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SINGLE CELL MASSIVE MIMO DOWNLINK SYSTEM: ENERGY EFFICIENCY SOLUTION

Z. Raza[1], Z. Akhtar[1], N. Nawaz[1,*], G. Hussain[1], S. Nawaz[2] and Bushra[3]

[1]Department of Electrical Engineering, NFC Institute of Engineering & Technology, Multan, Pakistan
[2]Department of Computer Science, University of Engineering & Technology, Taxila, Pakistan
[3]Department of Computer Science, COMSATS University, Islamabad
*Corresponding author's E-mail: engrnasirnawaz@gmail.com

ABSTRACT: As the world is moving towards 5G communication networks, more and more energy is consumed to maintain the quality-of-services. Therefore, energy-efficiency or green communication becomes an important indicator because it guarantees a sustainable evolution. In this regard, the massive multiple-input multiple-output (MIMO) technology, where base-stations are equipped with a greater number of antennas M to achieve energy efficiency. In this paper, we analyze and investigate the single cell massive MIMO downlink system with various processing schemes at the base-station to optimize a number of base-station antennas M, active user-equipment's K and transmit power. Moreover, a new redefine power consumption model is proposed for energy-efficiency. Various simulations are conducted based on minimum mean-square error (MMSE), maximum ratio transmission/combining (MRT/MRC) and zero-forcing (ZF) processing schemes. These results reveal that the optimal energy-efficiency is achieved by a massive MIMO setup wherein hundreds of antennas are deployed to serve the relatively large number of users using zero-forcing processing.

Keywords: Energy efficiency, Massive MIMO, zero-forcing, Optimization.

INTRODUCTION

The rapid growth and development of communication technologies resulted in increase of mobile users, around five billions of the global population depends on the mobile based information and communication technologies for their daily life.The cost of energy consumption and corresponding environmental issues are becoming significant economic and social concerns (Zhou *et al.*, 2018). At present, more than 4 million base-stations are serving to its users and this number is expected to be double by 2022. Along with this, every station is consuming about 25 MWh per day and this power consumption is distributed across various functionalities of the networks. Among these functionalities, base-stations utilizes much more energy (Tan *et al.*, 2018). Similarly, the communication industry produces about 2% of total carbon emissions and this amount expected to be increased in future. Due to these factors, energy-efficiency is gaining attention for communication industry as the reduction in energy consumption can reduces the overall cost for energy and decreases the environmental impact. It depends on the transmit power, system architecture, circuits power consumption, transmission protocol and spectral efficiency.

Massive MIMO systems are gaining attention for next generation technologies because hundreds of antennas are attached to the base-station and serving a small number of users which results in higher throughput and provide energy efficiency (Kamga *et al.*, 2016). The energy-efficiency define as the ratio of average data rate and total power consumption by various components and it has very importance in communication system due to its environmental and economic issues. The Primary concern of energy-efficiency is associated to the number of base-station antennas but also depends on the circuits power and it cannot be ignored when considering an actual real system.

Recently, multiple research is presented for energy efficiency in single-cell massive MIMO downlink systems based on optimization of base-stations antennas M. In (Hu *et al.,* 2015), authors discussed the optimization of base-station antennas (M), but they consider a circuits power consumption independent of M and K. Estimation of optimal number of users and antennas are discussed in (Mohammad, 2014)., but authors have not considered the signaling factors. These factors are considered in (Bjornson et al., 2015). and enhanced the energy-efficiency by optimizing the number of users and transmitters but when coverage area is increased then transmitted power decreases which makes that system not accurate. Energy-efficiency of massive MIMO by considering nonlinear devices is discussed in (Bjornson *et al.,* 2014), but assumed a fixed power consumption. Similar studies are also presented in (Khan *et al.,* 2016) and (Khan *et al.,* 2018). A practical model where M and some communication resources are optimized for downlink MIMO system discussed in (Ng *et al.,* 2012). Downlink transmission in MIMO system is presented in (Bjornson *et al.,* 2014) and provide a mathematical expression for energy efficiency based on M. However, they neglected the circuit power consumptions. In (Miao, 2013), the authors discussed about power allocation issues of multiuser MIMO systems and the results of their analysis show that energy-efficiency is maximum when user-equipment's are switched off. Energy efficiency for downlink was presented in (Bjornson *et al*., 2013), which showed that it is concave function of M while a similar result was shown for K in (Yang and Marzetta, 2013). Total power consumption, which is an important factor for this optimization is discussed in (Zheng and Gharavi, 2019). Various type of model for total power consumptions are presented and discussed by authors. In (Senel *et al.,* 2019), a simple and widely used model is presented but this model gives an unbounded energy efficiency where $M \to \infty$. This is impossible because they do not consider the power consumption analog circuits and signal processing. As most of the researchers considered a fixed power consumption model which gives unreal unbounded output.

