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

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***Abstract*— A promising massive multiple input multiple output (M-MIMO) system is required to meet the growing need for highly traffic data, highly-resolution of streaming video, and intelligent communication on the fifth-generation wireless networks (5G). M-MIMO systems are essential for the optimization of the trade between energy efficiency (EE), throughput (R), and spectral _efficiency (SE) in wireless 5G networks. M-MIMO system architecture is proposed in this paper to enhance the trade-off between energy efficiency and uplink and downlink throughput at the optimum EE. Furthermore, using linear precoding techniques such as M MMSE, RZF, ZF, and MR, the EE-SE trade-off is optimized for uplink and downlink (M-MIMO) systems. The analysis of simulation results proved that throughput (R) is enhanced by increasing the number of antennas at optimum EE. After that, the proposed trading scheme is optimized and improved using M_MMSE compared to RZF, ZF. Finally, the results prove that M_MMSE gives the optimum trade-off between EE and R at the proved optimum ratio between the number of active antennas and the number of active users UEs.**

***Keywords*—5G; throughput; massive MIMO; spectral efficiency; energy efficiency; trade off**

I. INTRODUCTION

EVEN though the available electromagnetic spectrum is restricted, the need for higher data rates on wireless networks will continue to rise [1]. In contrary to fiber communications, wireless communications are looking for creative ideas and new technology to satisfy future demands. Massive multiple-inputs multiple outputs (M_MIMO), also known as very large-scale MIMO, is one of the most recent suggested technologies, and it is recognized for its promising prospects [2]. It essentially depends on providing base stations (BSs) with much more antennas than the number of users.

As shown in fig1, massive MIMO systems provide benefits, such as improved spectrum efficiency to satisfy future demand, particularly in crowded regions [3]. Furthermore, this new technology will provide more secure networks as well as a more energy-efficient system. Moreover, the cost of the hardware components in the BSs will be reduced due to the simplicity of signal processing [1], [4].

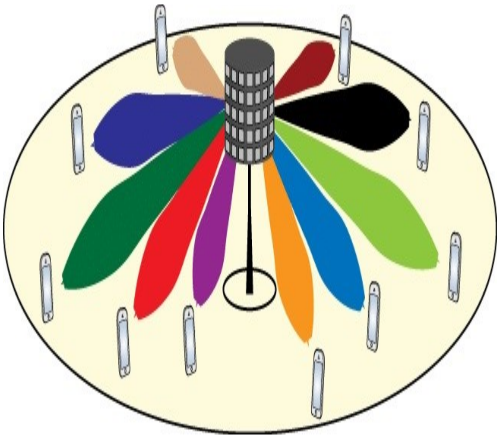

Fig.1. The massive MIMO UL and DL [5]

As discussed in [5] the spectral efficiency of this future technology may be increased in UL and DL without the deployment of more costly and complex BSs. Massive MIMO performance may be improved by increasing Spectral _Efficiency (SE) and Energy _Efficiency (EE) [6]. Therefore, green communication metrics like EE have emerged as essential design requirements for viable cellular_ networks [7,8]. Hence, EE, SE and throughput are deemed essential to massive MIMO systems, so they are the most used in our analysis and simulation of the proposed scheme. Massive _MIMO technology, which has recently been proposed, promises numerous spectrum and energy efficiency augmentations over present LTE technologies, making it a possible enabling for 5G.
Based on the previous research, the author in [10] investigated the optimal trade-off between EE and SE based on the user connection, the antennas number, energy coordination, and backhaul capability to enhance EE-SE performance. Increasing the following factors influence the trade-off between EE and SE in the presence of the Rayleigh fading channel: Using different kinds of hypothetical energy utilization models and practical energy consumption schemes according to [11]. Hence in a massive MIMO system, the maximum EE-SE trade-off is accomplished by providing many active users for less energy and a pilot training signal.

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In [12], the best design of EE-SE was strengthened by the uplink and downlink of high data rates with insufficient channel state information (CSI) paired with maximum ratio, matching filter, and zero force (ZF). Whereas in [13] authors provided that in a downlink massive MIMO system with many BSs for SE, the maximum of EE-SE is determined by analysing the signal to interference noise ratio (SINR) and optimum signal strength in each cell.

