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Achieving Near Optimal Sum Rate in Downlink Massive Multiple-Antenna System

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Abstract—In this paper, a massive multiple input multiple output (massive-MIMO) system with up to 600 base station antennas exploiting the channel state information (CSI) to improve the capacity of system while serving multiple UEs was proposed. Two precoding schemes: zero-forcing (ZF) and maximum ratio transmission (MRT) were implemented and used to test the effectiveness of the proposed system. In order to study the effectiveness of the system, its performance was analyzed in terms of achievable sum rate. MATLAB codes were developed for the simulations test conducted to study the sum rate performance of the system. Simulations were carried out by varying the number of base station antennas from 300 to 600 with respect to the number of users to determine the achievable sum rate of the system. Results showed that increasing the number of base station antennas brings about better spectral efficiency for optimal multiuser interference reduction such that highest sum rates: 317.5 Bits/s/Hz and 317.0 Bits/s/Hz, were achieved using ZF considering vector/matrix normalizations for number of base station antennas (M) equal to 600 and number of UEs (K) equal to 200 when sum rate is plotted against number of base station antennas in high transmitted power scenarios. Also, when sum rate is plotted against number of users, the system achieves highest sum rate of 433.7 Bits/s/Hz and 433.3 Bits/s/Hz for ZF considering vector/matrix normalizations at M 600, for K equal to 200 for high transmitted power scenarios. The results show that for low transmitted power, MRT outperforms ZF, while ZF gives better performance than MRT for high transmitted power. Generally, the results obtained revealedthat increasing the number of base station antennas can provide near optimal (or best possible) achievable sum rate and mitigate multiuser interference (MUI).

Keywords—Achievable sum rate, massive MIMO, maximum ratio transmission, multiuser interference, zero-forcing

I. Introduction

Multiuser multiple-input multiple-output (MU-MIMO) system is mainly faced with the challenge of signal interference among the several users on the network during communication between base station and users. This is called inter user interference, and has significant effect on the performance of the system. More precisely, it reduces MU-MIMO system performance. Dirty-paper coding has been put forward to reduce the effect of inter user interference in the downlink by Viswanath and Tse [1] and Weingarten et al. [2], but the strategy introduces considerable implementation complexity.

In recent times, large MU-MIMO (commonly known as massive MU-MIMO) system has attracted huge research attention. The system is equipped with large multiple antenna arrays at the base station to serve tens of single-antenna users at the same time. The term large or massive means that up to hundreds of antennas can be deployed for wireless communication at the same time. Precisely, massive MU-MIMO denotes MU-MIMO where the base station is equipped with large antenna arrangement to serve tens of single-antenna users concurrently. The random channel vectors between the base station and the users turn out to be practically orthogonal [3]. Other essential benefit of massive MU-MIMO systems is the ability to reduce transmitted power. For uplink communication, reduction of terminal power extends the lifetime of battery. On the hand, for downlink operation, a large amount of electrical base station power is used by power amplifier and associated circuit and cooling system [4]. Therefore, the electrical power consumed at the base station can be limited by reducing the radio frequency (RF) [5].

Today, massive MU-MIMO is gaining substantial attention for fifth generations (5Gs) mobile communication. A massive multi-antenna (or massive MIMO) is essentially a Multi-User MIMO (MU-MIMO) technique with several base station antenna in which a large numbers of antennas are severed at the same time [6].This paper tends to provide near optimal performance capacity of multiuser cell in massive multi-antenna system using pre-coding technique.

II. PREIVIOUS STUDIES

In this section, an empirical review of previous studies in literature related to massive MU-MIMO system is considered. However, the reviewed papers are publications made in this area of research in wireless communication in recent years from 2011 to 2021 (that is in recent decade).

Mokhtari et al. [7] examined massive MIMO systems in presence of channel and hardware impairments. The study maintained that massive MIMO technique faces issues such as degradation as a result of hardware impairments, and channel estimation and channel ageing effect, mainly in fast mobility environments. These two issues were studied in details considering two most essential candidates of waveforms massive MIMO systems namely, orthogonal frequency division multiplexing (OFDM) and single-carrier frequency domain processing (SC-FDP). The study indicated that hardware impairments and inaccurate channel knowledge can degrade the performance of massive MIMO systems extensively. Nevertheless, it stated that with proper low complex estimation and compensation methods and also selecting the appropriate waveform can minimize these effects.

Nalband et al. [8] proposed an optimal hybrid precoding scheme for massive MIMO transmission with data stream adaptation for high throughput and energy-efficient millimeter wave (mmWave) systems. The study examined hybrid precoding for both perfect channel state information (CSI) and imperfect CSI along with power scaling capacities. The objective was to evaluate the achievable sum-rate and highlight the energy efficiency properties of mmWave massive MIMO system. The model is equipped with 32 antennas each at the transmitter and receiver, with 8 radio frequency chains at the base station, such that 10 users are serviced simultaneously. Simulation results showed that the hybrid precoding scheme provided near-optimal system capacity compared with conventional MIMO.

Raisa et al. [9] proposed a multi-user hybrid precoding for mmWave massive MIMO channels utilizing minimum mean squared error (MMSE) precoders at the base station under ideal channel. A mmWave MIMO system works with radio frequency of spectrum band ranging from 30 GHz to 300 GHz, which is referred to as mm-waves frequencies. The performance of the proposed hybrid MMSE precoding technique was examined using numerical simulation conducted in MATLAB. The analysis of MU-MIMO system was considered with 8×8 base station antennas and 4×4 mobile station antennas. Four mobile stations were considered with each having single-path transmission. The channel effect was taken to be ideal. Simulation at 0dB signal-to-noise ratio showed that the sum rate of the proposed MMSE precoding scheme was 6 bps/Hz.

Lim et al. [10] carried out performance analysis of massive MIMO systems for both downlink and uplink scenarios, where 3 radio units connected via one digital unit support multiple user equipment (UE) at the cell-boundary through the same time-frequency slot. For the downlink transmitter operations, the study used zero forcing (ZF) and maximum ratio transmission (MRT), while for uplink receiver operations, ZF and maximum ratio combining (MRC) was used. Uniform power allocation was done to all downlink data streams, and it was observed that for the downlink, vector normalization was better for ZF while matrix normalization was better for MRT. The structure of the multi radio unit massive MIMO system, which is referred to as a single-radio unit massive MIMO is shown in Figure 2.16. The maximum number of base station transmitters used was 100 with maximum number of K users being 24.

