$ achieves the power limit in (21). Regularization of the scalar coefficient. The $\zeta$ can be chosen the various ways, based on $P$, $\sigma^2$, $\tau$, and device proportion.

The user efficiency characteristic in $\text{SINR}_d$ in (22). Whereas the SINR is a randomized quantity. The SINR be conditional on the instant random user channel values in $H$ and the instant estimate of $\hat{H}$ the large ($M, K$) regime [23–26] can be used to estimate deterministic quantities. Such tests change based on channel statistics and are frequently mentioned as finding equivalents, as they are within the asymptotic limit almost definitely.

This process of stiffening property is due in part to the law of large numbers. The speaker Hachem has been proposed for first deterministic equivalents. In [23], Who also demonstrated their capture capability essential measures of system performance. Once applied to finite $M$ and $K$ the deterministic equivalents are pointed to as huge scale extrapolations.

A) Imperfect Channel State Information at BSs:
Uplink pilot transmissions are used to receive instant CSI based on the TDD protocol at each BS. Yet each of the UT in such a cell detects a reciprocally orthogonal pilot pattern, Due to the incomplete channel coherence of the fading channels, The equal set of orthogonal chains is reused in each cell. Thus, pilot interference originating from neighboring cells weakens the channel estimate [27]. When testing the User Terminal $k$ channel in cell $j$ the subsequent BS takes its pilot signal obtained and compares it to the pilot sequence of this UT.

$$y_{j,k}^{tr} = h_{j,k} + \sum h_{j,l,k} + \frac{1}{\sqrt{\rho}} q_{j,k}^{tr}$$  \hspace{1cm} (26)

Where $q_{j,k}^{tr} \sim \text{CN}(0_{M \times 1}, I_M)$ and $\rho > 0$ is effective training SNR [30]. The Matched Filter estimate $h_{j,k} + h_{j,l,k}$ is given as [31].

B) Issues of RZF in complexity:
Where the precoding of the SINR achieved by RZF converges in the major reign. However, random quantities of precoding matrices that need to be retrieved at the same rate as channel command are modified, so with the typical consistency of fewer milliseconds, they are essential to reverse hundreds of times per second to calculate the large-dimensional matrix. The number of arithmetic activities needed for matrix expression grows cubically in the matrix range, rendering this matrix operation inflexible in huge-scale devices, reducing the complexity of implementation and retaining the majority of RZF performance; Precoding of low-complexity TPEs for single-cell systems was proposed in [28] and [29]. The latest precoding strategy has two advantages over RZF precoding 1) at the beginning of each coherence interval the pre-coding matrix is not pre-computed, so there are no mathematical loops, and the mathematical processes are distributed over time uniformly. 2) The precoding method is classified into easy matrix-vector integer arithmetic which can be extremely parallel and implemented.

4. TPE Precoding
The idea of truncated polynomial expansion (TPE) is, we furnish the multi-cell scenario with a new type of low complication linear precoding strategy. We recalled that the definition of TPE comes from those in the
Cayley-Hamilton theorem stating that it is possible to write the extreme of a dimension M matrix F as a calibrated amount of the first M power.

\[ F^{-1} = \frac{(-1)^{M-1}}{\det(F)} \sum_{i=0}^{M-1} \alpha_i F^i \]  

(27)

where \( \alpha_i \) is the coefficient of the habitual polynomial. The simplified precoding is evaluated by taking only a truncated number of the matrix capabilities.

For \( Z_j = 0_{M \times M} \) and truncated order of TPE precoding \( J_j \).

\[ U_j^{TPE} = \sum_{n=0}^{J_j-1} w_{n,j} \left( \frac{\hat{H}_{j,j} \hat{H}_{j,j}^H}{K} \right)^n \frac{\hat{H}_{j,j}}{\sqrt{K}} \]  

(28)

and \( w_{n,j}, j = 0,...,J_j - 1 \) are the \( J_j \) scalar coefficients that are used in cell \( j \). Meanwhile, RZF precoding only the design parameter \( \phi_j \), the proposed TPE precoding scheme is a larger set of \( J_j \) design parameters. These concepts of polynomial coefficients explanation a parameterized class of precoding schemes ranging from MRT to RZF precoding when \( J_j=\min(M, K) \) and \( w_{n,j} \) specific by the coefficients establish on the characteristic polynomial of \( \sqrt{K} (\hat{H}_{i,j} \hat{H}_{i,j}^H + K\phi_j I_M)^{-1} \) we mention to \( j \) as the TPE order to the jth cell and polynomial coefficient in(28) is \( J_j -1 \). For an ability that would choose to maximize proper device performance metric[28]. An starting option is

\[ w_{n,j}^{initial} = \beta_j k_j \sum_{m=n}^{J_j-1} \left( \frac{m}{n} \right)(1-k_j \varphi_j)^{m-n} (-k_j)^n \]  