This paper's leftovers are structured as follows: Section 2 introduces the trade-off between EE and SE (EE-SE. Section 3 considers the trade-off between EE and throughput. Section 4 demonstrates the simulation analysis and results. In Section 5, the conclusion of this paper is discussed.

II. TRADE-OFF BETWEEN EE AND SE (EE-SE)

Each cell is considered a square area (L*L) in this system. The number of users (K UEs) is independently and uniformly distributed within 50 meters of the BS. Where, (M) antennas are in each BS.

Figure. 2 concerns the block diagram of the proposed system. The number of active users served by the cell is firstly sent to the Maximum EE Estimator block via the base station (BS) database or spectrum sensing systems [14]. First, equation (2) is employed to predict Max EE values for various antenna (M) numbers. Second, using the optimization technique, an Optimizer based on an antenna selector is formed to determine the optimum number of active antennas. Then, to maximize EE, the RF switch works the pre-determined number of active antennas while turning off the ones that are not needed. Finally, an optimized linear precoding scheme is applied before the uplink.

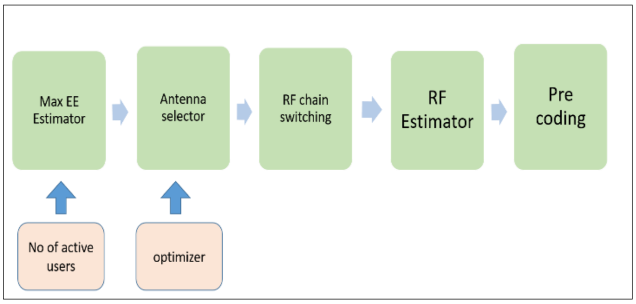

Fig.2. The proposed scheme's block diagram

Each UE's uplink (UL) SE [15] is determined according to equation (1).

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

Where, M defines the number of antennas, K donates the number of UEs, p is the power of transmission, σ^2 determines the noise power, and β denotes the active UE's average channel gain. In [16,17], the associated EE of cell can be determined according to equation (2)

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

Where, B is the bandwidth, and ν_0 is calculated from equation (3)

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

$\boldsymbol{\mu}$ component is The Effective Transmit Power of power amplifier where, $0<\boldsymbol{\mu}<1$. Furthermore, the Circuit Power (CP) required by a single UE is evaluated according to [16, 17] using the formula of equation 4:

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

In which $P_{\boldsymbol{FIX}}$ refers to the fixed power, whereas P_{BS} signifies the energy required by the circuit components needed for each BS antenna's operation (e.g., "DACs, I/Q mixers, filters, and Local Oscillator").

Equation (5) is used to approximately calculate the additional (CP) utilized by all active UEs.

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

Where, $P_{\boldsymbol{UE}}$ represents the power demanded by all circuit components of UE's single antenna.

The Maximum EE (Max EE) is estimated using the derivative of equation (2) that provides the expression:

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

$$\boldsymbol{maxEE} \approx \frac{\boldsymbol{eB}}{\boldsymbol{(1+e)}}\frac{\boldsymbol{log_2(MP_{FIX})}}{\boldsymbol{P_{FIX}}} \tag{6}$$

Equation (6) indicates that the maximum EE increases logarithmically with the increase in the number of antennas (M) per BS and has a nearly linear declining function with P_{FIX}.As a result, the optimal number of antennas may be computed from.