Anjos et al. [11] cconsidered a massive MIMO system and equally designed a channel precoder and security scheme. The objective was to ensure that the precoding operation would not reduce the degree of privacy offered by the security scheme. The main concept of proposed method was to apply selective random rotations in the transmitted signal at antenna level so as to achieve a concession between legitimate and eavesdropper channel capabilities. The phase of the reciprocal wireless channels was used by the selective random rotations as a common random source between the transmitter and the intended receiver.

Crâşmariu et al. [12] presented a reduced complexity linear transmitter precoding scheme that eliminates inter-user interference in a downlink MU-MIMO system. With multiuser massive MIMO becoming one of the key technologies that responds well to the 5G needs, the study attempted to address the problem of inter-user interference that is common in downlink direction of massive MIMO system. The reduced complexity was achieved through re-using of many low-level operations as possible. The authors stated that the approach was suitable for implementation on any modern processor and shown to be scalable to a massive MIMO scenario without any loss in performance. The MU-MIMO system considered uses block diagonalization (BD) precoding technique and is dimensioned as follows: transmit antennas = 128, receive antennas = 4, varying K number of users (mobile stations).

Hassan et al. [13] studied the performance of multiuser massive MIMO systems. The evaluation of the system performance was carried out in terms of bit error rate (BER). The study focused on the case of a downlink single-cell scenario with linear precoding as zero forcing (ZF) and conjugate beamforming (CB). The performance was evaluated over a statistical mmWave 5G propagation channel using New York University Simulator (NYUSIM) developed in 2015. The simulation results in single-user scenario show better performance with an increasing number of base station antennas due to increase of system diversity. For multiuser scenario, the performance degrades for a higher number of cell users due to inter-user interference. The base station antenna was of 64.

Parfait et al. [14] examined the performances of zero-forcing (ZF) and maximum ratio transmission (MRT) techniques in downlink massive MIMO system. A large number of base station (BS) antennas, up to 200, serving multiple users within the same cell were deployed. Achievable sum rate and the downlink transmit power required using the ZF and MRT precodings were determined. Simulations were conducted to analyze and compare the effectiveness of the precoders assuming the same conditions. The results obtained indicated that ZF did not only provide higher data rates than MRT, but also was more power efficient than MRT.

Singh and Kedia [15] analyzed and compared performance of zero-forcing (ZF) and conjugate beamforming (CB) precoding schemes for massive multi-user (MU) MIMO system. The performance of the precoding schemes were evaluated based on spectral efficiency and downlink power with imperfect channel state information (CSI) as well as perfect CSI. The simulation results showed that ZF outperformed the CB precoding by achieving higher spectral efficiency and required lower downlink power. However, the CB performed better than the ZF precoding in terms of downlink power when there was a need to achieve low spectral efficiency and also for cell edge users. Generally, ZF provided better option for achieving higher spectral and energy efficiency for a large scale MU-MIMO system. The base station antenna M varied from 50 to 100 while K number of users was fixed at 15. It was observed that by increasing transmitter antennas from 50 to 100 resulted to improved spectral efficiency or throughput by approximately 15bits/s/Hz.

Multi-User Multiple Input Multiple Output (MU-MIMO) using very large scale antenna arrays is a promising wireless technique where the same time-frequency channel resources are allowed to be used by multiple UEs simultaneously through spatial precoding with improved spectral efficiency. The performance of LTE systems critically depends on how the interference either across different cells or due to MU-MIMO is managed. Several techniques have been examined to evaluate the performance of several users' equipment (UE) in massive MIMO system. Generally, precoding schemes are designed to isolate data streams and reduce the inter-user interference in a MU-MIMO system [15]. The desired signal for users in downlink is pre-filtered at the base station while post-filtering of received signal occurs at users' terminals. The channel state information (CSI) is required at the base station to carry out these processing. In downlink [16], the optimum precoding is the Dirty Paper Coding (DPC) based on the fact that it achieves the sum-rate capacity. On the other hand, successive interference cancellation detection attains capacity in the uplink. These techniques are nonlinear methods that are very complex in practice [15] for interference handling in MU-MIMO system. Linear precoding techniques are of low computational complexity and have suboptimal performance in conventional MU-MIMO [15,17].

With considerable research done so far on application of linear precoding involving different number of base station (or transmitter) antennas and number of users (or mobile stations), there is ever need to increase the number of antennas that can be possibly combined for improved spectral efficiency or throughput performance. Hence, near-optimal performance is attained at base station as number of transmit antenna increases using linear precoding schemes [15]. In this paper, having examined various studies done by previous researchers especially, the recent study by Singh and Kedia [15], where it was observed that increasing transmitter antennas results to improved spectral efficiency and overall system performance in MU-massive MIMO. Therefore, designing a system with transmit antennas six times larger than 100 provide even optimal spectral efficiency or achievable sum rate capacity.

III. SYSTEM DESIGN

In this section the concept of using precoding techniques in Multi-User (MU) massive multi antenna system for downlink wireless communication to address the problem of multiuser interference (MUI) is presented.

1.1 Downlink Massive MU-Multiple Antenna System Model

A general downlink large scale Multi-User (MU)- multiple antenna system for the proposed solution is shown in Fig. 1 having a base station (e-Noode B) equipped with large number of M transmit antennas and with K number of users such that each user is equipped with one single antenna (with $M >> K$). The K users are simultaneously serviced by the base station. In order to reduce model complexity, the following assumptions have been made in this work:

- The same time and frequency resources are shared among the K user equipment.
- There is no pilot contamination.
- The base station is considered to have ideal (or perfect) channel state information (CSI). That is transmitter is assumed to know the channel parameters.
- The channel is estimated at the base station via reverse link (uplink pilots) suppose channel reciprocity.
- Each of the user equipment (UE) has single antenna.

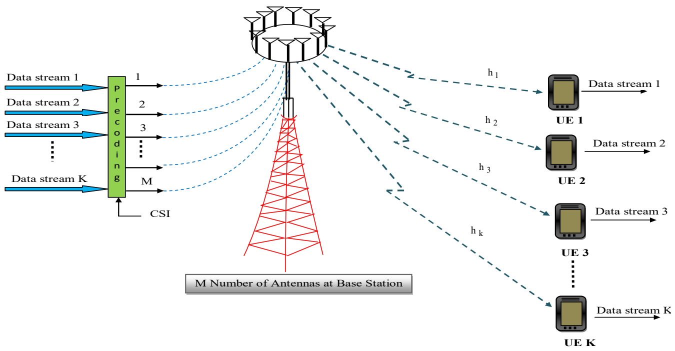

Fig. 1 A downlink massive multiuser multiple antenna system model

During the training sequence at the base station, the channel information is acquired. The kind of training techniques relies on the time-division duplex (TDD) and frequency-division duplex (FDD) algorithms. When using FDD at the base station, it is difficult to determine CSI as the number of downlink resources needed for training pilots happens to be proportional to number of base station antennas.

