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Throughput, Spectral, and Energy Efficiency of 5G Massive MIMO Applications Using Different Linear Precoding Schemes

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***Abstract*— On fifth-generation wireless networks, a potential massive MIMO system is used to meet the ever-increasing request for high-traffic data rates, high-resolution streaming media, and cognitive communication. In order to boost the trade-off between energy efficiency (EE), spectral efficiency (SE), and throughput in wireless 5G networks, massive MIMO systems are essential. This paper proposes a strategy for EE 5G optimization utilizing massive MIMO technology. The massive MIMO system architecture would enhance the trade-off between throughput and EE at the optimum number of working antennas. Moreover, the EE-SE tradeoff is adjusted for downlink and uplink massive MIMO systems employing linear precoding techniques such as Multiple - Minimum Mean Square Error (M-MMSE), Regularized Zero Forcing (RZF), Zero Forcing (ZF), and Maximum Ratio (MR). Throughput is increased by adding more antennas at the optimum EE, according to the analysis of simulation findings. Next, utilizing M MMSE instead of RZF and ZF, the suggested trading strategy is enhanced and optimized. The results indicate that M-MMSE provides the best tradeoff between EE and throughput at the determined optimal ratio between active antennas and active users equipment's (UE).**

***Keywords*—throughput; massive MIMO; spectral efficiency; energy efficiency; trade off**

I. INTRODUCTION

THE need for faster data rates on wireless networks will increase despite the constrained electromagnetic spectra that are now accessible [1]. Wireless communications, instead of fiber communications, are searching for innovative solutions and cutting-edge technology to meet future demands. One of the most recently proposed technologies, massive multiple-input multiple outputs (M_MIMO), often called extremely large-scale MIMO, is praised for its bright future [2]. The key is to equip base stations (BSs) with many more antennas than subscribers / UEs.

As shown in Fig. 1, massive MIMO system offer advantages, such as improved spectra efficiency to satisfy future demand, particularly in crowded regions [3]. Furthermore, this new technology will offer more secure networks and energy-efficient systems.

The ease of signal processing will also lower the cost of the hardware components in the BSs [1], and [4].

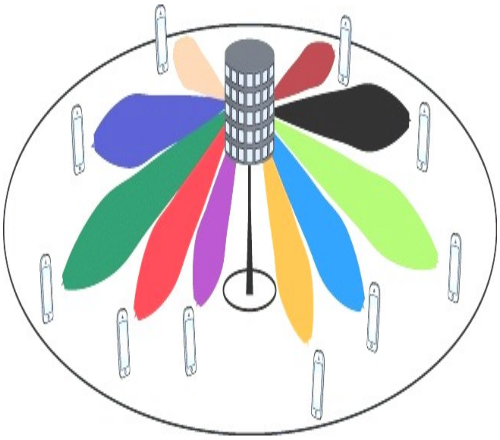

Fig.1. Massive MIMO uplink and downlink overview [5]

As mentioned in [5], such future technology may achieve higher spectral efficiency in UL and DL without needing more expensive and sophisticated Base Stations.

By enhancing Spectral _Efficiency and Energy _Efficiency, Massive MIMO performance may be enhanced [6]. So, for effective cellular networks, green communication metrics such as EE have become key design criteria [7]. Therefore, EE, SE, and throughput are employed the most in our study and simulation of the proposed schemes since they are considered critical to massive MIMO systems [8-9]. Recent proposals for massive M MIMO technology offer significant spectra and energy efficiency gains over present LTE technologies, opening the door for 5G.

For enhancing EE-SE performance, authors in [10] looked at the optimal tradeoff between EE and SE based on the user connection, antenna number, energy coordination, and backhaul capabilities.

The tradeoff between EE and SE is impacted by an increase in the following parameters when the Rayleigh fading channel is present: Using several fictitious energy use models and realistic energy consumption plans, per [11]. Therefore, in a massive MIMO system, a pilot training signal and many active users are provided for less energy to achieve the optimum EE-SE tradeoff.

