On the Performance of Massive Multiuser MIMO with Different Transmit Beamforming Techniques and Antenna Selection

Said E. El-Khamy(1), Karim H. Moussa* (2), and Amr A. El-Sherif(1)
(1) Department of Electrical Engineering, Alexandria University, Alexandria 21544, Egypt.
(2) Alexandria Institute of Engineering and Technology, Alexandria 21311, Egypt.
elkhamy@ieee.org, karim.moussa@aiet.edu.eg, aasherif@alexu.edu.eg

ABSTRACT

In this paper, the performance of massive multiuser multiple-input-multiple-output (MIMO) transmit beamforming techniques and antenna selection is analyzed. Transmit antenna selection is used to reduce the number of radio frequency units, system complexity and system cost, making massive MIMO more applicable. Special attention is given to study the effect of the number of available antennae and radio frequency units on the performance of the system. Three types of transmit beamforming techniques are considered, namely, maximum ratio transmission beamforming, zero forcing beamforming, and minimum mean square error beamforming. The numerical results of the paper clearly show that transmit antenna selection affects the performance of massive MIMO systems for all considered types of transmit beamforming. In particular, it is shown that lower bit error rate can be achieved with small number of selected antennae from a large group of actual transmit antennae. This is of course in addition to the great advantage from the system complexity perspectives.

Keywords: Massive, MIMO, Multiuser, Beamforming, Spatial, ZFBF, Optimum, Regularized.

I. INTRODUCTION

In modern communication systems, network traffic is growing rapidly because of the spreading of smart devices. The multiple input multiple output (MIMO) techniques are strongly recommended, as it can achieve higher throughput compared to the single input single output systems [1], [2]. Recently, multiuser MIMO (MU-MIMO) systems have seen great interest. In downlink MU-MIMO, the base station (BS) transmits signals to several mobile stations (MS) using the same time and frequency resources. The desired signal to each user is considered as an interference signal to other users which degrades system performance. Hence, research efforts have been steered towards reducing interference, maximizing transmission capacity and improving performance for downlink MU-MIMO systems [3]–[5]. A new approach was proposed with the capability of improving downlink performance. It's known as massive MU-MIMO (MMU-MIMO). In MMU-MIMO, each BS has a very large number of transmitting antennae [6], [7]. MMU-MIMO requires implementation of massive number of radio frequency (RF) chains which is very expensive. Transmit antenna selection (TAS) technique is about using a subset of transmit antennae in MMU-MIMO systems. When TAS is added, it will reduce the cost of the overall system and will retain many advantages of MMU-MIMO [8], [9]. This system will be noted as TAS-MMU-MIMO system in the rest of the paper.

Increasing the number of transmitting antennae has the ability to improve the Bit Error Rate (BER) performance, spectral efficiency and energy efficiency. In [10], [11] Massive MIMO wireless communications is overviewed. Information theoretic analysis is illustrated and implementation issues related to channel estimation, detection, and beamforming schemes is addressed. The energy efficiency achieved by massive MIMO systems is analyzed and demonstrated. MMU-MIMO offers huge improvements over conventional point-to-point

MIMO as it works with cheap single-antenna user terminals, a rich scattering environment is not required, and resource allocation is simplified because every active terminal utilizes all of the time-frequency resources. The propagation losses are mitigated by a large array gain due to coherent beamforming, and the interference leakage due to channel estimation errors vanishes in large dimension vector space. Low complexity signal processing algorithms are optimal and inter-user interference is easily mitigated by increasing the beamforming resolution[12], [13].

Energy efficient power allocation scheme is investigated for the massive MIMO system with the maximum ratio transmission beamforming (MRTBF) in [14], since MRTBF can balance the system performance and complexity. Power allocation algorithm is proposed to achieve the optimal energy efficiency (EE) according to convex optimization theory. It also shows that both the EE and spectral efficiency (SE) are improved by increasing the number of antennae at BS and the number of multiple user terminals (UT). Zero forcing beamforming (ZFBF) in [15] chooses the beamforming vectors to mitigate interference among users. However, if some users' channel conditions are strongly correlated, the received power of certain users will be small due to the use of ZFBF [15]. Hence, when the total transmit power is small, some users suffer from low receive signal to noise ratio (SNR). Compensation for transmit power is required to maintain satisfactory performance for these users. In [5], Minimum-mean-square-error beamforming (MMSEBF) scheme can be used to mitigate noise enhancement. Likewise, MMSEBF performs similar to transmit matched filter to enlarge the receive signal power in the region of low transmit power and can be used to improve system performance [5].