In this paper, we have maximized the energy-efficiency of massive MIMO system and find the optimal number of users and antennas along with optimized transmitted power under various linear processing schemes; minimum mean square error (MMSE), maximum ratio transmission/combining (MRT/MRC) and zero-forcing (ZF). A new modified model for total power consumption is discussed to highlight that the actual power scaled faster than linear function of M and K To attained energy-efficiency. Then at the end comparison between the processing is presented. Our results exhibit that:

1. A system with 150-200 base-stations antennas are effective to attain energy efficiency.
2. The number of base-station antennas and transmitted power is directly proportional.
3. ZF processing scheme provides a highest energy efficiency because of active-interference suppression.

The rest of this article is organized as follows. Section 2 explains the system and signal modeling. Section 3 presents the problem statement. Simulations and results for the various scheme are discussed in Section 4. Then this article is concluded in Section 5.

MATERIALS AND METHODS

A single-cell multiuser MIMO system is considered and illustrated in Fig. 1. In which the base-station antennas M are equipped with M number of antennas to serve K single antenna user-equipment through the flat-fading (i.e. channel bandwidth is higher than signal-bandwidth $f_o > W$). These user-equipments are picked in round-robin fashion within range from various number of equipment. Along this, we supposed that base-station and user-equipment are fully synchronized and operating according to the time-division duplex (TDD) mode with the structure as presented in Fig. 2. This protocol utilizes single frequency for transmit and receive operations. The downlink pilot allows every single user-equipment to estimate its interface and channel with current precoding. This TDD protocol requires same number of base-station antennas and user-equipment for uplink and downlink systems. The downlink pilots let each user equipment to estimate its effective channel and interference. As the user-equipment are picked up in round-robin fashion, user distribution function $F(x)$ defines the user density and shape of coverage area. The large-scale fading is considered, as the distance between antennas are much smaller than the distances among user-equipment and base-station. Here, we assumed that user-equipment are distributed uniformly with a radius between r_{max} and r_{min} then distribution function F(x) is represented as:

$$F(x) = \frac{1}{\pi(r_{max}^2 - r_{min}^2)} \quad (1)$$

where: $r_{min} \leq ||x|| \leq r_{max}$

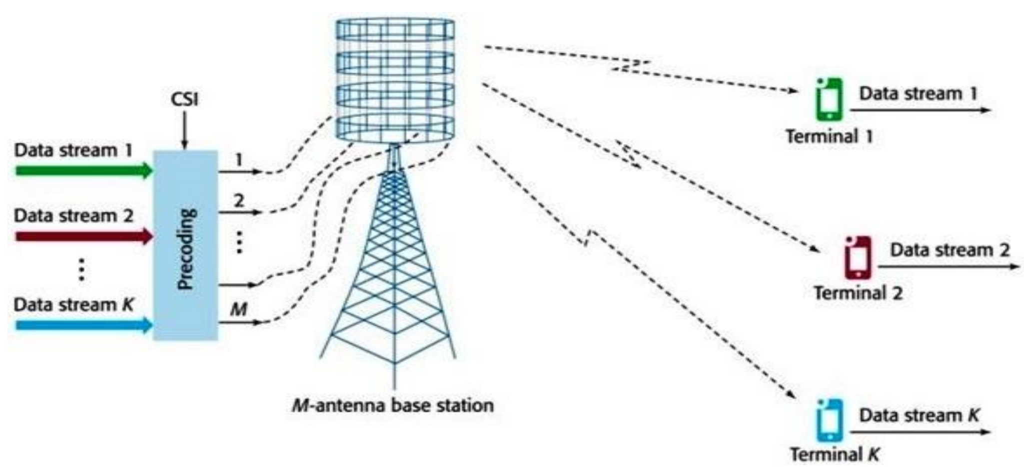

Figure 1: System modeling for Downlink process

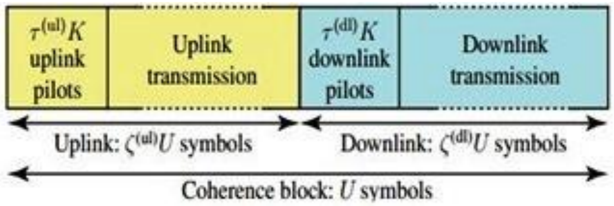

Figure 2: Time division duplex TDD protocol

***Channel modeling and linear processing*:** Base-stations and user-equipment antennas are uncorrelated and the channel coefficient between the n^{th} base-station antenna and k^{th} user is represents by $h(n,k) = \sqrt{d_k}h(n,k)$ where: $h_{(n,\,k)}$ and $\sqrt{d_k}$ represents the fast and slow fading coefficients respectively. For downlink transmission analysis, we consider ZF, MRT/MRC and MMSE processing schemes. As $V = [v1; v2; v3; :::; v^k]$ € $C^{M \times K}$ precoding matrix which gives,

Table I: Simulations Parameters

Parameters		Parameters	
Cell radius (d_{max})	250 m	Cell radius (d_{min})	35 m
Transmission fraction ζ	0.6	Base-stations PA efficiency η	0.39
Base-station computational efficiency	12.8	Fixed power consumption (P_{FIX})	18 W
User-equipments computational efficiency	5	Circuits power consumption at base-stations	1 W
Transmission bandwidth	20 MHz	Power for backhaul	0.25 W
Channel-coherence time T_C	10 ms	Circuit power consumption at user-equipments	0.1 W
Coherence block (U)	1800	Total noise power ($B\sigma^2$)	-96 dBm
Relative pilot lengths: $\mathcal{T}$	1	Power required for decoding	0.8 W/(Gb/s)

$$V = \begin{cases} H(H^H H)^{-1} & for\ ZF, \\ H & for\ MRT, \\ (HPH^H + \sigma^2 I_M)^{-1} & for\ MMSE \end{cases}$$

where: H represents the user channels and σ^2 is the variance in noise. Here, we are designing a system to provide uniform gross-rate (R) for all active user-equipment. The signal to k^{th} user-equipment allocated to transmit a power P_k and precoding vector $\frac{V_k}{kV}$. The downlink rate of k^{th} user-equipment using linear processing can be presented as:

$$R_k = (1 - \frac{TK}{U\zeta})\zeta R_k \qquad (2)$$

where: $(1 - \frac{TK}{U\zeta})$ represents the pilot-overhead and R_k represents the gross-rate.

Problem formulation: The energy-efficiency in communication systems can be determined from the ratio of average sum-rate and the average total-power-consumption (Hu *et al.*, 2015). This energy-efficiency can be calculated from this relationship:

$$EE = \frac{\sum_{K=1}^{K}(\varepsilon R_k)}{P_{TX} + P_{CP}} \qquad (3)$$

In existing prior works, PCP is defined as $P_{CP} = P_{FIX}$ where the term P_{FIX} represents the fixed amount of power consumption which requires for processors, signal control and cooling purposes (Auer *et al.*, 2013; Khan *et al.*, 2018; Khan *et al.*, 2016). But this model gives an unbounded energy efficiency by adding more antennas because it ignores the requirements of dedicated circuits for each antenna at base station with zero power consumption. A new redefine proposed this power consumption model for the system is presented below:

$$P_{CP}(K,M,R) = P_{FIX} + P_{LP} + P_{TC} + P_{C/D} + P_{CE} + P_{BH} \qquad (4)$$

where: P_{LP} denotes the power consumption of base-station for linear processing, P_{TC} is the transceiver power consumption, $P_{C/D}$ denotes the power consumption of channels for coding decoding purposes and P_{CE}, P_{BH} are the channel estimation and load dependent power consumptions respectively.