Conversely, when using TDD operation, the CSI can be obtained by the base station from the uplink training phase as a result of the use of channel reciprocity. Thus, operating cost as a result of pilots being proportional to the users makes TDD operation preferable to FDD in most of the scenarios involving massive multiuser multiple antenna system [18-20]. Thus a TDD multiuser massive multiple antennas technique for downlink transmission is considered in this work.

1.2 Mathematical Description of Data Transmission

This subsection considers the mathematical definition of downlink data transmission. Now, consider the simplified down link massive multiple antenna system in a single cell shown in Fig. 2.

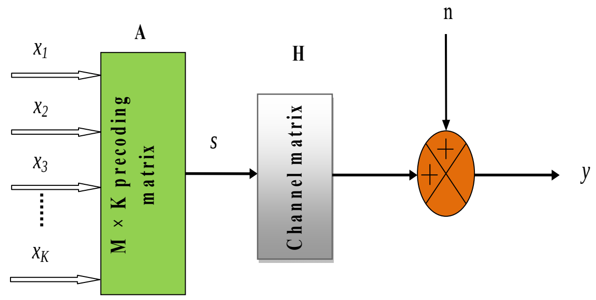

Fig. 2. A model of downlink massive multiple antenna system in a single cell

Assuming a perfect channel given by $K \times M$ channel matrix $H = \left[h_1^T \quad \cdots \quad h_K^T\right]^T$, where h_K respresents the $1 \times M$ channel vector among K^{th} user equipment (UE) and base station. With the propagation channel usually designed by assuming large-scale and small-scale fading [15], small-scale fading has been considered in this work assuming the elements of H defined as the channel matrix among base station antennas and users' equipment given by (1) are separately and identically distributed Gaussian distribution with unit variance and zero mean.

$$H = \begin{bmatrix} h_{11} & h_{12} & h_{13} & \cdots & h_{1M} \\ h_{21} & h_{22} & h_{23} & \cdots & h_{2M} \\ h_{31} & h_{32} & h_{33} & \cdots & h_{3M} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ h_{K1} & h_{K2} & h_{K3} & \cdots & h_{KM} \end{bmatrix} \tag{1}$$

Since the K number of users will receive their respective information signal from the vector $K \times 1$, so the received signal is defined by the input-output relationship of the massive multiuser multiple antenna channel considering Fig. 2 and is given by:

$$y = Hs + n \tag{2}$$

where s denotes the $M \times 1$ vector of precoded transmitted symbols (or signals), y is the $K \times 1$ vector of signals received by UEs, n is $K \times 1$ user equipment additive white Gaussian noise (AGWN) vector having independently and identically distributed Gaussian distribution with zero-mean and with variance N_0.

Assuming linear precoding at the base station for both effectiveness and analytical simplicity, s in (2) can be defined looking at Fig. 3 without considering the power of the transmitted signal by:

$$s = Ax \tag{3}$$

where A represents a $M \times K$ precoding matrix, and x denotes input vector such that $x = \left[x_1 \quad x_2 \quad x_3 \quad \cdots \quad x_K\right]^T$ with x_k the data symbol of k^{th} user which is assumed independently and identically distributed Gaussian distribution with zero-mean with unit variance.

Considering the precoding matrix having $\|A\| = 1$ [15] and P_s representing the transmitted power from the base station (that is the total average energy available at the base station in one symbol period). Hence, the transmitted signal from the base station is defined such that (3) becomes:

$$s = \sqrt{P_s} A x \quad (4)$$

Substituting (4) into (2) gives:

$$y = \sqrt{P_s} H A x + n \quad (5)$$

Using the notation $A = [a_1 \quad a_2 \quad a_3 \quad \cdots \quad a_k]$, the transmitted signal on the i^{th} antenna can be expressed by:

$$s_i = \sqrt{P_s} \sum_{j=1}^{k} a_{ij} x_j \quad (6)$$

The k^{th} user equipment received signal can be defined by:

$$y_k = \sqrt{P_s} \sum_{j=i}^{K} \sum_{m=1}^{M} h_{k,m} a_{m,j} x_j + n_k \quad (7)$$

Looking at (7), the desired signal part when $j = k$ and the interference part can be expressed by:

$$y_k = \underbrace{\sqrt{P_s} \sum_{m=1}^{M} h_{k,m} a_{m,k} x_k}_{\text{desired signal}} + \underbrace{\sqrt{P_s} \sum_{j \neq k}^{K} \sum_{m=1}^{M} h_{k,m} a_{m,j} x_j}_{\text{interference}} + \underbrace{n_k}_{\text{noise}} \quad (8)$$

It can be seen from (8) that received signal of each user (that is k^{th} user equipment) consists of desired signal, interference known as multiuser interference (MUI), and noise (which is an AWGN) having zero-mean with variance $N_0 = 1$, such that $n_k \in CN(0,1)$ for all users.

Therefore, the received signal-to-interference –plus-noise ratio (SINR) of the k^{th} user can be written as given by:

$$SINR_k = \frac{\sqrt{P_s} \sum_{m=1}^{M} h_{k,m} a_{m,k} x_k}{\sqrt{P_s} \sum_{j \neq k}^{K} \sum_{m=1}^{M} h_{k,m} a_{m,j} x_j + n_k} \quad (9)$$

Equation (9) is a function of transmit precoding matrix a_k and x_k, which is transmit signal vector for k^{th} user. The same holds for all K users connected in downlink multiuser multiple antenna system.

1.3 Downlink Precoding Techniques

At the base station, precoding or pre-filtering scheme takes place during downlink operation. This technique is used to direct the transmitted signal towards the intended users and it is designed to cancel inter-user interference signal arising from multiple users accessing the link at the simultaneously. Since (8), which is the received signal at user's equipment (UE), contains desired signal, signal interference and noise, mitigating the interference can be achieved using linear precoding schemes. This section is set to define mathematical modelling of two precoding techniques namely; zero-forcing (ZF) precoding and maximum ratio transmission (MRT) precoding that will later be used to develop a MATLAB algorithm to evaluate the performance of the proposed solution in terms of spectral efficiency while mitigating multiuser interference (MUI) under increasing base station antenna and number of users.