Maximum ratio, matching filter, and zero force in combination with the downlink and uplink of high data rates with insufficient channel state information (CSI) in [12] strengthened the best

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EE-SE design (ZF). While in [13] authors claimed that in a downlink massive MIMO system with many BSs for SE, the signal-to-interference noise ratio (SINR) and optimal signal strength in each cell are used to estimate the maximum of EE-SE.

Recent years have seen the emergence of cell-free massive multiple-input multiple-output (MIMO) systems, which combine massive MIMO, network MIMO, and distributed antenna systems (DAS). In these systems, many randomly distributed access points (APs) are connected to a central processing unit (CPU), simultaneously serving fewer users [21]. Precoding and power allocation algorithms are run on the CPU. In rural and urban settings, cell-free approaches have been demonstrated to improve energy efficiency (EE) and throughput per user compared to cellular systems.

The rest of this paper is arranged as follows: Section 2 discusses the trade-off between EE and SE (EE-SE). In Section 3, the trade-off between throughput and EE is covered. Section 4 displays the results of the computational analysis. Finally, Section 5 of the paper discusses its conclusion.

II. TRADEOFF BETWEEN ENERGY EFFICIENCY AND SPECTRAL EFFICIENCY (EE-SE)

In this method, each cell is seen as having a square area (L*L). Within 50 m of the BS, the number of users (K UEs) is independently and uniformly distributed where each BS's (M) antennas are situated.

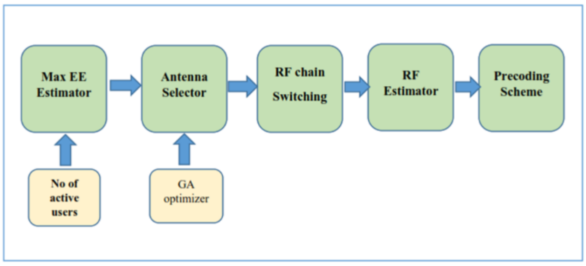

Fig. 2. The proposed scheme's block diagram

The block diagram of the suggested system is shown in Fig. 2. Using the BS database or spectrum sensing technologies, the number of active users serviced by the cell is initially provided to the maximum EE Estimator block [14].

Maximum EE values are predicted for a range of antenna (M) numbers using equation (2). The optimal number of active antennas is then determined using the optimization approach by forming an Optimizer based on an antenna selector. Then, to maximize EE, the RF switch operates the specified number of active antennas while shutting off the inactive ones. Before the uplink, a linear precoding technique that has been optimized is used.

Each UE's uplink (UL) spectral efficiency is determined according to equation (1), as derived in [15]:

$$SE_0 = \log_2\left(1 + \frac{M-1}{(K-1)+K\overline{\beta}+\frac{\sigma^2}{p\beta_0^0}}\right) \tag{1}$$

In this equation, M stands for the number of antennas, p for transmitted power, K for the number of user equipment (UE), σ^2 express the power of noise, and β denotes the average gain of channel for active UE's. In [16,17], the corresponding EE of a cell is estimated based on (2):

$$EE_0 = \frac{BKSE_0}{K\left(\frac{M-1}{2^{SE_0-1}}-K\overline{\beta}+1-K\right)^{-1}\nu_0+CP_0} \tag{2}$$

The best way to maximize the EE is to choose a decent power level and utilize it sensibly rather than reducing the overall power.

In which, B represents the bandwidth, whereas ν_0 is given using the following (3)

$$\boldsymbol{\nu_0 = \frac{\sigma^2}{\mu\beta_0^0}} \tag{3}$$

Where, $\boldsymbol{\mu}$ is the power amplifier's Effective Transmit Power, 0<$\boldsymbol{\mu}$<1.

