ISSN: 2456-3676

Analysis of Optimal Spectral-energy Efficiency Tradeoff Linear Precoding Massive MIMO 5G and Beyond

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doi: 10.51505/ijaemr.2022.8107 URL: http://dx.doi.org/10.51505/ijaemr.2022.8107

Abstract

In this article, we consider cellular wireless communication with a large number base station antennas deployement, called Massive-MIMO systems, are inspected. Massive MU (multi-user), (MIMO) multiple-input-multiple-output technique gives a significant SE (spectral efficiency) using easy techniques precoding while high EE (energy efficiency) is expected to be offered. Our paper works on two famous schemes, linear precoding Zero-Forcing and Maximum-Ratio-Transmission taking into account of system circuit power consumption, where that important aspect was ignored in the literature. Both EE (energy efficiency) and SE (spectral efficiency) are considered to be the important key indicators in 5G and beyond communications, which need to be taken into account at the same moment with respect to nowadays environmental consideration. To realize an optimal tradeoff between SE-EE, that precoding schemes are been formulated under CSI-imperfection (channel state information) in a realistic way. Simulation results illustrate that our proposed method achieves better optimal balance between Energy Efficiency and Spectral Efficiency. Under Matlab experimentation, simulation result shows an optimal performance, while tradeoff aspect is observed clairly between SE and EE using such two precoders algorithms. Although such tradeoff SE-EE coincide at first but later on their interests become conflicting and divergent then leading EE to so gradually decrease while SE continues increasing logarithmically. ZF pre-coding method is the appropriate scenario to achieve higher pre-coder performance.

Keywords: Optimal tradeoff Spectral-Energy Efficiency, Massive MIMO, ZF-MRT Precoding, Imperfect CSI, Circuit power.

1. Introduction

With the increase of intelligent terminals, the mobile services demand for high-speed are rapidly growing, the lack of present frequency resources with excessive energy for mobile devices consumption, that issue is becoming more important. Regarding spectrum resources limitation case, enhancing frequency efficiency of wireless communication, spectral efficiency (SE), that is an effective way to overcome spectrum resources scarcity. This is why, m-MIMO(massive-muliple-input-multiple-out) can reduce the high energy consumption in the mobile communication system and enhance the network energy efficiency (EE) [1], [2] while increasing spectral efficiency SE by using large number of BS antennas[3]. That leads to to green communication requirements for scale development. Wireless communications infrastructure is not meet cellular requirements of 5G-beyond environment because of traffic flows large number that is produced between big amount of heterogeneous wireless devices. The new strategies of cellular deployment are being considered as one of that promising solution expected to meet 5G and beyond world services demands. Massive-MIMO communication is one that promissing technique to enhance both Energy and Spectral efficiencies (ESE) in wireless cellular networks[4]. With nowadays advanced cellular communication technologies, the data services requirements have been greatly increased. Cellular communication bandwidth is a limited resource by radio spectrum cost needed [5]. It has been specified any data rate enhancement can be produced without enhancing bandwidth, which reduces consumption of power, that leads to more power and spectrally efficient with less cost [6], [5]. Although, m-MIMO (Massive-multiple input multiple output) technique, spectral-energy efficiencies are a couple of confliting indicators that limit everyone. Optimizing one among the two indicators will necessarily cause and conduct to the degradation of other [7].

The massive m-MIMO method is the key to enhance spectral efficiency and energy efficiency in 5G wireless generation systems[8]. Deployment strategy of mobile networks has a notable capability to enhance low power BS base station and improve the energy efficiency in cellular mobile system. With respect to this growing interest in mobile cellular systems, the overall 5G performance relies upon on estimating energy efficiency in the system massive m-MIMO. A large antenna array on the serving BS is capable of offering the multiple connection to more and more active smarts users with TDD resource. It is has been known as spectral efficiency and spectral efficiency can't be concurrently optimized [1], [3]. It remains quasi-concave because of noise amplifier, from huge antennas, with price of material, that reduces frequency chain radio. With huge antennas number in linear precoder is required to choose the optimum antenna to restrict the noise with unrelated interference. Furthermore, deploying huge antennas may imply bigger power consumption circuit. therefore, this attitude of energy-efficiency, is increasing base stations consumption of mobile power system. Improvement of energy and spectral efficiencies are achieved by low system power consumption of a circuit due to performing linear precoding schemes systems, especially maximum ratio transmission and zero forcing, respectively MRT and ZF, from which spectral efficiency can be achieved [5] [4], [8].