- Zero-Forcing Precoding Technique

This scheme is a linear pre-filtering process that allows a multiuser transmission without producing MUI. It is a type of beamforming that is practicable when the number of transmit antennas M at the base station is greater than or equal to K number of users (that is $M \geq K$) with user equipment having single antenna. The use of ZF precoding can guarantee interference cancellation at each user. This precoding scheme is assumed to implement a pseudo-inverse of the channel matrix. Therefore, ZF precoding used by base station considering the $M \times K$ linear precoding matrix A and $K \times M$ channel matrix H is given by

$$A_{ZF} = H^{*}\left(H \times H^{*}\right)^{-1} \tag{10}$$

where the expression $H^{*}\left(H \times H^{*}\right)^{-1}$ is known as pseudo inverse of complex channel matrix H.

- Maximum Ratio Transmission Precoding Technique

The maximum ratio transmission (MRT) precoding scheme is one of the common method that optimizes the SNR of desired received signal at each k^{th} user terminal implementing the hermitian of channel matrix that is conjugate transpose of channel matrix. The precoding scheme for MRT is given by:

$$A_{MRT} = H^{*} \tag{11}$$

It should be noted that A_{ZF} and A_{MRT} are the precoding matrices A of the precoding schemes respectively and consisting of each column vector a_k that is $A = \left(a_1 \quad a_2 \quad a_3 \quad \cdots \quad a_k\right)$.

- Normalization of Precoding Techniques

The precoding schemes are normalized in this section so as to meet the power constraint. Two methods of normalization are considered in this work, which are: vector normalizations and matrix normalizations. The normalized transmit beamforming vectors (column of precoding matrix) with vector and matrix normalizations are given by:

$$a_k = \frac{a_1}{\sqrt{K}\left\|a_k\right\|} \tag{12}$$

$$a_k = \frac{a_k}{\left\|A\right\|_a} \tag{13}$$

Equations (12) and (13) are the vector and matrix normalizations. Therefore the corresponding ZF and MRT precoding schemes with vector normalization considering the received signal at the k^{th} user terminal is defined by:

$$y_k = \sqrt{P_s}\sum_{m=1}^{M} h_k \frac{a_k}{\sqrt{K}\left\|a_k\right\|} x_k + \sqrt{P_s}\sum_{j=1, j\neq k}^{K} h_k \frac{a_j}{\sqrt{K}\left\|a_j\right\|} + n_k \tag{14}$$

Similarly, the matrix normalization for ZF and MRT is given by:

$$y_k = \sqrt{P_s}\sum_{m=1}^{M} h_k \frac{a_k}{\|A\|_a} x_k + \sqrt{P_s}\sum_{j=1, j\neq k}^{K} h_k \frac{a_j}{\|A\|_a} + n_k \tag{15}$$

1.4 Achievable Sum Rate

The performance of the system can be analyzed by a number of parameters. One of such parameters to measure system performance is the achievable sum rate. This theorem provides the maximum rate that the transmitter can transmit signal over the channel. In this subsection, the description of achievable sum rate in terms of ZF and MRT precoding techniques is presented. It is assumed that the overall transmitted power is constant and evenly distributed among all the K users in the network. Thus, following Shannon theorem, the channel capacity over AGWN channel in bits/s/Hz is given by [21, 22]:

$$R = \log_2(1+SNR) \tag{16}$$

where SNR is the signal to noise ratio.

In multiuser multiple antennas downlink system, the channel state information (CSI) must be known by the transmitter. This is because the CSI is a key factor in wireless communication involving multiuser. Usually, multiple data streams are transmitted to each k^{th} UE at the same time and selectively with CSI by the transmitter. Based on assumption 4, channel estimation feedback is sent to the transmitter on the reverse link (uplink operation) by all receivers so that CSI is obtained by the transmitter. Thus, the transmitter communicates to all receivers with ideal CSI. Looking at (8), it can be deduced that with a multiuser multiple antenna system, the received signal by each k^{th} user in the network does contain both interference among the K users themselves and additive noise. In that case, the achievable rate in bits/s/Hz for each k^{th} user in a single-cell downlink multiuser massive multiple antennas system with ideal CSI is defined by:

$$R_k = \log_2(1+SINR_k) \tag{17}$$

Also for K number of users, the achievable sum rate is given by:

$$R_{sum} = K\log_2(1+SINR_k) \tag{18}$$

Now, the achievable sum rate for zero-forcing (ZF) and maximum ratio transmission (MRT) precoding algorithms are presented as follows:

- Achievable sum rate for zero-forcing precoding scheme

The achievable sum rate with ZF considering (18) is given by:

$$R_{sum}^{ZF} = K\log_2\left(1+SINR_k^{ZF}\right) \tag{19}$$

The mathematical expressions of achievable sum rate for ZF utilizing vector and matrix normalization methods using the property of Wishart matrices in Tulino and Verdu (2004) are defined by [10]:

$$R_{Sum}^{ZFvec} = K\log_2\left[1+\frac{P_s(M-K+1)}{K}\right] \tag{20}$$

$$R_{Sum}^{ZFmat} = K\log_2\left[1+\frac{P_s(M-K)}{K}\right] \tag{21}$$

- Achievable sum rate for maximum ratio transmission precoding scheme

From Equation (3.19) the achievable sum rate with MRT precoding at the base station is given by:

$$R_{sum}^{MRT} = K\log_2\left(1 + SINR_k^{MRT}\right) \tag{22}$$

The sum rate for MRT precoding by using vector and matrix normalization methods is given by using the following mathematical expressions [10]:

$$R_{sum}^{MRTvec} = K\log_2\left[1 + \frac{P_s M}{P_s(K-1)+K}\right] \tag{23}$$

$$R_{sum}^{MRTmat} = K\log_2\left[1 + \frac{P_s(M+1)}{P_s(K-1)+K}\right] \tag{24}$$

1.5 Simulation Parameter

The simulation parameter for the proposed multiuser massive multiple antennas system using preconding algorithm for single cell downlink operation is presented in Table 1. The values of these parameters have been selected from similar study done by [5, 15, 24].