Furthermore, the Circuit Power (CP) denoted by a single UE is evaluated using the formula of (4), as proven in [16,17]:

$$\boldsymbol{CP_0 = P_{FIX} + MP_{BS}} \tag{4}$$

Where, M is the number of active antennas per BS, $\boldsymbol{P_{FIX}}$ represents the amount of fixed power, whereas $\boldsymbol{P_{BS}}$ denotes the required energy by the circuit components at each BS antenna's operation (e.g., " filters, I/Q mixers, DACs, and Local Oscillator").

The circuit's power CP represents the total amount of power used by all analog components and digital signal processing in the circuit.

Equation (5) calculates (CP₀), the additional consumed circuit power by all active UEs.

$$\boldsymbol{CP_0 = P_{FIX} + MP_{BS} + NP_{UE}} \tag{5}$$

Where, $\boldsymbol{P_{UE}}$ denotes the consumed power by CPs of user equipment's single antenna.

The following optimization challenge must be resolved to create an EE-optimal Massive MIMO configuration.

$$\underset{M\in\mathbb{Z}_+,K\in\mathbb{Z}_+,\bar{R}\geq 0}{\textbf{maximize}} \quad \mathrm{EE} = \frac{\sum_{k=1}^{K}\left(\mathbb{E}\left\{R_k^{(\mathrm{ul})}\right\}+\mathbb{E}\left\{R_k^{(\mathrm{dl})}\right\}\right)}{P_{\mathrm{TX}}^{(\mathrm{ul})}+P_{\mathrm{TX}}^{(\mathrm{dl})}+P_{\mathrm{CP}}(M,K,\bar{R})}. \tag{6}$$

Selecting an appropriate power level and using it sensibly is the key to maximizing the EE rather than reducing the overall power.

The maximum EE (max.EE) is also computed based on the first derivative of equation (2), which gives the formula of the maximum EE.

$$\boldsymbol{maxEE = \frac{d}{dSE0}(EE_0)}$$

$$\boldsymbol{maxEE \approx \frac{eB}{(1+e)}\frac{log_2(MP_{FIX})}{P_{FIX}}} \tag{7}$$

Equation (7) demonstrates that the maximum EE has a roughly linear decline function with $\boldsymbol{P_{FIX}}$ and rises logarithmically as the number of antennas (M) per BS increases. Consequently, it is possible to calculate the optimum number of antennas:

$$\boldsymbol{opt.\ M = \frac{N\ of\ UEs}{2}}$$

Various linear receive combining techniques have already been thoroughly described in [18–20]. Before up linking, the system employs multiple minima mean square error (M-MMSE) [21-27].

We take into consideration a multi-cell, synchronous massive MIMO cellular network. The most prominent processing techniques used in uplink reception and downlink transmission are zero-forcing (ZF), matched filtering (MF), and minimum mean square error (MMSE) processing.

Equation 8 displays the M-MMSE vectors in matrix form for each of the UEs in the cell.

$$V_j^{M-MMSE} = \left[V_{j1} \dots V_j K_j\right]$$

$$= \left(\sum_{l=1}^{L} H_l^j P_l \left(\widehat{H}_l^j\right)^H + \sum_{l=1}^{L} \sum_{i=1}^{K_l} \mathcal{P}_{li} C_{li}^j + \sigma_{UL}^2 I_{M_j}\right)^{-1} \widehat{H}_j^j P_j \qquad (8)$$

Where, $\widehat{H}_j^j$ gives the matrix of the estimated channel from all UEs in the cell, P_j represents the diagonal matrix of transmit powers by all UEs', C_{li}^j determines the matrix of the correlated received signal, and I_{M_j}denotes the total received whitened signal.