The CSI (channel state information) transmission quality is an important key element impacting both energy and spectral efficiencies performance. The author [9] examines power loading scheme issue with imperfect CSI thinking about tradeoff among spectral and energy efficiencies. In contrast to conventional studies that makes use of energy efficiency like objective function also that obliges constraints both at spectral efficiency, conceivable rate, it introduces multi-objective optimization method whitch may flexibly swap among Spectral efficiency and energy efficiency capabilities or modification priority degree of every function the usage of a tradeoff setting. The early result found the issue of maximizing spectral efficiency and energy efficiency singularity, after which show multi-objective optimization of spectral efficiency and energy efficiency is equal to an easy issue that minimizes the overall consumption of power and maximizes system capacity. Acquiring an appropriate perfect CSI in m-MIMO is really challenging, it's miles affordable and realistic to layout a m-MIMO strategy transmission the use of CSI statistically. On the way to optimize resource efficiency of wireless system to obtain balancing between SE-EE, the tradeoff SE-EE is inspected based on m-MIMO statistical CSI transmission[10].

Thes authors have inspected systems massive m-MIMO tradeoff energy efficiency and spectral efficiency scheme with selection of transmission M-antenna and a linear precoding, in which both are considered, respectively large scale (fading) and circuit intake power. It is shown with regard to transmission power and M-antenna number from Base station were essentially optimized in this particular tradeoff performance analysis [11]. Besides, selection of RF (radio frequency) chain is performed otherwise for suitable performance tradeoff SE and EE. According [12], most suitable layout of SE and EE enhanced with the aid of using downlink also uplink excessive rates of data based CSI inaccuracy integrated matched filter, zero forcing and maximum ratio. With equipping BS, huge active smarts users with signal pilot training and reduced system power, therefore maximum is achieved from tradeoff between SE and EE performance system. By performing huge M-antenna transmission high sum rate is obtained, Tradeoff between SE and EE relies upon acknowledging active M-antenna Transmitter and optimal smarts users number by price of consumption power [13]. Certain researchers pointed-out in downlink system massive m-MIMO that maximizing SE and EE relies upon evaluating SNR with optimal power transmission every cellular system if BS number required high SE [14]. Guaranteeing optimal rate, smaller user association power enhances SE-EE tradeoff overall performance. But, other inspected HeNets systems tradeoff SE-EE performing traffic data offloading in massive m-MIMO miniature cell network [15].

2. Method

It is assumed in our scenario of a single-cell massive m-MIMO downlink system consisting transmitter M-antenna from cellular BS, serving K smarts terminals with only one antenna (K<<M), thus as specifically to serve them at same time by same system TDD resource[16]. Therefore, cellular BS obtains downlink CSI through uplink pilot training relying on TDD multiplexing. K-terminal smart M-antenna are both huge and ratio α=M/K being fixe [17]. We expect CSI imperfection at BS station small-scale scenario fading. With estimated CSI at the BS station, therefore precoded vector are essentially shaped after which transmitted simultaneously to smarts terminals. In addition, BS station antennas transmits M×1 vectors signals to every antenna and consequently at receiver quit the K smarts terminals get or received K×1 vector signal named by y as formulated.

$$\mathbf{y} = \sqrt{\rho_d}\,\mathbf{H}^T\mathbf{s} + \mathbf{n}, \tag{1}$$

where $\boldsymbol{\rho}_\mathbf{d}$ represents downlink Tx transmit power, superscript $(.)^T$ names transpose of this matrix, where s represents precoded data q symbols, meanwhile n represents K×1 vector noise, *i.i.d. CN(0,1)* entries. The downlink power transmission is normalized like $E=\{\|s\|^2\}=1$, each antenna thus sends at a power of ρ_d/M, while a term H denotes M×K channel matrix which corresponds to the small-scale m-MIMO channel Rayleigh fading and with assumed *i.i.d. CN(0,1)* entries [18], [19]. Channel estimation (CSI) is so assumed instead of channel assumption accuracy to analyse precoding techniques performance in practically wireless communication environnement way, which is realistic model compare to many existing works.

2.1 Channel imperfection

With imperfection assumption CSI, system BS station estimates channel for downlink precoding design matrix by the help of reciprocity channel, then from (24) authors mentioned imperfect scheme channel where BS station knows CSI inaccuracy to perform transmitter Tx at downlink. In which channel $\hat{H}$ is under estimation, that verifies below relation

$$\mathbf{H}=\xi\hat{H} + (1-\xi^2)E, \quad \textbf{(2)}$$

and E represents error matrix estimation channel, components $i.\ i.\ d.\ CN$ (0,1). Whereas $\xi \in [0,1]$ be accuracy of CSI interval or more reliability precision of channel estimated (quality CSI control), while huger ξ sounds perfect CSI. It is known E and $\hat{H}$ are not related using MMSE estimator channel.