Table1 Simulation Parameters Of System For Single Cell Downlink Operation

Definition of Parameter	**Symbol**	**Value**
Number of base station antennas	M	600
Number of receiver antennas	N	50/200
Number of users	K	200
Number of users served	N_K	[50 100 150 200]
Low downlink transmission power	P_{s1}	-10 dB
High downlink transmission power	P_{s2}	0 dB
Packet size	N	100
Modulation scheme	-	QPSK
Signal to noise ratio	SNR	0:5:25 (dB)
Channel	-	Perfect

IV. SIMULATION RESULT

This section presents simulations for the vector normalization method, the matrix normalization method and the comparison of both methods so as to examine the near optimal performance of massive MU-MIMO over increasing number of base station antennas in terms of achievable sum rate.

1.6 Vector Normalization

The simulation parameters for the vector normalization are as follows: low power (LP) = -15dB, high power (HP) = 0dB, number of base station or transmit antennas (M) = [300, 600] and number of users (K) = [50, 100, 150, 200]. The section shows the performance analysis of ZF and MRT precoding schemes in the proposed single cell downlink massive multiple antenna system over an ideal channel in terms of achievable sum rate using vector normalization scheme. The simulation study is conducted as shown in Fig. 3a through Fig. 3d for M number of base station antennas varied from 1to 300 (M = 1:300), and Fig. 4a through Fig. 4d for M = 1:600 with respect to K users equipment of 50, 100, 150 and 200. The performance results from the simulation plots are presented in Table 2 and Table 3 respectively.

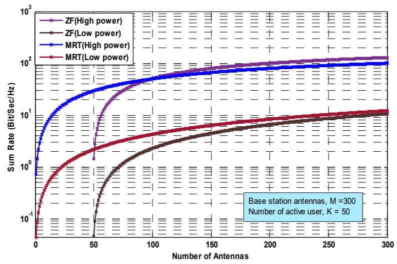

Fig. 3a ZF and MRT using vector normalization at M = 300 and K = 50

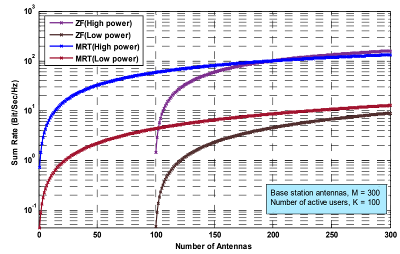

Fig. 3b ZF and MRT using vector normalization at M = 300 and K = 100

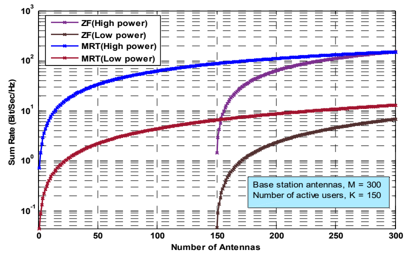

Fig. 3c ZF and MRT using vector normalization at M = 300 and K = 150

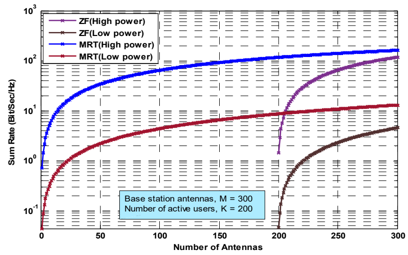

Fig. 3d ZF and MRT using vector normalization at M = 300 and K = 200

Fig. 3 Simulation plot of ZF and MRT using vector normalization (at M = 1:300)

Table 2 Sum Rate Performance For M = 1:300 Using Vector Normalization

Number of Users (K)	**Number of Base Antennas M = 1:300**			
	Zero Forcing (ZF)		**Maximum Ratio Transmission (MRT)**	
	Low Power	**High Power**	**Low Power**	**High Power**
50	10.63 Bit/s/Hz	129.5 Bit/s/Hz	12.19 Bit/s/Hz	100.5 Bit/s/Hz
100	8.89 Bit/s/Hz	159 Bit/s/Hz	12.7 Bit/s/Hz	132.6 Bit/s/Hz
150	6.782 Bit/s/Hz	150.7 Bit/s/Hz	12.83 Bit/s/Hz	150.4 Bit/s/Hz
200	4.571 Bit/s/Hz	118 Bit/s/Hz	12.97 Bit/s/Hz	161.8 Bit/s/Hz

Table 2 shows the achievable sum rate (or spectral efficiency) performances when the number of base antennas (M) = 1:300 and active users K varies from 50 to 200. It is the performance analysis of simulation plots in Fig. 3. It can be seen that at low power of transmission, MRT outperforms ZF. At Higher power of transmission, it can be seen that ZF provides better spectral efficiency performance than MRT for K = 50, 100, 150. But surprisely, MRT performed better than ZF when K = 200.

It was also observed from the simulation results that for K = 50, ZF offers better spectral efficiency than MRT at high transmission power at M > 99. With M = 99, the sum rate performance of MRT was equal to that of ZF with a value of 50 Bit/sec/Hz. For K = 100, it was observed that MRT and ZF yielded the same spectral efficiency of 100 Bit/s/Hz when M = 199.

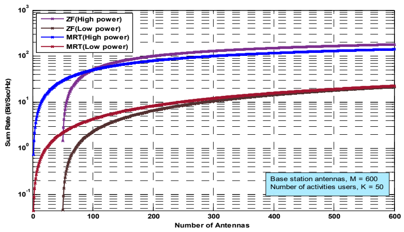

Fig. 4a ZF and MRT using vector normalization at M = 600 and K = 50

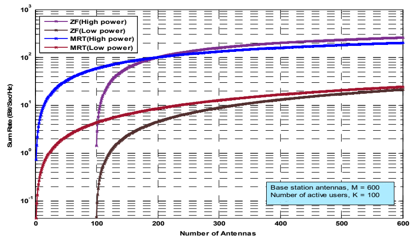

Fig. 4b ZF and MRT using vector normalization at M = 600 and K = 100

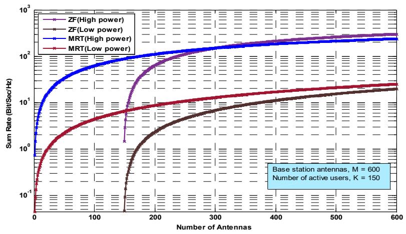

Fig. 4c ZF and MRT using vector normalization at M = 600 and K = 150

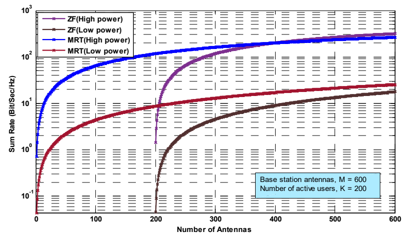

Fig. 4d ZF and MRT using vector normalization at M = 600 and K = 200

Fig. 4 Simulation plot of ZF and MRT using vector normalization (at M = 1:600)