Based on this $P_{CP}(K,M,R)$ new model, energy-efficiency can be represented as:

$$EE = \frac{\sum_{K=1}^{K}(\varepsilon R_k)}{P_{FIX} + P_{LP} + P_{TC} + P_{C/D} + P_{CE} + P_{BH}} \qquad (5)$$

Then the energy-efficiency can be optimized, and performance of massive MIMO system is analyzed based on ZF, MRC/MRT and MMSE processing.

RESULTS AND DISCUSSION

This section exhibits the simulations results of various schemes for energy-efficiency in a single-cell massive MIMO system and illustrates the comparison between these schemes. These all schemes are tested and simulated on MATLAB.

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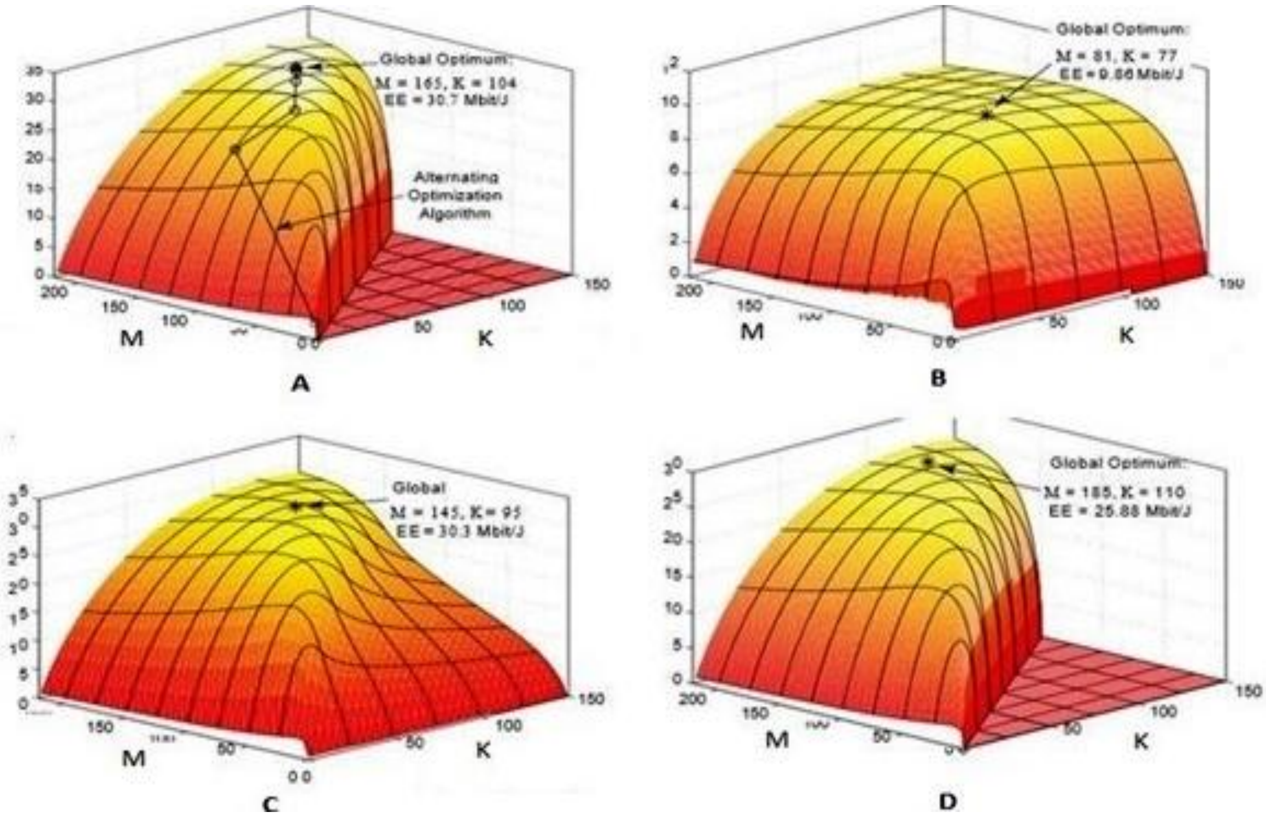

Figure 3: Energy efficiency in single-cell scheme with different processing.