(29)

Where \( \beta_j \) and \( \varphi_j \) are in RZF Precoding can take any value to \( ||I_M - k_j \left( \frac{1}{K} \hat{H} \hat{H}^H + \varphi_j I_M \right)|| < 1 \). This equation is determined by calculating a Taylor expansion of the matrix inverse. The coefficients in (29) provide performance near to that of ZRF precoding when \( J_j \to \infty \) [28]. However, we can acquire far and away superior execution than the imperfect RZF, using just little TPE orders.

5. SIMULATION RESULTS

Six cases represent the performance analysis for linear precoding techniques i.e., ZF and MRT, based on the method of vector normalization, the method of matrix normalization, and the contrast of the two methods of normalization. The findings are presented in displayed achievable sum-rate (bit/s/Hz) vs the number of base station antennas and the achievable sum-rate vs the number of users.

Fig.3 displays the achievable sum-rate according to calculations over the whole antenna spectrum (15 and 18). This method is made up of the number of antennas and users \( M=1:256, \quad K=10 \). The results show that MRT offers better performance at low power value and better performance when the number of base station antennas at high power is less than 50. On the other hand, ZF provides better high-power efficiency when the number of base station antennas reaches 50.
Fig. 3: ZF and MRT efficiency with vector normalization at K=10 users

Fig. 4 displays the achievable sum-rate according to equations over the entire user range (15 and 18). This method is made up of the number of antennas and users M= 256, K= 1:10. The results show that when the number of users is up to six users and up to four at high power, MRT delivers the better performance at low power value, ZF gives better results when the number of users at high power is greater than four and at low power is greater than six.

This segment shows the performance of ZF and MRT in a single-cell downlink mMIMO network over a perfect channel by taking into account the achievable sum rate depending on the method of matrix normalization. Select user numbers K= 10 and antenna numbers are 256. Then set the transmitting power downlink to 0dBm and -15dBm for the BS.

Fig. 4: ZF and MRT efficiency with vector normalization at M=256 and k=1:10
Fig. 5: ZF and MRT efficiency with matrix normalization at k=10 and M=1:256

Fig. 5 shows the achievable sum-rate according to the equations over the entire user range (15 and 18). This method is made up of the number of antennas and users M=1:256, K=10. The results show that the number of antennas is greater than 22 antennas, ZF fares better at a high power value.

Fig. 6: ZF and MRT efficiency with vector normalization at k=10 and M=256

Fig. 6 displays the achievable sum-rate according to equations over the entire user range (15 and 18). This method is made up of the number of antennas and users M=256, K=1:10. The results show that when the number of users is less than seven users and less than five users at MRT e at low power value. On the other hand, ZF provides better results when the number of users at high power is greater than four, and at low power is greater than seven.
Fig. 7 shows the achievable sum-rate according to equations over the entire antenna range (15 for ZF and 18 for MRT). This method is made up of the number of antennas and users $M=1256$, $K=10$. The downlink power transmitted is $-15$ dBm. The results show the same output provided by vector and matrix normalization for ZF. The MRT and ZF give equal performance than the number of antennas greater than 60 at a low power value.

This segment gives a numerical approval of the proposed TPE precoding in fig. 8 a down-to-earth arrangement situation. We consider a four-part site $L=4$ made out of cells and BSs. see Fig.1. Like the channel model introduced in [32], we expect that the UTs in every cell is separated into $G=2$ gatherings in fig. 9. UTs of a gathering share roughly a similar area and factual properties.

![Matrix normalization vs Vector normalization](image1)

Fig. 7: Matrix versus Vector normalizations at $k=10$, $M=1256$ and $P_d=0$ dBm

![Average UT rate vs. transmit power to noise ratio](image2)

Fig. 8: Average UT rate vs. transmit power to noise ratio for different orders $J$ in the TPE precoding ($M=512$, $K=256$, $\tau=0.3$).
Let's see Fig. 8. It sees a $J=4$ TPE order and three separate CSI quality levels at the BS: From Fig. 8, We see it when a poor channel estimate is available, RZF and TPE accomplish nearly the same typical UT performance Additionally, at low SNR values, TPE and RZF perform almost similarly for any $\tau$. The understandable observation is that the difference in the rate increases at high SNRs and when $\tau$ is small.