Table 3 Sum Rate Performance For M = 1:600 Using Vector Normalization

Number of Users (K)	**Number of Base Antennas M = 1:600**			
	Zero Forcing (ZF)		**Maximum Ratio Transmission (MRT)**	
	Low Power	**High Power**	**Low Power**	**High Power**
50	21.57 Bit/s/Hz	179.4 Bit/s/Hz	22.61 Bit/s/Hz	141 Bit/s/Hz
100	21.22 Bit/s/Hz	258.7 Bit/s/Hz	24.36 Bit/s/Hz	200.5 Bit/s/Hz
150	19.66 Bit/s/Hz	300.4 Bit/s/Hz	25.03 Bit/s/Hz	238.2 Bit/s/Hz
200	17.74 Bit/s/Hz	317.5 Bit/s/Hz	25.39 Bit/s/Hz	264.8 Bit/s/Hz

The performance of the system for M = 1:600 is presented for each number of users in Table 3. It can seen that low power transmission, MRT gives better sum rate performances than ZF. At high power gain, the ZF outperforms MRT. At $M < 99$, MRT gives better sum rates than ZF for K = 50 but equal sum rate of 50 Bit/s/Hz occurs at M = 50 in Fig. 4a. Looking at Fig. 4b, equal sum rate of 100 Bit/s/Hz occurs at M = 199 when K = 100 for ZF and MRT for higher power gain. When K = 150 as shown in Fig. 4c, equal sum rate of 150 Bit/s/Hz is observed for ZF and MRT at M = 150 at high power gain. In Fig. 4d, at M = 399, the same sum rates of 200 bit/s/Hz are given by ZF and MRT for K = 200 during transmission utilizing high power gain.

1.7 Vector Normalization when K = 1:200

In this subsection, the sum rate or spectral efficiency performance of the massive MIMO system considering the situation when the number of users K increases from 1 to 200 while the number base antennas M = 300 to M = 600. Fig. 5 shows the simulation plots of K = 1:200 for M = [300, 400, 500, 600]. Table 4 shows the performance analysis of simulation plots.

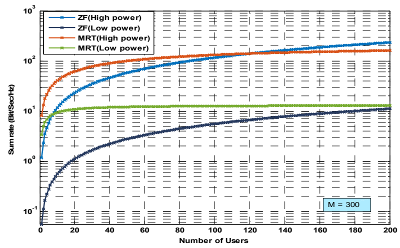

Fig. 5a ZF and MRT using vector normalization at K = 1:200 and M = 300

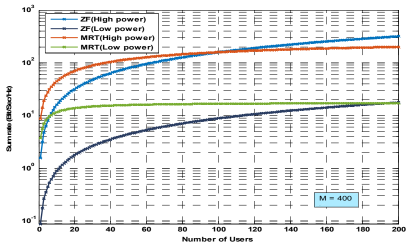

Fig. 5b ZF and MRT using vector normalization at K = 1:200 and M = 400

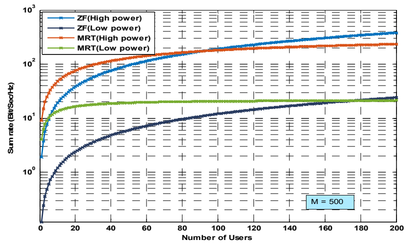

Fig. 5c ZF and MRT using vector normalization at K = 1:200 and M = 500

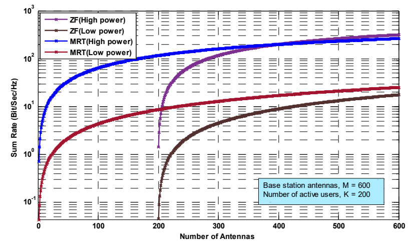

Fig. 5d ZF and MRT using vector normalization at K = 1:200 and M = 600

Fig. 5 Simulation plot of ZF and MRT using vector normalization (at K = 1:200)

Table 4 Sum Rrate Performance For K= 1:200 Using Vector Normalization

Number of Base Antennas (M)	**Number of Users K = 1:200**			
	Zero Forcing (ZF)		**Maximum Ratio Transmission (MRT)**	
	Low Power	**High Power**	**Low Power**	**High Power**
300	11.2 Bit/s/Hz	234.2 Bit/s/Hz	12.97 Bit/s/Hz	161.8 Bit/s/Hz
400	17.69 Bit/s/Hz	317.0 Bit/s/Hz	17.17 Bit/s/Hz	200.4 Bit/s/Hz
500	24.04 Bit/s/Hz	381.2 Bit/s/Hz	21.31 Bit/s/Hz	234.4 Bit/s/Hz
600	30.26 Bit/s/Hz	433.7 Bit/s/Hz	25.39 Bit/s/Hz	264.8 Bit/s/Hz

In Table 4, it can be seen that at low power gain transmission, ZF outperforms MRT except when M = 300. For high power gain transmission, ZF outperforms MRT in all the cases. However, it is observed that for M = 500 and 600 in Fig. 5c and 5d, for low power gain transmission, MRT initially outperforms ZF at K < 177, and K < 170. Also for high power gain, MRT initially gives better sum rates than ZF at K < 121 for M = 300 in Fig. 5a, at K < 101, for M = 400 in Fig. 5b, at K < 92 for M = 500 in Fig. 5c, at K < 88 for M = 600 in Fig. 5d.

1.8 Matrix Normalization

In order to further validate the spectral efficiency performance of the proposed massive multiple antenna system, further simulations are conducted in terms of matrix normalization technique. The simulation parameters for the matrix normalization are as follows: low power (LP) = -15dB, high power (HP) = 0dB, number of base station or transmit antennas (M) = [300, 600] and number of users (K) = [50, 100, 150, 200].