The Regularized_ Zero-Forcing combing method (RZF), a different alternative scheme, assumes that the channel is good since there is no interference from nearby cells. ZF is employed to achieve capacity-approaching performance. Therefore, equation 9 is used in place of the correlation matrix in equation (8), as indicated.

$$\boldsymbol{V_j^{RZF} = \widehat{H}_j^j \left(\left(\widehat{H}_j^j\right)^H \widehat{H}_j^j + \sigma_{UL}^2 P_j^{-1}\right)^{-1}} \qquad (9)$$

when the SNR is assumed to be very high, the regulation term $\sigma_{UL}^2 P_j^{-1}$ can be neglected. Therefore, the Zero _Forcing (ZF) combining scheme matrix can be expressed as:

$$\boldsymbol{V_j^{ZF} = \widehat{H}_j^j \left(\left(\widehat{H}_j^j\right)^H \widehat{H}_j^j\right)^{-1}} \qquad (10)$$

Finally, Maximum Ratio (MR) combined precoding scheme is utilized according to equation (10)

$$\boldsymbol{V_j^{MR} = \widehat{H}_j^j} \qquad (11)$$

III. ENERGY EFFICIENCY - THROUGHPUT (EE-TR) TRADEOFF IN M-MIMO

The CP model is used to examine the tradeoff between throughput and EE. We concentrate on the massive MIMO network throughput to emphasize that EE analysis requires bandwidth. There are M antennas in each cell for each BS and K UEs. M and K have different values. The throughput is computed as in (12):

$$\boldsymbol{TR = B \sum_1^k (SE_k^{ul} + max(SE_k^{dl}))} \qquad (12)$$

After that, the actual value of Cell j is estimated according to equation 13.

$$\mathbf{EEj} = \frac{\mathbf{TRj}}{\mathbf{ETPj + CPj}} \qquad (13)$$

Where ETPj stands for the cell j's effective transmit power. These metrics account for the power to transmit UL and DL signals and pilot sequences. Therefore, ETP is estimated according to equation (14):

$$\mathbf{ETP_j = ETP\ for\ pilots + ETP_{UL} + ETP_{DL}} \qquad (14)$$

The equations (15-17) are then used to calculate ETP for pilot, uplink and downlink modes.

$$\mathbf{ETP_{for\ pilots}} = \frac{\tau_p}{\tau_c} \sum_{k=1}^{K_j} \frac{1}{\mu_{UE,jk}} \boldsymbol{p\, jk} \qquad (15)$$

$$\mathbf{ETP_{UL}} = \frac{\tau_u}{\tau_c} \sum_{k=1}^{K_j} \frac{1}{\mu_{UE,jk}} \boldsymbol{p\, jk} \qquad (16)$$

$$\mathbf{ETP_{DL}} = \frac{1}{\mu_{BS,j}} \frac{\tau_d}{\tau_c} \sum_{k=1}^{K_j} \boldsymbol{p\, jk} \qquad (17)$$

Where $\boldsymbol{\tau_u}$ represents the UL samples of coherence block. $\boldsymbol{\tau_p}$ refers to K samples, $\boldsymbol{\tau_d}$ is the number of DL samples of coherence block. $\boldsymbol{\tau_u}$ mentions to UL samples of coherence block. Moreover, $\boldsymbol{\mu_{BS,j}}$ represents the efficiency of PA at BS. Whereas, $\boldsymbol{\mu_{UE,jk}}$ refers to the efficiency of PA at UE in each cell. The next section determines and compares the tradeoff between EE and throughput for several methods.

IV. SIMULATION RESULTS AND DISCUSSION

The analysis and simulation of the proposed model are estimated using MATLAB/ SIMULINK (R2020b).

The averaged uplink (UL) summation SE for universal pilot reuse with (f = 1) is depicted in Fig. 3 as a function of the quantity of antennas' base stations. The strategy that produces the greatest SE is the M-MMSE, and the SE gets lower with each approximation used to produce a less complicated strategy than the M-MMSE.

Compared to RZF and ZF, the M-MMSE scheme has a greater obtained SE. For M greater than 20, however, the SE with ZF quickly degrades because the BS cannot reject the interference without canceling a large portion of the intended signal. However, for M more than 20, the SE with ZF rapidly deteriorates due to the BS's inability to cancel the interference without simultaneously canceling a substantial percentage of the intended signal. ZF should thus be avoided in order to have a reliable implementation. MR only provides half the SE of the other systems, which is surprising. As a result, the M-MMSE provides the greatest SE and performance with more antennas.