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

Different linear receive combining schemes are previously discussed in [18-20]. Firstly, multiple -minimum mean square error (M_MMSE) is applied to the system before uplink [21, 22]. Therefore, the M_MMSE vectors for all the UEs in the cell is presented as a matrix form in equation 7.

$$V_j^{M-MMSE} = \left[V_{j1} \dots V_j K_j\right] = \left(\sum_{l=1}^{L} H_l^j P_l \left(\widehat{H}_l^j\right)^H + \sum_{l=1}^{L}\sum_{i=1}^{K_l} \mathcal{P}_{li} C_{li}^j + \sigma_{UL}^2 I_{M_j}\right)^{-1} \widehat{H}_j^j P_j \tag{7}$$

Where P_j defines the diagonal matrix of all UEs transmit powers, $\widehat{H}_j^j$ donates the matrix of the estimated channel from all UEs in the cell, C_{li}^j determines the correlated received signal matrix and I_{M_j} represents the total whitened received signal. Another alternative scheme is the Regularized_ Zero-Forcing combing scheme (RZF), which implies that the channel is good as there is no interference from other cells. Therefore, the correlation matrix in (7) is replaced by equation 8 as shown.

$$V_j^{RZF} = \hat{H}_j^j \left(\left(\hat{H}_j^j\right)^H \hat{H}_j^j + \sigma_{UL}^2 P_j^{-1} \right)^{-1} \tag{8}$$

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:

$$V_j^{ZF} = \hat{H}_j^j \left(\left(\hat{H}_j^j\right)^H \hat{H}_j^j \right)^{-1} \tag{9}$$

Finally Maximum Ratio (MR) combined scheme is utilized.

$$V_j^{MR} = \hat{H}_j^j \tag{10}$$

III. TRADE-OFF BETWEEN THROUGHPUT AND ENERGY EFFICIENCY OF M-MIMO (TR-EE)

The trade-off between EE and throughput is analyzed according to the CP model. We focus on the Massive MIMO network throughput to highlight that EE analysis cannot be performed without bandwidth. Each BS and K UEs have M antennas in each cell. The values of M and K are varied. The throughput is computed as in equation (11)

$$TR = B \sum_1^k (SE_k^{ul} + max(SE_k^{dl})) \tag{11}$$

Then, The EE of cell j is obtained

$$\text{EEj} = \frac{\text{TRj}}{\text{ETPj+CPj}} \tag{12}$$

Where ETPj represents the Effective Transmit Power of the cell j. These metric counts for the power to transmit pilot sequences and UL and DL signals. Hence ETP is given by:

$$\text{ETP}_j = \text{ETP for pilots} + \text{ETP}_{\text{UL}} + \text{ETP}_{\text{DL}} \tag{13}$$

Then, ETP for uplink and downlink is obtained as the following equations (14-16).

$$\text{ETP}_{\text{for pilots}} = \frac{\tau_p}{\tau_c} \sum_{k=1}^{K_j} \frac{1}{\mu_{UE,jk}} \, p\,jk \quad , \tag{14}$$

$$\text{ETP}_{\text{UL}} = \frac{\tau_u}{\tau_c} \sum_{k=1}^{K_j} \frac{1}{\mu_{UE,jk}} \, p\,jk \qquad \text{and} \tag{15}$$

$$\text{ETP}_{\text{DL}} = \frac{1}{\mu_{BS,j}} \frac{\tau_d}{\tau_c} \sum_{k=1}^{K_j} p\,jk \tag{16}$$

Where τ_p is considered as K samples, τ_u is the number of UL samples of coherence block, also τ_d is the number of DL samples of coherence block. $\mu_{UE,jk}$ is the efficiency of PA at UE in each cell whereas, $\mu_{BS,j}$ represents the efficiency of PA at BS.

The trade-off between EE and throughput for different schemes is computed and compared in the next section.

IV. SIMULATION RESULTS AND DISCUSSION

The analysis and simulation of the proposed model is estimated based on the MATLAB/ SIMULINK (R2020b).

TABLE I
THE SIMULATION MAIN 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
*P*BS	1 W
*P*UE	0.5 W
(μ) BS	0.5
tau_c	200
Pilot reuse factor (f)	1
tau_p	F*k

Figure.3 illustrates the averaged uplink (UL) sum SE for universal pilot reuse with (f = 1) as a function of the number of BS antennas. The M-MMSE yields the highest SE. The SE decreases somewhat with each approximation used to create a strategy with lower complexity than M-MMSE.