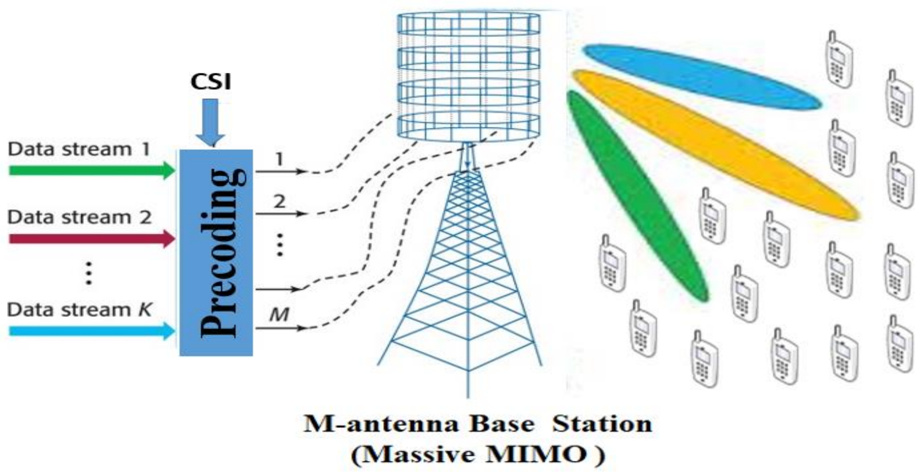

Figure 1. Downlink massive m-MIMO multi-user Downlink systems.

2.2 Power Consumption

Consumption of power consists of circuit consumption and transmission powers for overall 5G beyong systems, it is known that PA is related to transmission power. To analyse tradeoff SE-EE realistically with circuit intake existence power along with radio frequency in chains energy attention is seen as more attractive research subject. Our version is taken into attention to be reality of system design, in contrast to a few others preceding works achieved in subject of tradeoff SE-EE performance analysis. Certains previous articles focus on transmit Tx power downlink highlighted to analyse tradeoff SE-EE performance in which we assume and trust that is certainly now no longer sufficient and enough regarding SE-EE tradeoff performance analysis [8],[3], [11]. For the reason that, there are different parameters setting that required taking this account by including circuit intake power that we assume to be crucial parameter regarding power-intake massive m-MIMO that may influence rather the results. While thinking about the circuit-power consideration, we will address the RF chains power-intake uniquely and forget about baseband processing power-intake with our proposed version.

In turn, energy-intake PA relies on downlink transmitter power Tx, ρ_d per the PA efficiency η with and losses from feeder σ_{feed}. Thus, power-consumed because to amplifiers is referring to transmitter power Tx as given

$$\frac{\rho_d}{\eta(1-\sigma_{feed})} \qquad (3)$$

where $\eta \leq 1$ be represented efficiency PA.

In other hand, P_{CP} power-consumption for RF chains is given as function of power used for digital/analog conversion operation denoted by P_{DAC}, power used for mixer operation denoted by P_{Mix}, power used for frequency-synthesizer P_{Syn}, and power used at transmitter Tx for active filters is denoted by P_{FiltTx}. Note that circuit consumption-power P_{CP} grows linearly respect to number service BS M-antenna. Therefore, the circuit-consumption-power of total BS number of M-antenna at transmitter is then formulated by following equation

$$P_{CP}=M\left(P_{DAC}+P_{Mix}+P_{FiltTx}\right)+P_{syn} \qquad (4)$$

With respect large-scale of fading incorporation, then the equation (4.29) of this kind of system consideration will become intractable to manage so, therefore large-scale of fading effect is omitted in our proposed model.

Additionally, overall system power-consumption is impacted by certain losses incurred due to direct-current to direct-current DC-DC power/main power MS supplies and finally active site cooling. In summary, total consumption-power scales with these loss factors σ_{DC}, σ_{MS} and σ_{Cool}, respectively, and then given as the following

$$P_T=\frac{\frac{\rho_d}{\eta(1-\sigma_{feed})}+P_{CP}}{(1-\sigma_{DC})(1-\sigma_{MS})(1-\sigma_{Cool})} \qquad (5)$$

2.3 Tradeoff SE-EE performance modeling

It can be seen as how maximum ratio Transmission MRT/zero-forcing ZF linear pre-codings are carried out in asymptotic approximation overall performance derivation imperfection existence CSI idea to enhance particularly spectral and energy efficiencies performance by the use of very massive provider BS M-antenna called the massive m-MIMO undergoing known as appropriate propagation environment. The MRT/ZF, linear precoding schemes are investigated in this paper, which might be appropriate concerning massive m-MIMO so as basically to analyse precoding schemes overall performance system. The aim is how a precoder basically wanted to eliminate basically interference from acquired smart k users signal. Therefore, together mitigate interference issue and maximization of SINR so as therefore to enhance surprisingly spectral efficiency and energy efficiency performance.