The averaged Down Link sum SE for f = 1. ZF, RZF, MR S-MMSE, and M-MMSE precoding schemes are considered, as shown in Fig. 4. These precoding schemes work similarly to their UL counterparts. No matter how many antennas are deployed, M-MMSE provides the maximum SE. Except for ZF, which has robustness difficulties for M with less than 20 antennas, S-MMSE, RZF, and ZF create a comparable SE. Lastly, MR is the sole scheme that favors the estimate bound above the hardening bound and has the lowest SE of all the schemes.

According to the results in Fig. 3 and Fig. 4, which use massive MIMO, the M-MMSE precoding method is the optimum for boosting SE in UL and DL with more antennas. The increasing number of antennas impacts both the SE and EE. Consequently, as shown in Table II, m = 1000 has the Max EE at a particular value of SE. With massive MIMO, it has been found that as the number of antennas M rises, so do SE and EE.

TABLE.I
SIMULATION PARAMETERS

The Parameter	**Value**
Max. Number of Antennas, M	1000
Number of UE K	10:100
Bandwidth (B)	100 KHz
(μ)UE	0.4
P_{FIX}	10 W
PBS	1 W
PUE	0.5 W
(μ) BS	0.5
tau_c	200
Pilot reuse factor (f)	1
tau_p	F*k

TABLE.II
THE EE&SE BASED M-MIMO

M	**2**	**10**	**100**	**1000**
EE	21251.3	42060.4	69218.2	97576.5
SE	3.4344	5.6199	8.3601	11.1997

TABLE III
THE TR&EE BASED PRECODING SCHEMES AT UE=10

scheme	**M-MMSE**	**RZF**	**ZF**	**MR**
TR(Mb/s)	600.8	524.013	509.99	317.01
EE(Mb/J)	21.3	19.205	18.70	10.18

TABLE.IV
TR&EE USING DIFFERENT PRECODING SCHEMES AT UE=20 USERS

scheme	**M-MMSE**	**RZF**	**ZF**	**MR**
TR(Mb/s)	1011.6	958.5	943	533.7
EE(Mb/J)	45.53	40.35	39	20.7

TABLE.V
THE MAXIMAL EE BASED PRECODING SCHEMES

Scheme	**M-MMSE**	**ZF**	**MR**
(Opt._EE(Mb/J)	20.8	20.2	10,6
(M,K)	(40,20)	(60,20)	(90,30)

Table VI and Fig. 5 show how spectral efficiency is highly improved by increasing no of antennas for various linear precoding schemes and the values obtained from the M-MMSE give the highest values of SE compared with other linear precoding schemes in UL and DL. For example, at M=100 the SE is equal to 50.34 (bit/s/Hz), which is almost greater than RZF, ZF and MR. Hence, the M-MMSE gives higher values of SE than other schemes for different values of M.

The cell's EE is depicted in Fig. 6 with various Antennas to Users ratios (M/K). Modifying the number of antennas M and setting the user count to 10 per cell. At the ideal EE, it is thought that (M = 20) antennas are the perfect number to achieve the optimum performance. Similar to this, M is estimated to be (M = 40) for k = 20. Therefore, the ideal (M/K) ratio is 2, which provides the maximum value of EE and SE.

Fig. 7 illustrates the relationship between throughput and EE for many linear precoding schemes. Table III and Fig. 7 demonstrate that for the number of UE = 10, the linear system (M-MMSE) provides the maximum tradeoff between TR&EE, where (TR=600.8Mb/s and EE= 21.3Mb/J**)**. The other schemes thus have lower values. However, the linear method (M-MMSE) showed the maximum tradeoff between TR&EE at UE = 20, as shown in Table IV and Fig. 8. where (TR = 1011.6 Mb/s and EE = 45.53 Mb/J**)** are the highest values. Hence, the M-MMSE scheme is considered as the best choice not only optimizing and enhancing the energy efficiency of massive MIMO. but also, increasing throughput.