The M-MMSE scheme has higher SE than RZF and ZF. Note that RZF and ZF produce nearly the same SE in the M in less than 20 regions of primary relevance in Massive MIMO. Still, the SE with ZF degrades fast for M greater than 20 because the BS lacks enough degrees of freedom to cancel the interference without also canceling a significant portion of the intended signal. As a result, ZF should be avoided to get a solid implementation. Surprisingly, MR only gives half the SE of the other systems. Hence, the M-MMSE gives the highest SE and better performance with an increasing number of antennas.

Figure 4 depicts the average DL sum SE for f = 1. M-MMSE, S-MMSE, RZF, ZF, and MR precoding schemes are considered. These precoding schemes work similarly to their UL counterparts. M-MMSE provides the highest SE regardless of the number of antennas used. S-MMSE, RZF, and ZF generate nearly similar SE, except for ZF, which has robustness issues for M with less than 20 antennas. Finally, MR has the lowest SE of any scheme and is the only one that prefers the hardening bound above the estimation bound.

The results in figure 3 and figure .4 show that the M-MMSE is the best precoding scheme for increasing SE in UL and DL with increasing antennas number (using Massive _MIMO).

As shown in figure.5, both the SE and EE are affected by the increase in the number of antennas. Therefore, m=1000 has the max EE at a specific value of SE, as indicated in table 2 .by using massive –MIMO, it is observed that both SE and EE are increased with an increase in the number of antennas M. Figure.6 illustrates the EE of the cell with various Antennas to Users ratios (M/K). By adjusting the number of users to be 10 per cell and changing the number of antennas, M. For the best performance, the adequate number of antennas at the optimal EE is estimated to be (M=20). Similarly, when k=20, M is guesstimated to be (M=40). Therefore, the optimum (M/K) ratio = 2.

Figure.7 shows the relation between EE and throughput for different linear precoding schemes. Table 3 and Figure 7 show that the linear scheme (M-MMSE) has the max trade-off between R&EE for the no of UE=10. Hence the other schemes have lower values. Furthermore, as shown in table 4, the linear scheme (M-MMSE) had the max trade-off between R&EE at UE=20.

Figures (8,9, and 10) show the range of EE values achievable with different precoding schemes (M-MMSE, ZF, and MR) for various M and K combinations. We take into account $K \in \{10,. . , 100\}$ 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 provides optimum EE = 20.2 Mbit/Joule at (M, K) = (60, 20), resulting in a throughput lower than M-MMSE. The optimum_ EE with MR yields an EE of 10.6 Mbit/Joule, which is around (48%) lower than with M-MMSE and ZF and is obtained at (M, K) = (60, 20) for the lower area throughput.

Table 5 summarizes the obtained results based on the assumption that MMSE is the best in terms of throughput and optimum _EE for every application. Any given (M, K) implies the (M/K) ratio = 2. Hence, the MMSE gives better performance for the system.

TABLE II
THE EE&SE BASED MASSIVE 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
THE TR&EE BASED DIFFERENT PRECODING SCHEMES
AT UE=20 USERS

scheme	M-MMSE	RZF	ZF	MR
R(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)