Selection diversity is a surplus solution for increasing the received signal to interference noise ratio (SINR). TAS is a common form of selection diversity, and much related research has been studied in single-user MIMO systems at the transmitter or the receiver. A comprehensive overview of MIMO antenna selection techniques was provided in [9]. In [16], a general framework for user selection in the broadcast channel with multiuser linear and nonlinear beamforming techniques is investigated. Several user selection algorithms based on the conventional incrementing and decrementing search approaches is proposed. Iterative user selection approach is introduced, offering a flexible performance complexity tradeoff. While [17] states that a subset of users which maximizes the system performance should be selected since the base station cannot support all the users in the cell. Low complexity MU-MIMO scheduling scheme using block diagonalization with chordal distance is studied. For a large number of users, the optimal scheduling technique needs an exhaustive search, which is impractical. Little research has been conducted to analyze how TAS affects the MMU-MIMO systems. These conditions motivate us to analyze the performance of TAS in MMU-MIMO systems using Rayleigh fading channel model.

In this paper, and for the first time, the performance of TAS-MMU-MIMO system in perfectly known Rayleigh channel model is studied with different number of transmit antennae, RF units (i.e. used transmit antennae) and with different transmit beamforming techniques. The performance is evaluated by the bit error rate (BER) against energy per bit to noise levels (E_b/N_o). It is shown that maximizing transmit antennae does not always lead to improving the performance because some transmit antennae may cause ill-conditioned matrices. In this case, removing these antennae and redistributing the power to the selected antennae results in the same performance.

The rest of this paper is organized as follows. In Section II, we introduce the TAS-MMU-MIMO system model. In Section III, we review the MRTBF, ZFBF and MMSEBF techniques in MMU-MIMO systems. In Section IV, the used TAS algorithm is discussed in details. The performance simulation results are proposed in Section V and Conclusions follow in Section VI.

II. SYSTEM MODEL

The block diagram of a downlink TAS-MMU-MIMO with N_T transmit antennae and N_U users is shown in Figure 1. The BS is equipped with N_{RF} RF transmission units each activates a single active (A) antenna and the rest of transmission antennae are considered not active (NA) as they are not connected to a RF unit. Each user has one receive antenna so that the number of receiving antennae are the same as the number of users N_U. Let F represents the size of data vector sent to each user independently, and for simulation purposes the power set to each user data vector is unity. T is the F x N_{RF} transmitted matrix and can be calculated by

$$T = D \times P \times W_S, \quad (1)$$

where D is the F x N_U transmitted symbols to all the UE served by the BS matrix, $P = diag\{\sqrt{p}, \sqrt{p}, ...\sqrt{p}\}$ is the N_U x N_U power matrix which represents the transmission power allocated to every user, and W_S is the N_U x N_{RF} selected beamforming matrix which its calculation depends on the selected antenna channel elements. The received data matrix at all user's terminals is symbolized as R with dimensions of F x N_U and can be calculated by

$$R = T \times H_S + N, \quad (2)$$

where H_S is the N_{RF} x N_U selected channel Matrix and N is the F x N_U additive white Gaussian noise (AWGN) matrix. Each user got its own noise vector which is independent and identically distributed (i.i.d) complex Gaussian distribution with zero mean, variance σ^2 and with covariance matrix equals to $\sigma^2 I$ where I is the identity matrix. The selected channel matrix H_S is a subset of the total channel matrix H which it's fully known coefficients have a Rayleigh distribution, normalized and representing Rayleigh channel model.