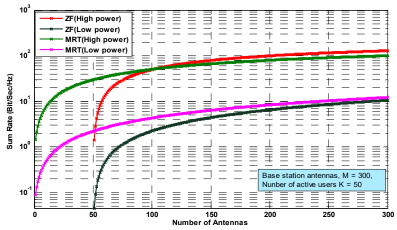

Fig. 6a ZF and MRT using matrix normalization at M = 300 and K = 50

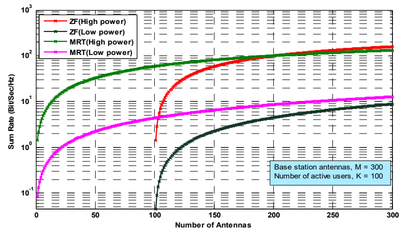

Fig. 6b ZF and MRT using matrix normalization at M = 300 and K = 100

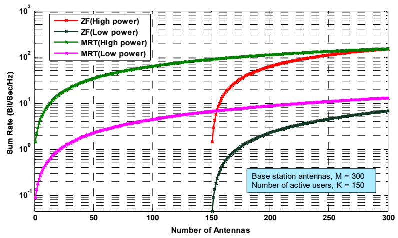

Fig. 6c ZF and MRT using matrix normalization at M = 300 and K = 150

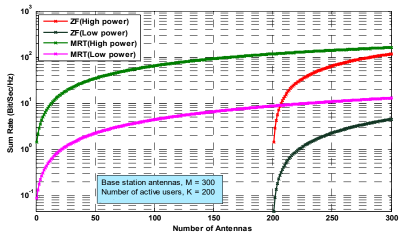

Fig. 6d ZF and MRT using matrix normalization at M = 300 and K = 200

Fig. 6 Simulation plot of ZF and MRT using matrix normalization (at M = 1:300)

Table 5 Sum Rate Performance For M = 1:300 Using Matrix Normalization

Number of Users (K)	**Number of Base Antennas M = 1:300**			
	Zero Forcing (ZF)		**Maximum Ratio Transmission (MRT)**	
	Low Power	**High Power**	**Low Power**	**High Power**
50	10.59 Bit/s/Hz	129.2 Bit/s/Hz	12.22 Bit/s/Hz	100.7 Bit/s/Hz
100	8.847 Bit/s/Hz	158.5 Bit/s/Hz	12.7 Bit/s/Hz	132.9 Bit/s/Hz
150	6.737 Bit/s/Hz	150.7 Bit/s/Hz	12.92 Bit/s/Hz	150.0 Bit/s/Hz
200	4.527 Bit/s/Hz	117 Bit/s/Hz	13.02 Bit/s/Hz	162.2 Bit/s/Hz

In Table 5, sum rate performances of the system with MRT at low power gain are better than that of ZF. But at high power gain, ZF outperforms MRT except when K = 200. It is observed as shown in Fig. 6a that at M < 101, during high power gain transmission, that MRT gives better spectral efficiency than ZF.

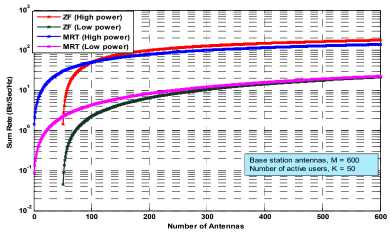

Fig. 7a ZF and MRT using matrix normalization at M = 600 and K = 50

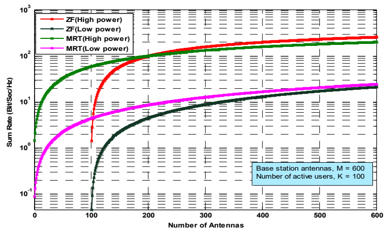

Fig. 7b ZF and MRT using matrix normalization at M = 600 and K = 100

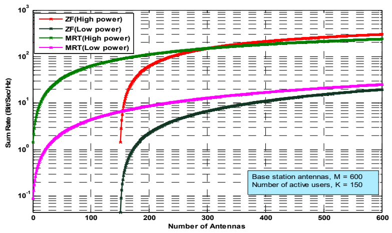

Fig. 7c ZF and MRT using matrix normalization at M = 600 and K = 150

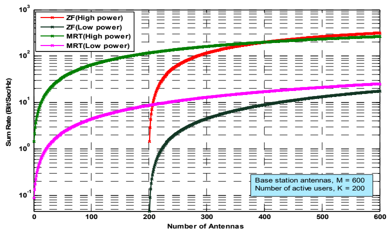

Fig. 7d ZF and MRT using matrix normalization at M = 600 and K = 200

Fig. 7 Simulation plot of ZF and MRT using matrix normalization (at M = 1:600)

Table 6 Sum Rate Performance For M = 1:600 Using Matrix Normalization

Number of Users (K)	**Number of Base Antennas M = 1:600**			
	Zero Forcing (ZF)		**Maximum Ratio Transmission (MRT)**	
	Low Power	**High Power**	**Low Power**	**High Power**
50	21.53 Bit/s/Hz	179.2 Bit/s/Hz	22.64 Bit/s/Hz	141.1 Bit/s/Hz
100	21.18 Bit/s/Hz	258.5 Bit/s/Hz	24.4 Bit/s/Hz	200.7 Bit/s/Hz
150	19.61 Bit/s/Hz	300.0 Bit/s/Hz	25.07 Bit/s/Hz	238.5 Bit/s/Hz
200	17.69 Bit/s/Hz	317.0 Bit/s/Hz	25.43Bit/s/Hz	265.1 Bit/s/Hz

Table 6 presents the sum rate performance analysis for M = 1:600, K = 50, 100, 150, 200. At low power transmission, it can be seen that MRT gives better results than ZF. However, at high power, ZF performs better than MRT. The simulation plots in Fig. 7a shows that MRT gives better result for high power transmission at M < 103. In Fig. 7b, the sum rate performance of MRT = ZF at M = 202 with a value of 101.4 Bit/s/Hz. Similarly, in Fig. 7c and 7d, the sum rate performances of MRT = ZF at M = 302 and M = 402 with values of 151.4 Bit/s/Hz and 201.4 Bit/s/Hz respectively.

1.9 Matrix Normalization when K = 1:200

The sum rate performance of the system is examined in this subsection for matrix normalization when the number of users being served by base station varies 1 to 200. The number of base station antennas are fixed for M = 300, 400, 500, and 600 as shown in Fig. 8.