To simulate zero-forcing, while Monte-Carlo simulations with small scale fading and random user locations were simulated to optimize the energy-efficiency. We considered a 250 m radius of circular-cell and 2 GHz band for these simulations. Table. I. represents the other associated simulation parameters, that are define in various prior works: computational efficiencies from (Yang and Marzetta, 2013), backhaul power from (Tombz *et al*., 2012), RF from (Auer *et al.,* 2013) and baseband power from (Kumar and Gurugubelli, 2011).

All possible results based on energy-efficiency with ZF processing for various M and K values are illustrated in Fig. 3-A. In ZF $M \geq k + 1$. A global optimum energy-efficiency of 30.7 Mb/J is obtained at M = 165, K = 104 with $\rho = 0.9$. As these results are quite smooth and concave. Moreover, there are variety of parameters that can gave results closer to the optimum energy-efficiency because they depend on the circuit power coefficients. Fig. 3-B presents the results of MRC/MRT processing. It gives global optimum energy-efficiency of 9.8 Mb/J at M = 81, K=77. The results of MMSE Processing are illustrated in Fig. 3-C. It gives the global optimum of 30.3 Mb/J at M = 145, K = 95.

From these results it can be seen that ZF gives higher energy-efficiency but MMSE gives optimal throughput. This is owing to the computational complexity of MMSE processing. The optimization difference between ZF and MMSE is quite small but MRC/MRT behave differently and energy efficiency of this processing is much lesser than ZF and MMSE. Furthermore, Fig. 4 presents the energy-efficiency for different number of base-stations antennas for various processing schemes. It is clear that ZF and MMSE gives the most optimized results that are very closer to each other but far away from MRT. It is clear that ZF and MMSE processing have nearly same optimizations. In Fig. 5, total PA power to maximize the energy-efficiency is presented. The processing schemes presents that transmit power of base-station is decreased and energy-efficiency can be increases with the increase in M. Area throughput that maximizes the energy efficiency for various M values are illustrated in Fig. 6. The greater part of this is gained under imperfect-CSI, this reveals that in massive MIMO systems with correct suppressing and interference precoding is achieve the energy-efficiency and area-throughput. In contrast, deploying a greater number of base-stations and using MRC/MRT processing scheme for energy-efficiency and area-throughput is uneconomical and wasteful.