Fig. 9 The relationship between the average attainable UT level and the TPE order $J$ is more clearly seen. To be in a regime where TPE performs poorly (see Fig.8) and the precoding complexity becomes a problem, we consider the case $\tau=0.3$, $M=512$, and $K=256$. From the figure, we can see that choosing a greater value for $J$ gives a TPE performance closer to RZF's. The proposed TPE precoding never surpasses the RZF efficiency, which is remarkable because TPE has $J$ degrees of freedom that can be optimized, while RZF has only one design parameter.

6. CONCLUSION

This paper offers an examination and investigation of direct precoding in mMIMO in a single-cell downlink. The parameters contemplated are the achievable sum-rate with a distinction in the number of dynamic users and the signal to noise ratio. Simulation results show a superior rate of error created by the MRT precoding scheme. The ZF precoding strategy, in the meantime, gives a superior achievable sum rate. A massive MIMO organize offers the chance to increment the achievable sum rate. The achievable sum rate changes for ZF and MRT when numbering the base station antenna 512. The achievable sum rate upgrades for ZF and MRT (18.8207 dBm and 16.6465dBm respectively at 0dBm and 10.2418dBm and 10.4415 dBm at 15dBm); Therefore vector/matrix normalization for ZF gives better performance at high downlink transmission power, while above normalizations MRT provides better performance at low downlink transmission power. This paper sums up the recently proposed TPE precoder to MIMO systems with multicell huge scale. This type of precoder series from the exceptional mind complex RZF precoding system through a truncated polynomial creation approximates the regularized channel reversal. The model contains basic multi-cell highlights, for example, client explicit channel measurements, different TPE arranges in various cells, and force requirements explicit to the cells. We acquired SINR expressions asymptotic.
7. References

[1] Subuh Pramono, Eddy Triyono on “Comparative Performance Analysis of Linear Precoding in Downlink Multi-user MIMO”, Proceeding of EECSI 2018, Malang - Indonesia, 16-18 Oct 2018.

[2] J.C. Guey, P. K. Liao, Y.S. Chen, A. Hsu, C. H. Hwang, G. Lin, “On 5G radio access architecture and technology [Industry Perspectives],” IEEE Wireless Communications, vol.22, no.5, October 2015.

[3] L. Zhao, K. Zheng, H. L. H. Zhao, W. Wang, “Performance Analysis for Downlink Massive MIMO System with ZF precoding,” Transactions on Emerging Telecommunications Technologies, vol.8, no.3, pp. 390-398, 2014.

[4] H. Quoc Ngo, “Massive MIMO: Fundamentals and System Designs,” Linköping University, Sweden, 2015.

[5] Nusrat Fatema, Guang Hua, Yong Xiang, Dezhong Peng, and Iynkaran Natgunananthan, on “Massive MIMO Linear Precoding: A Survey”, IEEE SYSTEMS JOURNAL, VOL. 12, NO. 4, DECEMBER 2018.

[6] J. Hoydis, S. ten Brink, and M. Debbah, “Massive MIMO in the UL/DL of cellular networks: How many antennas do we need?” vol. 31, no. 2, pp. 160–171, Feb. 2013.

[7] E. Bjornson, M. Bengtsson, and B. Ottersten, “Pareto characterization of the multicell MIMO performance region with simple receivers,” vol. 60, no. 8, pp. 4464–4469, Aug. 2012.

[8] C.B. Peel, B. M. Hochwald, and A. L. Swindlehurst, “A vector perturbation technique for near-capacity multiantenna multiuser communication, Part I: Channel inversion and regularization,” vol. 53, no. 1, pp. 195–202, Jan. 2005.

[9] T.K. Y.Lo, “Maximum ratio transmission,” vol.47, no.10, pp. 1458–1461, Oct. 1999.

[10] Y. Zhang, J. Gao, Y. Liu, “MRT precoding in downlink multiuser MIMO systems,” EURASIP Journal on Wireless Communications, vol. 241, October 2016.

[11] C. D. Ho, H. Q. Ngo, M. Matthaiou, T.Q. Duong, “On the Performance of Zero-Forcing Processing in Multi-Way Massive MIMO Relay Networks,” IEEE Communications Letters, vol. 21, no. 4, pp. 849–852, 2017.

[12] T. Parfait, Y. Kuang, and K.Jerry, “Performance analysis and comparison of ZF and MRT based downlink massive MIMO systems,” in Proc. 6th Int. Conf. Ubiquitous Future Netw., Shanghai, China, 2014, pp. 383–388.