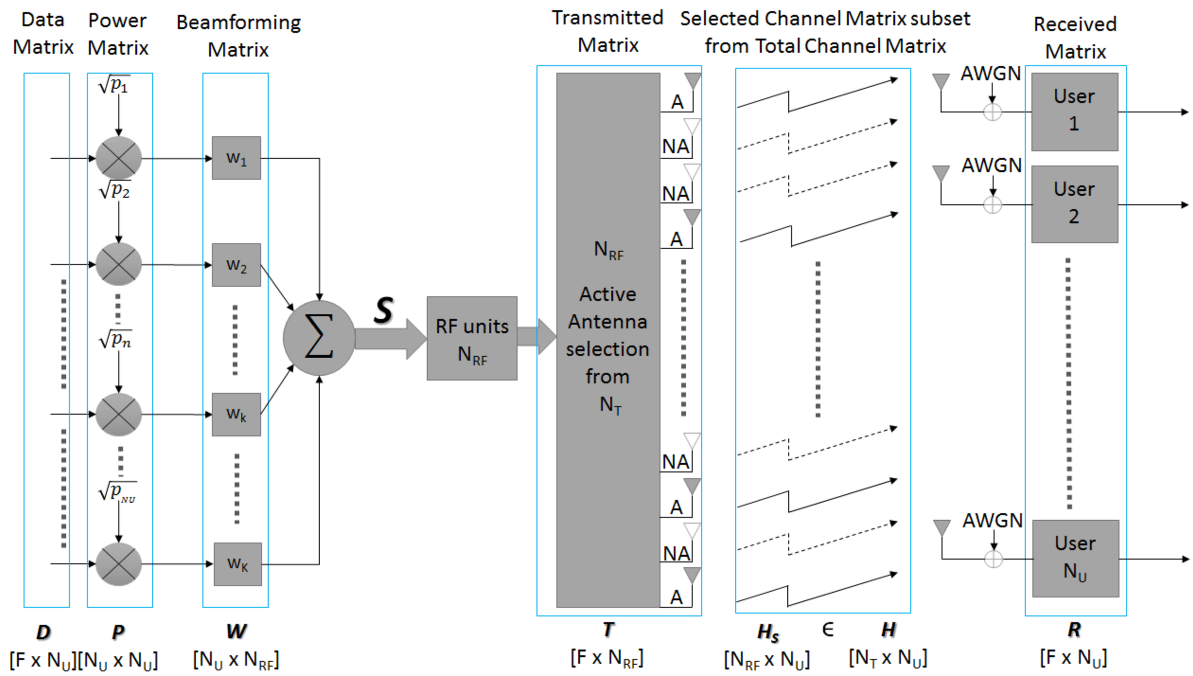

Figure 1. Transmit antenna selection Massive Multiuser MIMO system block diagram

III. TRANSMIT BEAMFORMING TECHNIQUES

Transmit beamforming is used to support multi-stream (or multi-layer) transmission in multi-antenna wireless communications sharing the same time and frequency resources. It means that multiple data streams are emitted from the same group of transmitting antennae with appropriate weightings such that a link to every user is established independently. Higher performance is achieved when the throughput is maximized at the receiver output [2]. Usually, the weighting calculation depends on the channel state information. In this techniques, overall throughput is not taken into consideration. It has been proved in [18] that when using MMU-MIMO there is no need for other high complexity beamforming techniques as it will results in the same performance as linear beamforming techniques. Linear beamforming techniques can be divided into three major types MRTBF, ZFBF, MMSEBF [19]. The antenna weights calculation depends on known CSI. These beamforming types concentrate on maximizing the received signal power at the prospected user and minimizing the power of the interference signal from co-users sharing the same resources but without concerning maximization of the sum rate for all users.

1) Maximum Ratio Transmission Beamforming

It's also called matched filtering it aims to maximize signal power at the prospected user ignoring the status of the co-users i.e. inter-user interference is unaccounted for MRTBF. It's multiplying the transmitted signal with channel conjugate eliminating any phase delays due to the Rayleigh channel [14]. The weights for MRTBF are calculated by

$$w_s^{MRT} = \frac{h_s}{\|h_s\|}, \quad (3)$$

where h_s represents transpose and Hermitian of the sought user particular channel vector and $\| h_s \|$ is the norm of this vector. MRTBF pattern is always pointing to the prospected user in case of line of sight (LOS) [18].

2) Zero Forcing Beamforming

Zero forcing denotes the signal processing that reduces interference to minimal. This can be achieved at the transmitter side by selecting beamforming vectors that are orthogonal to the channels of co-users ZFBF is the counterpart of zero-forcing filtering in receive processing[15]. ZFBF direction is always orthogonal to the subspace of co-users channels in order to cancel the interference from co-users signals while not concentrating on the power of the sought after signal that the prospected user received. The weights of the ZFBF are calculated by

$$W_S^{ZFBF} = \frac{H_S^{'}(H_S^{'} . H)^{-1}}{\|H_S^{'}(H_S^{'} . H)^{-1}\|}, \quad (4)$$

where $H_S^{'}$ is the transpose and Hermitian of the selected channel matrix for all users combined.

3) Minimum Mean Square Error Beamforming

MRTBF and ZFBF in the previous two subsections followed from straightforward extensions of the corresponding criteria for receive combining: maximize SNR and minimize interference power, respectively. The MMSEBF aims to maximize signal to leakage noise ratio in order to improve the received signal by minimizing the leakage signal, interference, to prospected user and also to reduce the noise effect on the same user. So MMSEBF is more practical [20]. The weights matrix of the MMSEBF can be calculated by

$$W_S^{MMSEBF} = \frac{H_S^{'}(H_S^{'} . H_S + \sigma^2 I)^{-1}}{\|H_S^{'}(H_S^{'} . H_S + \sigma^2 I)^{-1}\|}, \quad (5)$$

where $H_S^{'}$ is the transpose and Hermitian for the channel matrix for all users combined, σ^2 is the noise variance and I is the identity matrix.

IV. TRANSMIT ANTENNA SELECTION ALGORITHM

The advantage of MMU-MIMO systems is that superior performance can be reached devoid of consuming extra transmit power or bandwidth addition. On the other hand, its main drawback is that surplus high-cost RF modules are essential as massive multiple antennae are employed at the transmitter including analog to digital converter (ADC), low noise amplifier (LNA) and frequency down converter. In order to shrink the budget related to massive multiple RF modules, TAS techniques are employed.

Since N_{RF} antennae are selected from N_T transmit antennae, the effective channel matrix after selection can now be represented by H_S with N_{RF} x N_U dimensions instead of total channel matrix H with dimensions of N_T x N_U. The selected channel matrix H_S is the selected subset from the total channel matrix H. Error performance has been used as a design criterion for antenna selection. Transmit antennae can be selected in order to minimize the error probability.