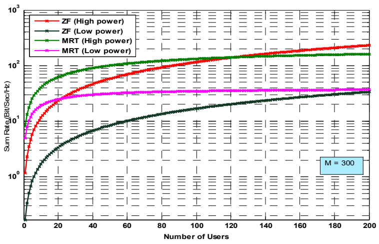

Fig. 8a ZF and MRT using matrix normalization at K =1:200 and M = 300

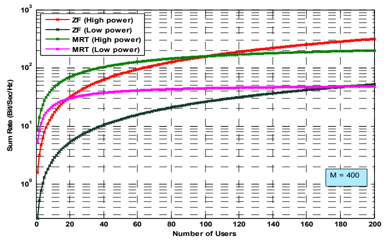

Fig. 8b ZF and MRT using matrix normalization at K = 1:200 and M = 400

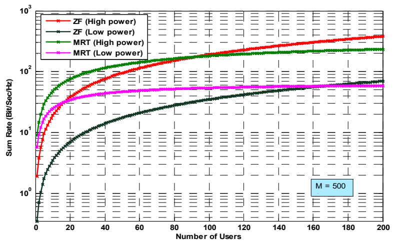

Fig. 8c ZF and MRT using matrix normalization at K = 1:200 and M = 500

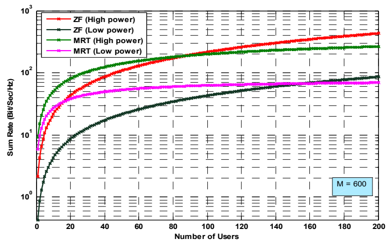

Fig. 8d ZF and MRT using matrix normalization at K = 1:200 and M = 600

Fig. 8 Simulation plot of ZF and MRT using matrix normalization (at K = 1:200)

Table 7 Sum Rate Performance For K= 1:200 Using Matrix Normalization

Number of Base Antennas (M)	**Number of Users K = 1:200**			
	Zero Forcing (ZF)		**Maximum Ratio Transmission (MRT)**	
	Low Power	**High Power**	**Low Power**	**High Power**
300	33.84 Bit/s/Hz	233.3 Bit/s/Hz	37.02 Bit/s/Hz	162.2 Bit/s/Hz
400	52.43 Bit/s/Hz	316.3 Bit/s/Hz	48.33 Bit/s/Hz	200.7 Bit/s/Hz
500	69.89 Bit/s/Hz	380.7 Bit/s/Hz	59.22 Bit/s/Hz	234.7 Bit/s/Hz
600	86.35 Bit/s/Hz	433.3 Bit/s/Hz	69.72 Bit/s/Hz	264.7 Bit/s/Hz

In Table 7, it can be seen that at low power gain transmission, ZF gives better sum rate performance than MRT except when M = 300. For high power gain transmission, ZF also outperforms MRT in all the cases. However, it is observed that for M = 400, 500 and 600 in Fig. 8b, 8c and 8d, for low power gain transmission, MRT initially outperforms ZF at K < 184, K < 167, and K < 157. Also for high power gain, MRT initially gives better sum rates than ZF at K < 122 for M = 300 in Fig. 8a, at K < 102, for M = 400 in Fig. 8b, at K < 92 for M = 500 in Fig. 8c, at K < 87 for M = 600 in Fig. 8d.

1.10 Matrix and Vector Normalization Comparison for High and Low Power

This sub-section presents the sum rate performance comparison of matrix normalization and vector normalization in terms of ZF and MRT precoding schemes. Simulations are conducted for high power and low power downlink operation as shown in Fig. 9 and10. Figure 9 is the achievable sum rate performance comparison for M = 1:600, K = 200 for high power (HP) transmission. Figure 10 shows the comparison for M = 1:600, K = 200 for low power (LP) transmission.

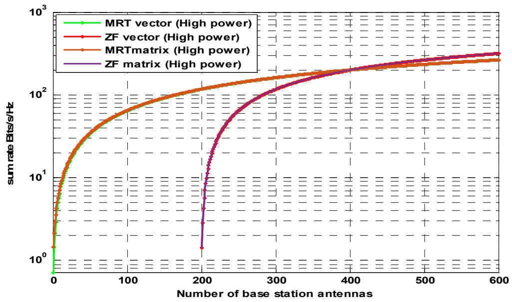

Fig. 9 Matrix normalization vs. vector normalization at HP

Figure 9 shows the spectral efficeincy or achievable sum rate over the entire antenna range for ZF and MRT. This techniques comprises M = 1:600, K = 200 and high downlink transmitted power. In Fig. 9, it is obvious that matrix/vector normalizations plots for MRT gives the same sum rate performance and this was better performance than that of matrix/vector normalizations plots for ZF when M < 403 at high power value. However, matrix/vector normalizations for MRT gives the same sum rate performance of 201.4 bits/s/Hz as matrix/vector normalizations for ZF at M = 402. Generally, matrix/vector normalizations for ZF outperform MRT matrix/vector normalizations when M > 403 and yielded sum rate of 317 Bits/s/Hz while MRT provided sum rate of 265.1 Bits/s/Hz at M = 1:600, K = 200.

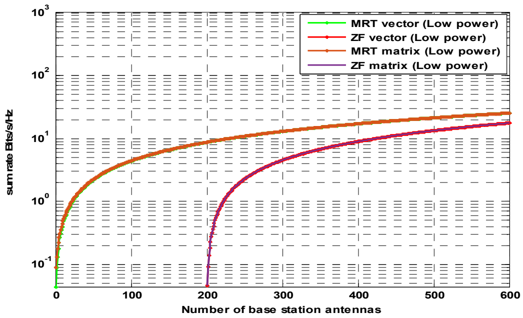

Fig. 10 Matrix normalization vs vector normalization at LP

In Fig. 10 shows the achievable sum rate over the entire antenna range. This technique consists of M = 1:600, K = 200 and low downlink transmitted power. It can be seen from the simulation plot that matrix/vector normalizations for MRT provides the same sum rate and better performance than ZF matrix/vector normalized scheme.

V. CONCLUSION

The large scale massive multiple antennas technique examined in this paper can provide increase achievable sum rate. The spectral efficiency of the system is examined considering low transmit power and high transmit power scenarios downlink operation at the base station. Two linear precoding schemes are considered namely: zero forcing (ZF) and maximum ratio transmission (MRT). It is assumed that each user is equipped with single antenna. With the increase in the number of base station antennas the sum rate tends to a high value. With the highest values of 317.5 Bits/s/Hz and 317.0 Bits/s/Hz for ZF considering vector/matrix normalizations at M = 1:600, for K = 200 when sum rate is plotted against number of base station antennas M in high transmitted power scenarios. Also, when sum rate is plotted against number of users K, the system achieves highest sum rate of 433.7 Bits/s/Hz and 433.3 Bits/s/Hz for ZF considering vector/matrix normalizations at M = 600, for K = 1:200 for high transmitted power scenarios. The results show that for low transmitted power, MRT outperforms ZF, while ZF gives better performance than MRT for high transmitted power. Generally, as antennas at base station M increases the sum rate will be favoured by ZF in high transmitted power scenario. In low transmitted power mode, sum rate will be favoured by MRT. In high power (which is cell centre), ZF has better spectral efficiency performance at vector/matrix normalization and in low power (cell boundary), MRT gives better result in vector/matrix normalizations.

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