[13] A.Muller, A.Kammounz, E.Bjornson, and M.Debbahx, “Efficient linear recoding for massive MIMO systems using truncated polynomial expansion,” in Proc. 8th Sens. Array Multichannel Signal Process. Workshop, A Coru na, Spain, 2014, pp. 273–276.

[14] A.Kammoun, A.Muller, E.Bjornson, and M.Debbah, “Linear precoding based on polynomial expansion: Large-scale multicell MIMO systems,”IEEE J. Sel.Topics Signal Process., vol.8, no. 5, pp. 861–875, Oct. 2014.

[15] A.Muller, R. Couillet, E. Bjornson, S. Wagner, and M. Debbah, “Interference-aware RZF precoding for multicell downlink systems,”IEEE Trans. Signal Process., vol.63, no. 15, pp. 3959–3973, Aug. 2015.

[16] S. Wagner, R. Couillet, M. Debbah, and D. T. M. Slock, “Large system analysis of linear precoding in correlated MISO broadcast channels under limited feedback,” IEEE Trans. Inf. Theory, vol.58, no.7, pp.4509–4537, Mar. 2012.

[17] Axel Mueller, Abla Kammoun, Emil Björnson “Linear precoding based on polynomial expansion: reducing complexity in massive MIMO”, EURASIP Journal on Wireless Communications and Networking (2016) 2016:63, DOI10.1186/s13638-016-0546-z.
[18] Ankita Sahu, Manish Panchal, and Rekha Jain, “Energy Efficient Optimum Design for Massive MIMO”, Springer Nature Singapore Pte Ltd. 2018 S. Bhattacharyya et al. (eds.), Advanced Computational and Communication Paradigms, Lecture Notes in Electrical Engineering 475, https://doi.org/10.1007/978-981-108240-5.

[19] M. Joham, W. Utschick, and J. A. Nossek, “Linear transmit processing in MIMO communications systems,” IEEE Trans. Signal Process., vol. 53, no. 8, pp. 2700–2712, Aug. 2005.

[20] A.H. Mehana and A.Nosratinia, “Diversity of MIMO linear precoding,” IEEE Trans. Inf. Theory, vol. 60, no. 2, pp. 1019–1038, Nov. 2013.

[21] S.Zarei, W.Gerstacker, R.R.Muller, and R.Schober, “Low Complexity Linear Precoding for Downlink Large-Scale MIMO Systems,” in Proc. IEEE PIMRC, 2013.

[22] S. Wagner, R. Couillet, M. Debbah, and D. T. M. Slock, “Large System Analysis of Linear Precoding in MISO Broadcast Channels with Limited Feedback,” IEEE Trans. Inf. Theory, vol.58, no.7, pp.4509–4537,2012.

[23] W.Hachem, O.Khorunzhy, P.Loubaton, J.Najim, L.A.Pastur, A new approach for capacity analysis of large dimensional multi-antenna channels.IEEE Trans. Inf. Theory. 54(9), 3987–4004(2008).

[24] V.K.Nguyen, J.S.Evans, in Global Telecommunications Conference,2008.IEEE GLOBECOM2008. IEEE. Multiuser Transmit Beamforming via Regularized Channel Inversion: A Large System Analysis (IEEE, New Orleans, LO,2008). DOI: 10.1109/GLOCOM.2008.ECP.176.

[25] S.Wagner, R.Couillet, M.Debbah, D.T.M.Slock, Large system analysis of linear precoding in MIS Broadcast channels with limited feedback. IEEE Trans. Inf. Theory.58(7),4509–4537(2012).

[26] R.Muharar, J.Evans, in Communications (ICC),2011 IEEE International Conference on 5–9 June 2011,Downlink Beamforming with Transmit-Side Channel Correlation: A Large System Analysis(IEEE, Kyoto,2011), pp.1–5. doi:10.1109/icc.2011.5962672.

[27] T.L.Marzetta, “Non-cooperative cellular wireless with unlimited numbers of base station antennas,” IEEE Trans. Communications., vol. 9, no. 11, pp. 3590–3600, Nov. 2010.

[28] E.Björnson, and M.Debbah, “Linear precoding based on polynomial expansion: Reducing complexity in massive MIMO (extended version),” IEEE Trans. Signal Process., Sep.2013, submitted to arXiv:1310.1806, submitted for publication.

[29] S. Zarei, W. Gerstacker, R. R. Müller, and R. Schober, “Low-complexity linear precoding for downlink large-scale MIMO.