The pairwise error probability that S_A symbol is transmitted and S_B symbol received conditional that the channel is H_S on a specific MISO channel can be given by[21]

$$\Pr\{S_A \to S_B \mid H_S\} = Q\left(\sqrt{\frac{\rho\|H_S(S_A - S_B)\|_F^2}{2N_{RF}}}\right) \le \exp\left(-\frac{\rho\|H_S(S_A - S_B)\|_F^2}{4N_{RF}}\right), \quad (6)$$

where ρ is the signal to noise ratio and (S_A-S_B) represents error matrix between the two symbols. In order to maximize the bit error probability, the $\|H_S(S_A - S_B)\|_F^2$ need to be maximized. From this condition, it can be deduced that selecting channels with the maximum $\|H_S\|_F^2$ will minimize the bit error rate. Description of the used TAS algorithm is followed

Algorithm: BER minimized TAS MMU-MIMO system
1: for all Nt
2: Calculate Frobenius norm to all user vector (i.e. sqrt(sum(diag(A'*A))))
3: Store calculation in ch vector
4: end for
5: Select N_{RF} with highest values from ch vector

V. SIMULATION RESULTS

In this section, the simulation results for different TAS-MMU-MIMO transmit beamforming techniques antenna selection technique is discussed. In the simulation, it's assumed that the transmitter has 198 antennae or 64 antennae, and the receivers (users) are assumed to have a single antenna. The system is assumed to have 8 active users to be served at the same time. The used channel model is Rayleigh channel model with no correlation between transmitter antennae and no correlation between the user's receiver antennae. Binary phase shift keying modulation is used in the simulation. TAS algorithm described in the previous section is used for selecting the required group of antennae from the available transmitting antennae. BER against energy per bit to noise ratio (E_b/N_O) is used in the analysis.

Figure 2 shows the performance analysis of TAS-MMU-MIMO system using MRTBF when 198 transmit antenna is employed and number of RF units is varied among 8, 10, 12, 16, 20, 24, 32 and 66. The performance curves improved by increasing the number of RF units and the improvement until 66 RF units did not saturate. From another point of view the performance curves are normal at low Eb/No keep improving with the increase of Eb/No until it's saturated (i.e. the performance is constant even with the increment of Eb/No). This behavior is predicted as by increasing a user power beyond a certain limit will show bad interference effects on other users. Figure 3 shows the performance of the same described system but with 64 transmit antennae and number of RF units varies among 8, 10, 12, 16, 24 and 32. By comparing Figure 2 and Figure 3, the performance of the system is improved by increasing the number transmit antennae when using the same number of RF units. This behavior is predicted as the diversity order has been decreased in the case 64 transmit antennae.

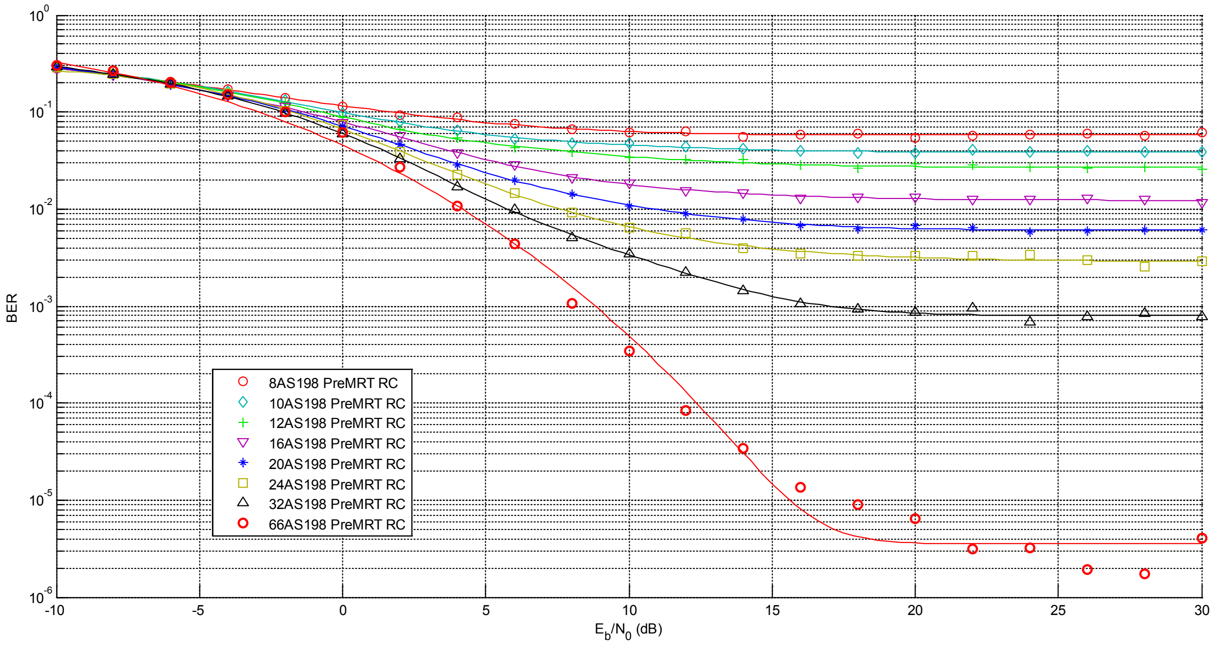

Figure 2. BER performance of TAS-MMU-MIMO with MRTBF using different number of RF units selected from 198 antennae.