Figs. (9,10, and 11) depict the range of EE values obtained with different precoding schemes (ZF, MR, and M-MMSE,) at different K and M combinations. Taking into consideration $K \in \{10, .\ 100\}$ and $M \in \{20, . . .\ 200\}$. (M, K) = (40, 20) offers a maximum EE of 20.8 Mbit/Joule with M-MMSE, resulting in maximum throughput.

ZF scheme offer an optimal EE of 20.2 Mbit/Joule at (M, K) = (60, 20), resulting in a lower throughput than M-MMSE. The optimal EE with MR results in an EE of 10.6 Mbit/Joule at (M, K) = (60,20) for the decreased area throughput, which is about (48%) lower than with M-MMSE and ZF. Table V summarises the findings, assuming that MMSE provides the best throughput and _EE for all applications. Any (M, K) indicates the (M/K) ratio = 2. As a result, the MMSE improves system performance.

Table .VII, shows that, the M-MMSE has the highest values of throughput and EE at various UEs. Hence, as the number of UEs is increased, the throughput and EE are improved and highly increased. In the case of UEs = 50 the (TR=2550.5*(Mb/s)* and EE=113.2(Mb/J)). Furthermore, it is proved that M_MMSE is the optimum technique for getting the maximum tradeoff between throughput and EE in massive MIMO systems.

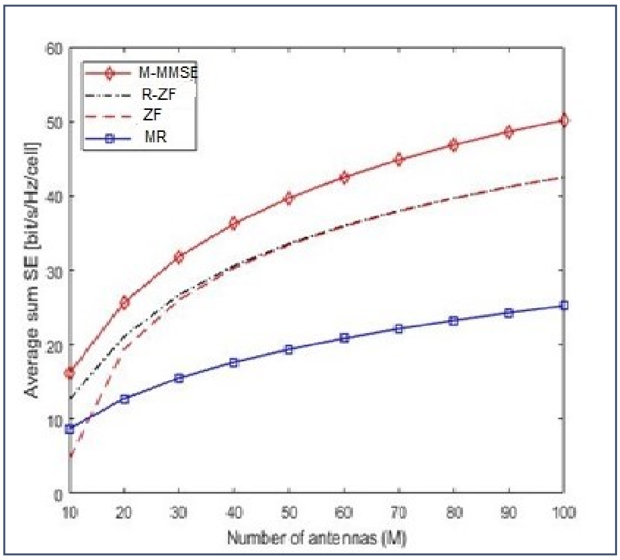

Fig. 3. SE Vs. M at different precoding schemes in UL

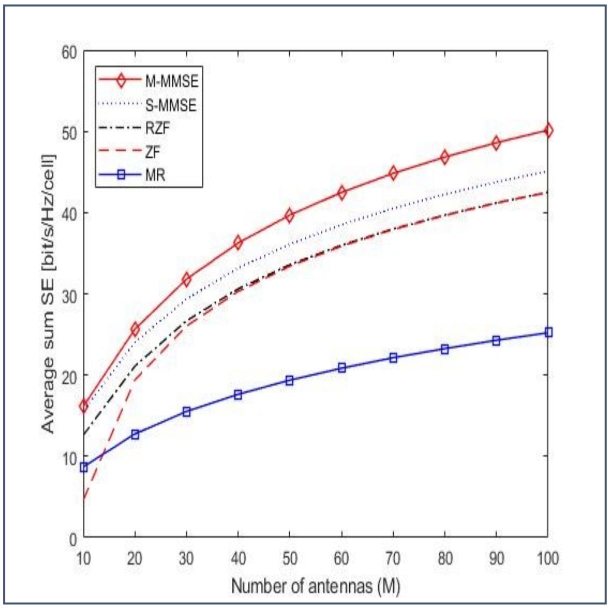

Fig. 4. SE Vs. M at different precoding schemes in DL

TABLE VI
SE FOR M-MMSE ,RZF,ZF AND MR PRECODING SCHEMES

Scheme	M=30	M=50	M=80	M=100
M-MMSE	**32.21**	**38.57**	**45.45**	**50.34**
RZF	25.00	30.10	36.55	42.81
ZF	24.89	30.00	36.55	42.81
MR	14.87	16.18	20.11	25.12