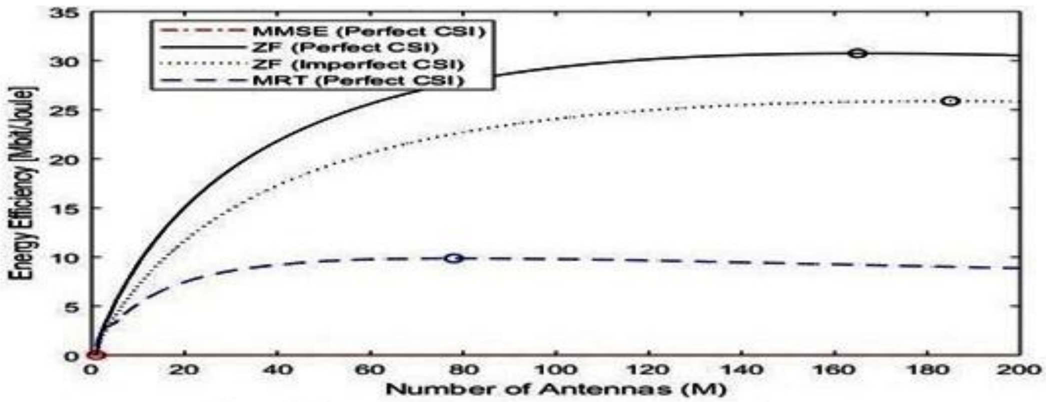

Figure 4: Energy-efficiency for mixed processing schemes

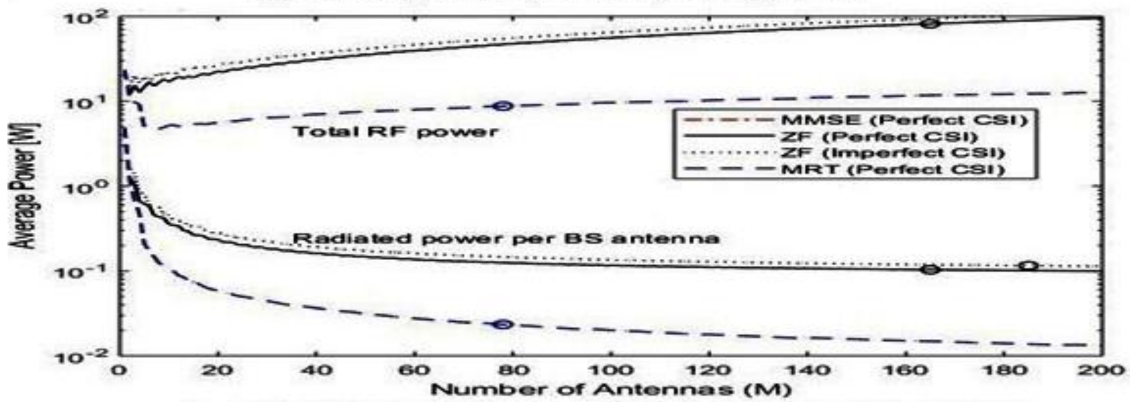

Figure 5: Total PA at optimal energy-efficiency for mixed base-station antennas

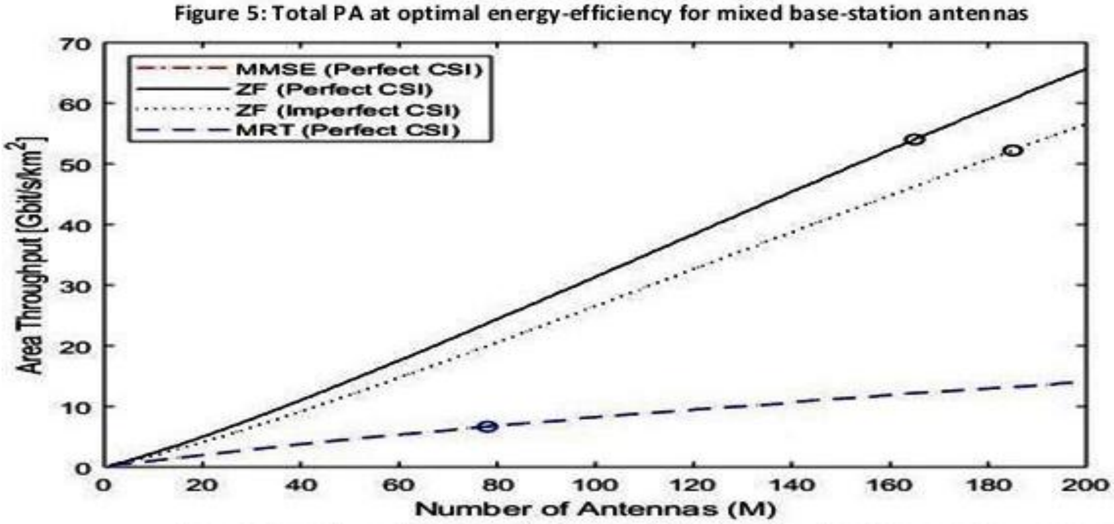

Figure 6: Area throughput at optimal energy-efficiency for mixed base-station antennas.

Conclusion: This paper discussed and analyzed the process of selecting base-station antennas M and user-equipment k for multi-user MIMO system to achieve maximum energy-efficiency and area throughput. A new redefine model for power consumption is proposed which describes a non-linear behavior that depends on gross-rate (R), base-stations antennas (M) and number of user-equipment (k). ZF, MMSE and MRT/MRC processing schemes are used to optimized energy-efficiency for the downlink MIMO system. These simulation results reveal that the deployment of a 145-165 base-stations antennas to serve a larger number of user-equipment is optimal solution for energy-efficiency. ZF processing gives 30.7 Mb/J at M =165 and K = 104, MMSE processing gives 30.3 Mb/J at M = 145 and K = 95, while MRC/MRT processing gives 9.8 Mb/J at M = 81, K = 77 optimal energy-efficiency. Here, we conclude that ZF processing is most reliable and efficient for optimal energy-efficiency. This analysis is supported spatially unrelated attenuation, where each station may have different channel variance due to the effect of fading.

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