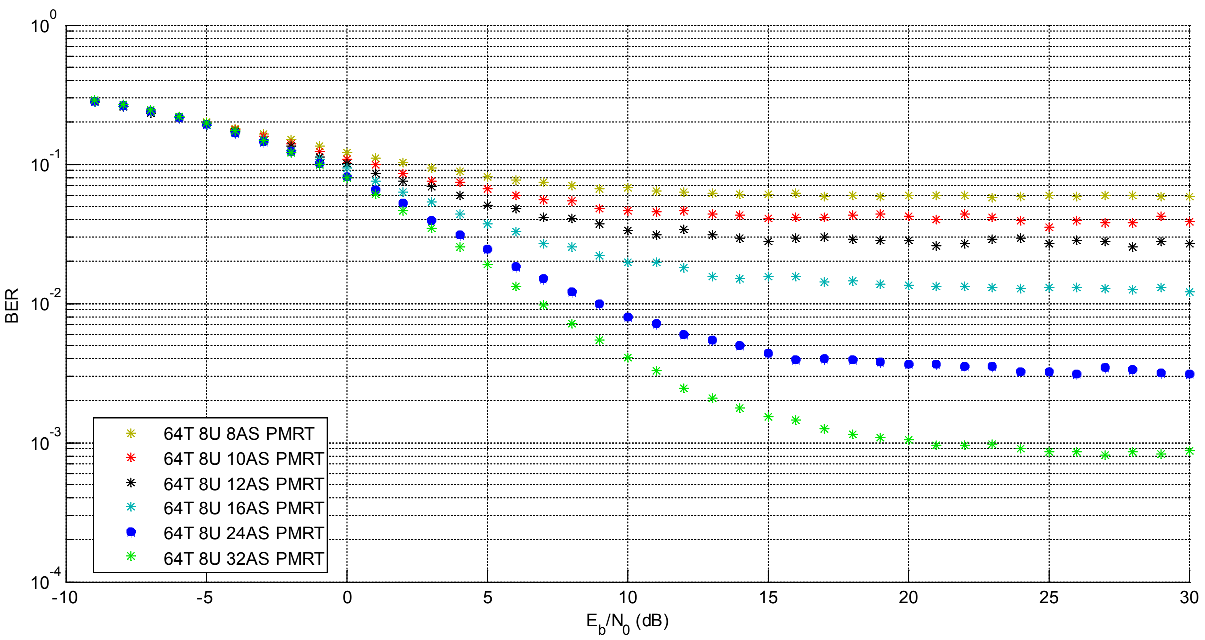

Figure 3. BER performance of TAS-MMU-MIMO with MRTBF using different number of RF units selected from 64 antennae.

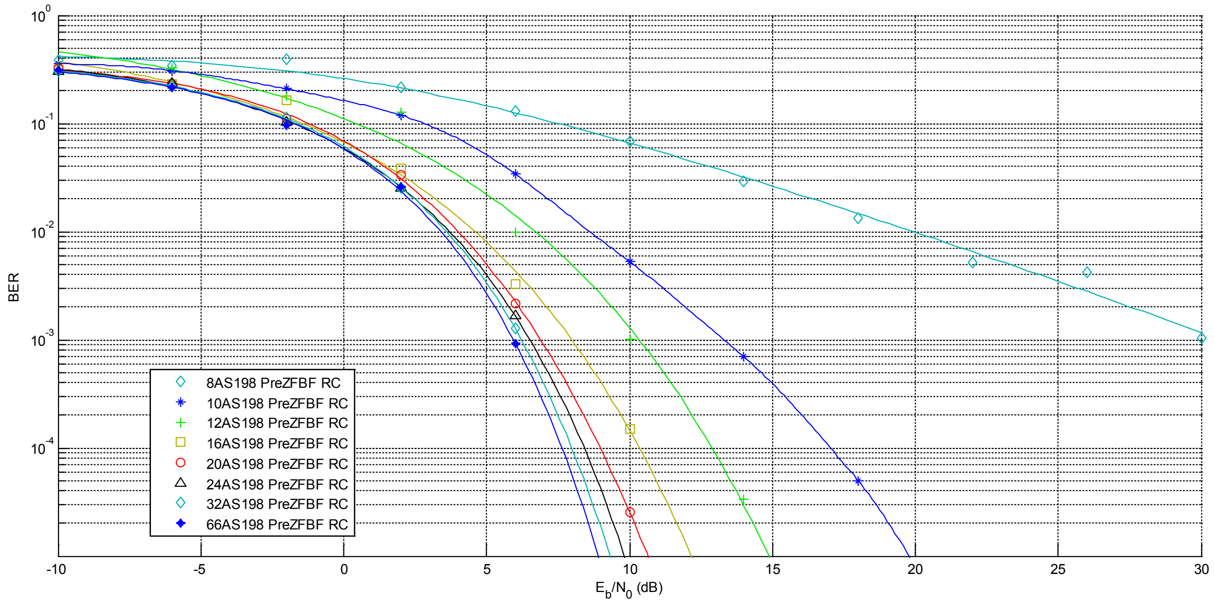

Figure 4. BER performance of TAS-MMU-MIMO with ZFBF using different number of RF units selected from 198 antennae.