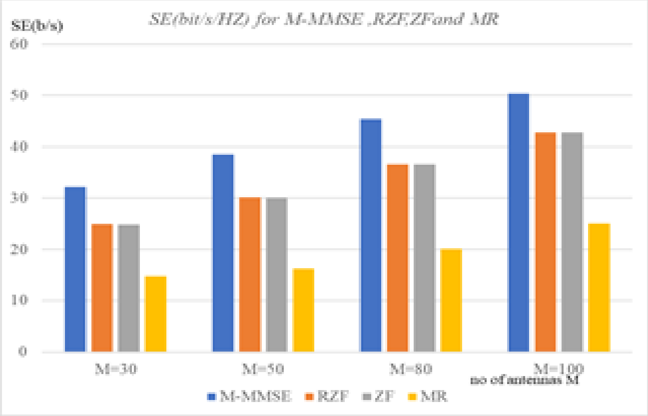

Fig. 5. SE(bit/s/HZ) for M_MMSE,RFZ,ZF and MR precoding schemes

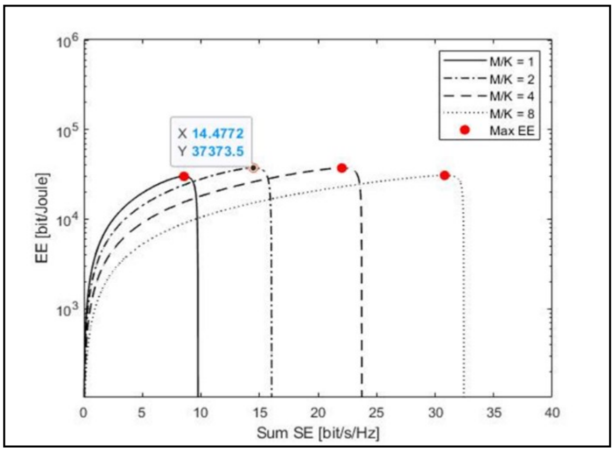

Fig. 6. Sum (SE) Versus EE for (M/K ratio=1,2,4,8) K = 10

TABLE.VII
TR&EE USING MMSE, RZF, AND MR FOR VARIOUS UEs

NO of UEs	MMSE		RZF		MR	
	TR(Mb/s)	EE(Mb/J)	TR(Mb/s)	EE(Mb/J)	TR(Mb/s)	EE(Mb/J)
10	600.8	21.3	524.013	19.205	317.01	10.18
20	1011.6	45.53	958.53	40.352	533.7	20.7
30	1500.4	69.71	1394.1	62.151	750.81	31.15
50	2550.5	113.2	2264.15	103.55	1187.11	53,2

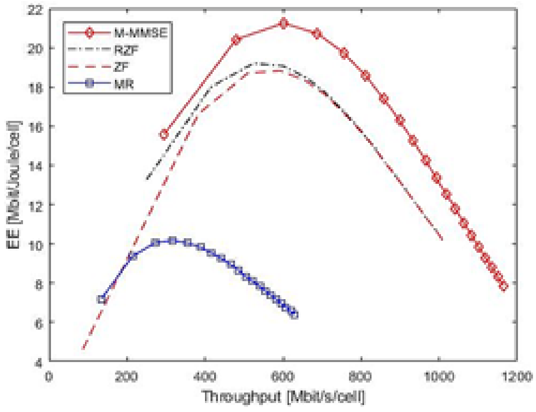

Fig.7 tradeoff between TR Versus EE (K = 10)