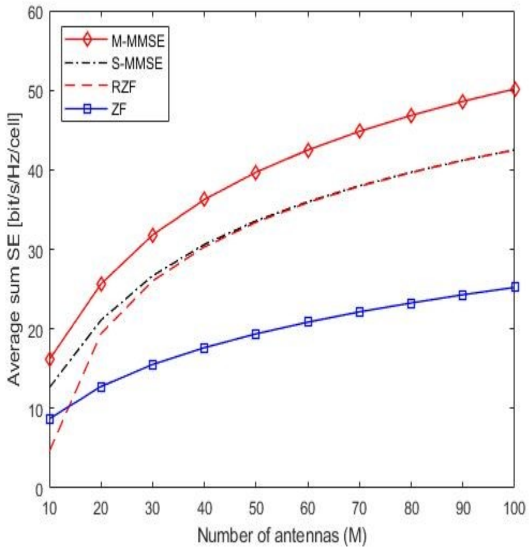

Fig. 3.The SE Vs. No of M in UL with different precoding schemes

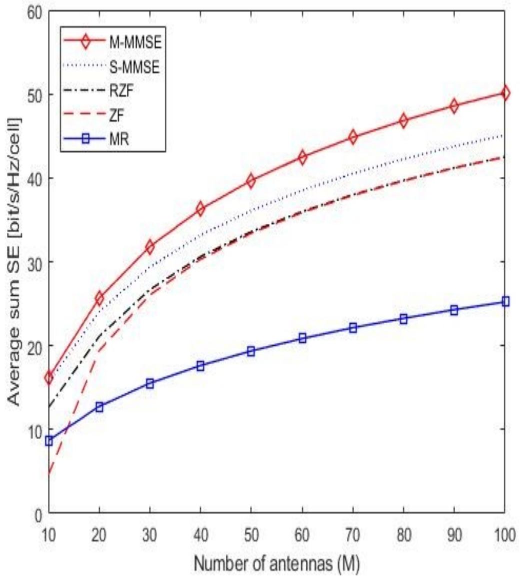

Fig. 4. The SE Vs. No of M in DL with different precoding schemes

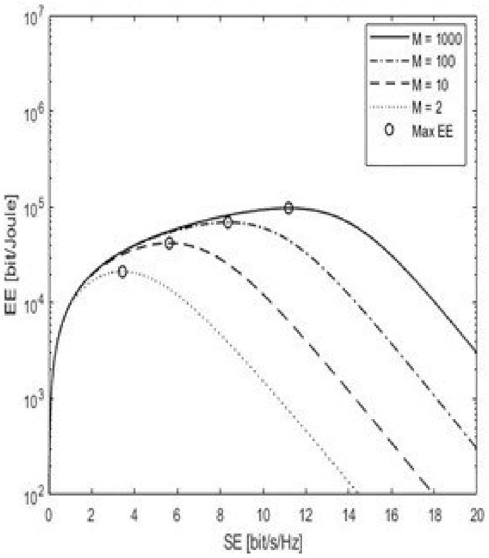

Fig. 5. The SE&EE relation with different values of antennas (M)