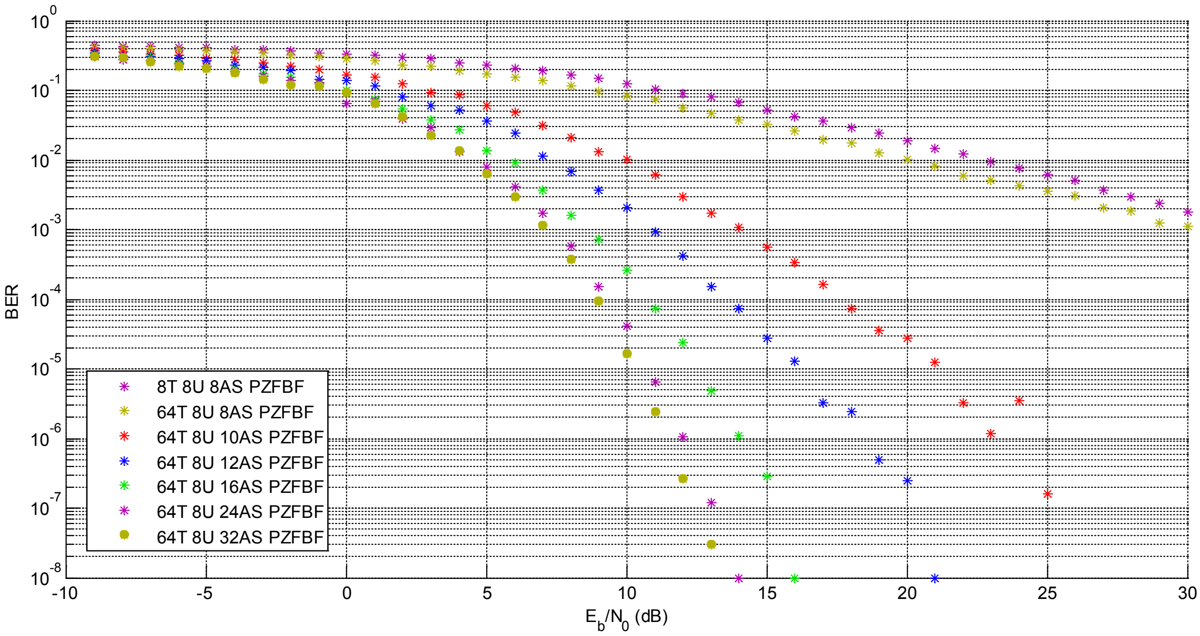

Figure 5. BER performance of TAS-MMU-MIMO with ZFBF using different number of RF units selected from 64 antennae.

Figure 4 shows the performance of TAS-MMU-MIMO with ZFBF when using 198 transmit antennae and 8, 10, 12, 16, 20, 24, 32 and 66 RF units. The performance of the system is the worst when 8 RF units are used and improved by increasing number of RF units. it can be noticed that the improvement due to increasing number of RF units from 8 to 10 is larger than the one due to increasing number of RF units from 24 to 66. The improvement due to increasing the number of RF units from 32 to 66 is barely noticeable. Figure 5 shows the performance of TAS-MMU-MIMO with ZFBF when using 64 transmit antennae and 8, 10, 12, 16, 20, 24 and 32 RF units. The performance is improved when number of transmit antennae are increased and it was predicted as the diversity order increased.