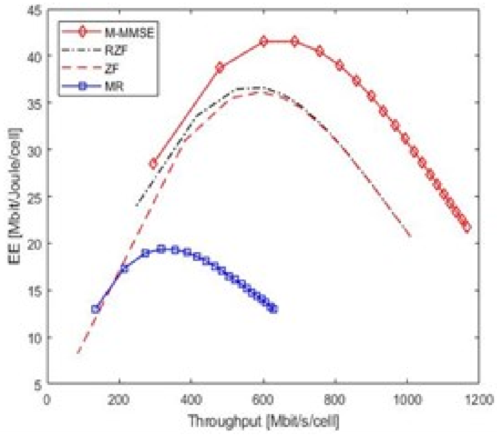

Fig. 8. TR & EE tradeoff at K = 20

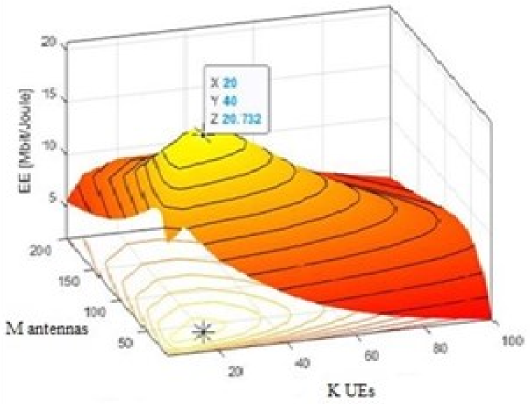

Fig. 9. Maximal energy efficiency for K&M (20,40) at M_MMSE

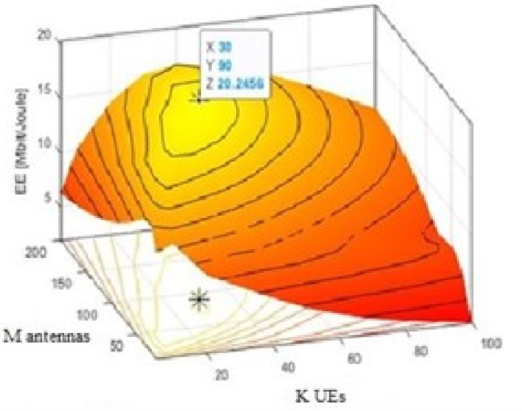

Fig. 10. Maximal energy efficiency for K&M (30,90) at ZF

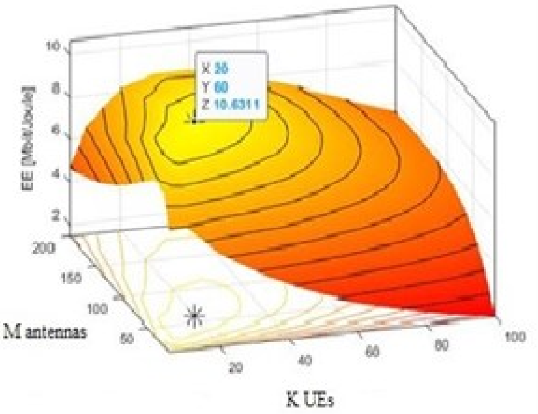

Fig. 11. Maximal energy efficiency for K&M (20,60) at MR

V. CONCLUSION

A proposed approach is used in this paper to enhance EE in 5G networks using numerous complicated antenna techniques, such as massive MIMO technology. The proposed strategy entails an adaptive number of active antennas that are updated in response to changes in the number of real users inside a cell to enhance the tradeoff between SE and EE and the tradeoff between EE and throughput. According to comparison simulation using multiple precoding techniques, M-MMSE is the optimum precoding approach for increased throughput. Furthermore, attaining optimal EE by dynamically modifying the antenna number to acquire maximum EE from the system utilizing (M/K =2). Because the suggested approach successfully improves EE and provides the best tradeoff between EE and throughput, as well as between EE and SE.

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