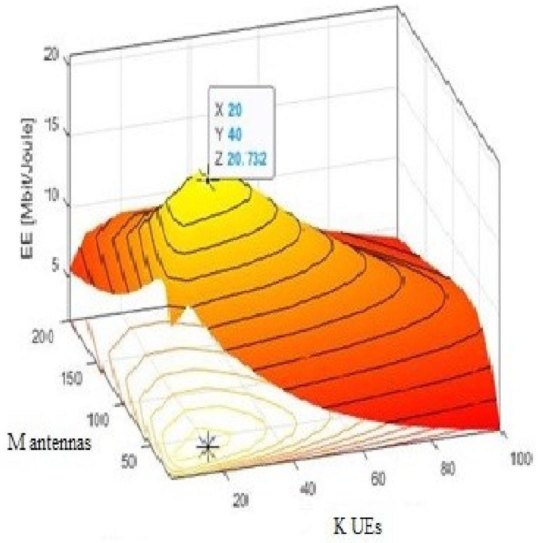

Fig. 8. Maximal Energy Efficiency for K&M(20,40) at M_MMSE

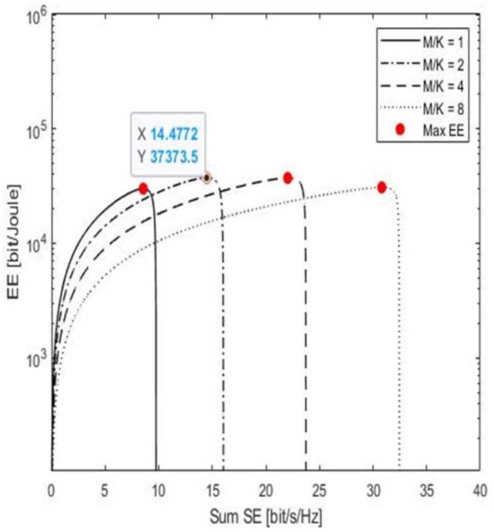

Fig. 6. The SE & EE for different (M/K) ratio when K=10

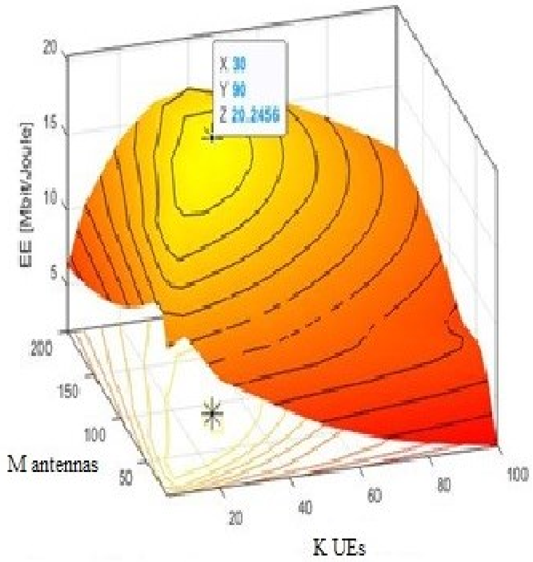

Fig. 9. Maximal Energy Efficiency for K&M(30,90) at ZF

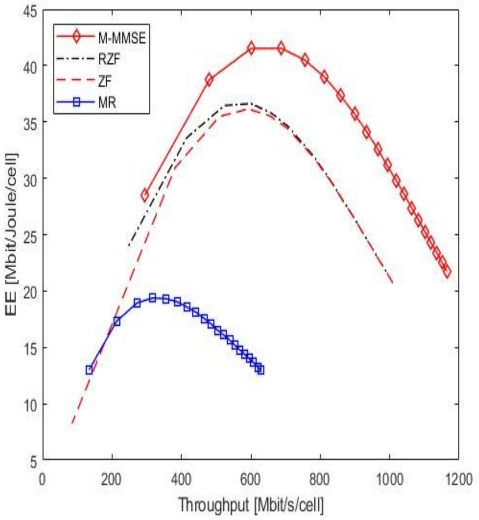

Fig. 7. The R&EE trade off at K=10

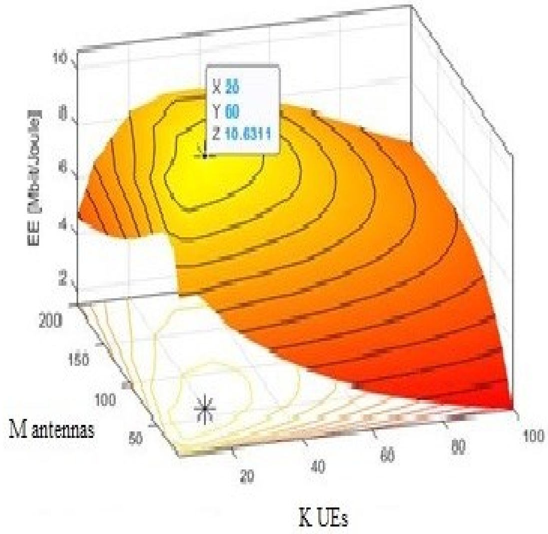

Fig. 10. Maximal Energy Efficiency for K&M (20,60) at MR

V. CONCLUSION

This paper proposes a scheme for enhancing EE in the 5G wireless network scenario with much complex antenna techniques such as Massive MIMO technology. The proposed method implies an adaptive number of active antennas that are adjusted in response to variation in the number of actual users within a cell to improve the trade-off between SE and EE and the trade-off between EE and throughput.

Comparative simulation using various precoding schemes showed that M-MMSE is the optimum scheme for higher throughput. Furthermore, achieving the optimal EE by adjusting the antennas number dynamically to obtain maximum EE from the system using (M/K =2). Hence, the simulation results show ed that the proposed scheme successfully improves EE and achieves the best trade-off between EE and throughput and the trade-off between EE and SE of the Massive _MIMO system.

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