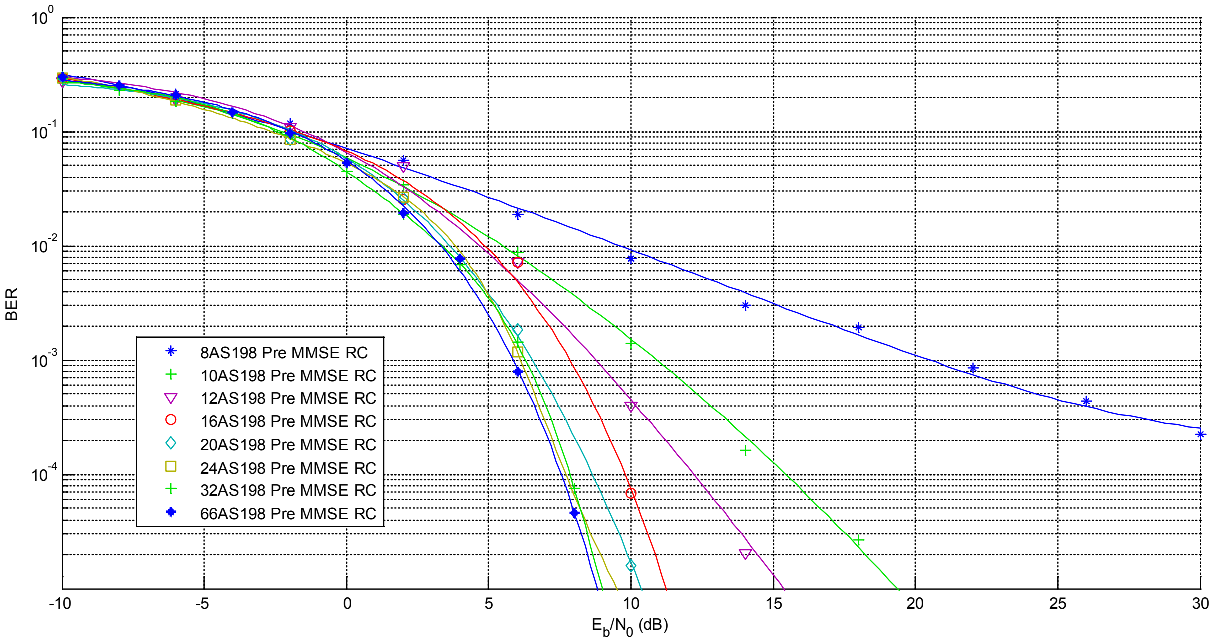

Figure 6. BER performance of TAS-MMU-MIMO with MMSEBF using different number of RF units selected from 198 antennae.

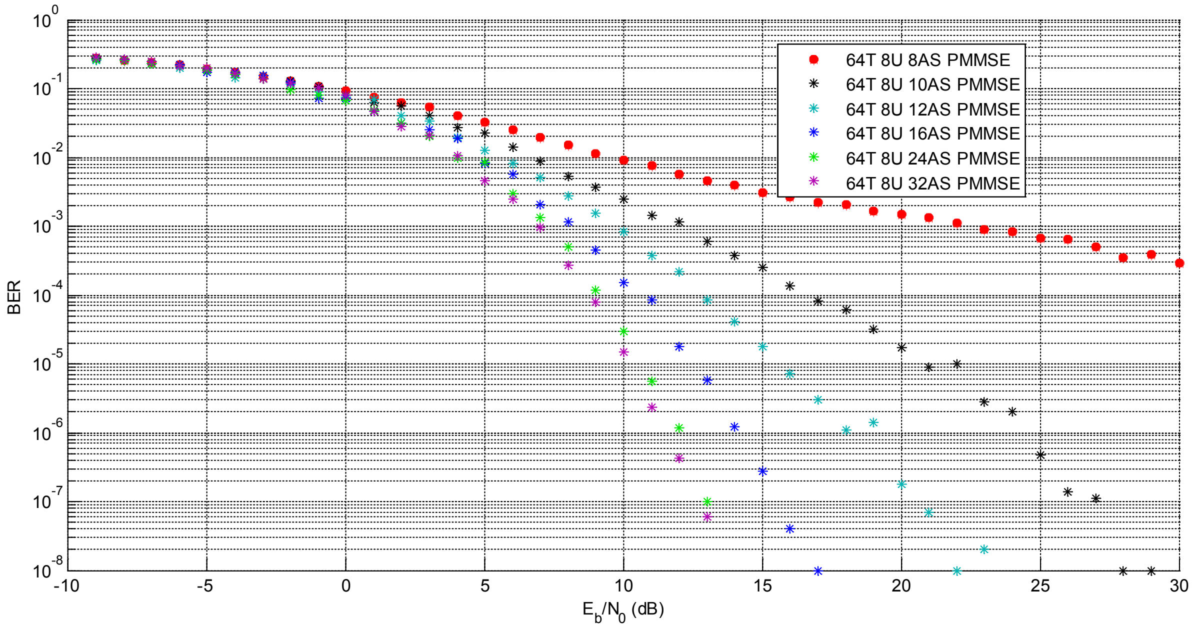

Figure 7. BER performance of TAS-MMU-MIMO with MMSEBF using different number of RF units selected from 64 antennae.

Figure 6 shows the performance of TAS-MMU-MIMO with MMSEBF when using 198 transmit antennae and no of RF units varies among 8, 10, 12, 16, 20, 24, 32 and 66. The performance of the system is the worst when 8 RF units are employed and improved by increasing number of RF units. it can be noticed that the improvement due to increasing number of RF units from 8 to 10 or 12 is larger than the one due to increasing number of RF units from 20 to 66. The improvement due to increasing the number of RF units from 20 to 66 is hardly recognized. Figure 7 shows the performance of TAS-MMU-MIMO with

MMSEBF when using 64 transmit antennae and no. of RF units varies among 8, 10, 12, 16, 20, 24 and 32. The performance is better when number of transmit antennae is enlarged.

VI. CONCULUSION

In this paper studied the performance of TAS-MMU-MIMO with different beamforming techniques, in particular, MRTBF, ZFBF and MMSEBF are discussed. It is shown that maximizing used transmit antennae does not always lead to improving the performance because some transmit antennae may cause ill-conditioned matrices. MRTBF needs a more RF units than ZFBF and MMSEBF to achieve the same performance, but its performance is good at low E_b/N_o values. ZFBF and MMSEBF performances are quite the same while MMSEBF is more applicable as it compensates for the noise added by the AWGN channel. The results of this paper show that TAS is a worthy technique to overcome a major disadvantage of MMU-MIMO systems by reducing the number of RF units required while a good performance is still maintained.

REFERENCES

[1] N. Chiurtu, B. Rimoldi, and E. Telatar, "On the capacity of multi-antenna Gaussian channels," *Proceedings. 2001 IEEE Int. Symp. Inf. Theory (IEEE Cat. No.01CH37252)*, 2001.

[2] G. J. Foschini and M. Gans, "On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas," *Wirel. Pers. Commun.*, vol. 6, pp. 311–335, 1998.

[3] M. Jiang and L. Hanzo, "Multiuser MIMO-OFDM for next-generation wireless systems," *Proc. IEEE*, vol. 95, pp. 1430–1469, 2007.

[4] R. L. U. Choi, M. T. Ivrlač, R. D. Murch, and W. Utschick, "On strategies of multiuser MIMO transmit signal processing," *IEEE Trans. Wirel. Commun.*, vol. 3, pp. 1936–1941, 2004.

[5] M. Joham, W. Utschick, and J. A. Nossek, "Linear transmit processing in MIMO communications systems," *IEEE Trans. Signal Process.*, vol. 53, 2005.

[6] F. Rusek, D. Persson, B. K. Lau, E. G. Larsson, T. L. Marzetta, O. Edfors, and F. Tufvesson, "Scaling up MIMO : Opportunities and challenges with very large arrays," *IEEE Signal Process. Mag.*, vol. 30, pp. 40–60, 2013.

[7] T. L. Marzetta, "Noncooperative cellular wireless with unlimited numbers of base station antennas," *IEEE Trans. Wirel. Commun.*, vol. 9, no. 11, pp. 3590–3600, 2010.

[8] X. Gao, O. Edfors, J. Liu, and F. Tufvesson, "Antenna selection in measured massive MIMO channels using convex optimization," in *2013 IEEE Globecom Workshops (GC Wkshps)*, 2013, pp. 129–134.

[9] S. Sanayei and A. Nosratinia, "Antenna selection in MIMO systems," *IEEE Commun. Mag.*, vol. 42, no. 10, 2004.

[10] L. Lu, G. Li, a. L. Swindlehurst, A. Ashikhmin, and R. Zhang, "An Overview of Massive MIMO: Benefits and Challenges," *IEEE J. Sel. Top. Signal Process.*, vol. 4553, no. c, pp. 1–1, 2014.

[11] E. G. Larsson, O. Edfors, F. Tufvesson, and T. L. Marzetta, "Massive MIMO for next generation wireless systems," *IEEE Commun. Mag.*, vol. 52, pp. 186–195, 2014.

[12] J. Hoydis, S. Ten Brink, and M. Debbah, "Massive MIMO in the UL/DL of cellular networks: How many antennas do we need?," *IEEE J. Sel. Areas Commun.*, vol. 31, pp. 160–171, 2013.

[13] Z. Xiang, M. Tao, and X. Wang, "Massive MIMO multicasting in noncooperative cellular networks," *IEEE J. Sel. Areas Commun.*, vol. 32, pp. 1180–1193, 2014.

[14] L. Zhao, H. Zhao, F. Hu, K. Zheng, and J. Zhang, "Energy efficient power allocation algorithm for downlink massive mimo with mrt precoding," *IEEE Veh. Technol. Conf.*, pp. 0–4, 2013.

[15] T. Yoo and A. Goldsmith, "On the optimality of multiantenna broadcast scheduling using zero-forcing beamforming," *IEEE J. Sel. Areas Commun.*, vol. 24, no. 3, pp. 528–541, 2006.

[16] N. D. Dao and Y. Sun, "User-selection algorithms for multiuser precoding," *IEEE Trans. Veh. Technol.*, vol. 59, pp. 3617–3622, 2010.

[17] K. Ko and J. Lee, "Multiuser MIMO user selection based on chordal distance," *IEEE Trans. Commun.*, vol. 60, pp. 649–654, 2012.

[18] S. E. El-khamy, K. H. Moussa, and A. A. El-sherif, "Performance Analysis of Massive MIMO Multiuser Transmit Beamforming Techniques over Generalized Spatial Channel Model," *32nd NRSC*, 2015.

[19] E. Bjornson, M. Bengtsson, and B. Ottersten, "Optimal multiuser transmit beamforming: A difficult problem with a simple solution structure [Lecture Notes]," *IEEE Signal Process. Mag.*, vol. 31, pp. 142–148, 2014.

[20] X. Gao, O. Edfors, F. Rusek, and F. Tufvesson, "Linear pre-coding performance in measured very-large MIMO channels," *IEEE Veh. Technol. Conf.*, 2011.

[21] Y. S. Cho, J. Kim, W. Y. Yang, and C. G. Kang, *MIMO-OFDM Wireless Communications with MATLAB*. 2010.