Highlighted pre-coders are needed to be designed by removing interference type and improved the two systems pre-coding [4], for overall massive m-MIMO of tradeoff SE-EE performance considering more and more attention of power model circuit consumption.

2.4 Spectral Efficiency

In perspective to analyse our tradeoff SE-EE performance system, so we want to know achievable rate that follows famous mentioned Shannon Capacity. It describes how maximum rate can be transmitted through channel. This ergodic channel is basically assumed and all the parameters are Gaussian random. From massive m-MIMO ergodic (sum-rate) $R_{\mathbf{sum}}$ is chosen to how describe its so effectiveness. Due to its simplicity analysis reason of spectral efficiency network we consider single-cellular where all terminals share a constant transmit power equally in the downlink system. Then, ergodic achievable k^{th} terminal rate is as [20]

$$R_k = E\left[\log_2\left(1+SINR_k\right)\right] \quad \text{(bits/s/Hz)} \tag{6}$$

In this study, both sum-rate determination of precoders MRT/ZF are based on asymptotic convergence derivation, where their limiting SINR and SNR expressions respectively given by results provided [18] with equal-power consideration scenarios.

Therefore, MRT precoding performance of massive m-MIMO is computed accordingly to formula derived from [21], [18] , [22] as lower bound sum-rate for total K smarts users with CSI consideration imperction in constrast to many others papers focused on perfect one

$$R_{sum} = \sum_{k=1}^{K} R_k = K\log_2\left(1+\frac{\rho_d\ \alpha\ \xi^2}{1+\rho_d}\right) \tag{7}$$

Similarly, ZF precoding performance of massive m-MIMO is computed then according to formula derived by [21], [18] , [22] as lower bound sum-rate of total K smarts users under CSI imperfect as

$$R_{sum} = \sum_{k=1}^{K} R_k = K\log_2\left(1+\frac{\rho_d\ \xi^2\left(\alpha-1\right)}{1+\rho_d\left(1-\xi^2\right)}\right) \tag{8}$$

ISSN: 2456-3676

2.5 Energy Efficiency

From this section, the full energy efficiency EE of ZF precoding that is given that needs system simulation so to analyse our proposed tradeoff SE-EE performance. The evaluation of overall energy efficiency per cell for ZF precoding in control of CSI imperfect considering circuit intake power from many components performed at transmitter side and Tx transmitter-power with some loss factors because of antenna feeder, main supply power, direct-current, efficiency of power amplifier PA and active cooling system without large scale of a fading effect attention. Finally, making use of sum-rate SE with overall power intake gives us total EE of ZF in massive m-MIMO system below.as [21].

$$\eta_{EE_{ZF}} = \frac{K\log_2\left(1+\frac{\rho_d\ \xi^2(\alpha-1)}{1+\rho_d\left(1-\xi^2\right)}\right)}{\frac{\frac{\rho_d}{\eta(1\text{-}\sigma_{feed})}+M\left(P_{DAC}+P_{Mix}+P_{FiltTx}\right)+P_{syn}}{(1\text{-}\sigma_{DC})(1\text{-}\sigma_{MS})(1\text{-}\sigma_{Cool})}}, \quad (9)$$

SINR for ZF can be looked higher like wanted for each such given reliability channel by simply scaling BS M-antenna up.

Correspondingly, this comes up with full EE expression of MRT one precoding that we focus on experimentation in order, then attractively to analyse this tradeoff SE-EE performance. Analysis of MRT precoding, CSI imperfection for overall EE per cell considered thus account power intake circuit of certains components performed at a transmitter transmit power with loss factors because feeder antenna, main power-supply, direct-current, PA efficiency, then and active system cooling without fading large scale effect. Thus, sum-rate SE and total power intake, at the ende gives us overall EE from MRT scenario as [21].

$$\eta_{EE_{MRT}} = \frac{K\log_2\left(1+\frac{\rho_d\ \alpha\ \xi^2}{1+\rho_d}\right)}{\frac{\frac{\rho_d}{\eta(1\text{-}\sigma_{feed})}+M\left(P_{DAC}+P_{Mix}+P_{FiltTx}\right)+P_{syn}}{(1\text{-}\sigma_{DC})(1\text{-}\sigma_{MS})(1\text{-}\sigma_{Cool})}}, \quad (10)$$

SINR for MRT can be looked higher like it is needed from any given reliability channel by simply scaling BS M-antenna up.

2.6 Simulation Parameters

To evaluate our EE performance massive MIMO with MRT/ZF precoding schemes, there will be listed some related parameters provided to analyze proposed model. Model does consider only small-scale of fading and ignore effect of case large-scale of fading in our channel modeling as we already mentioned before. Regarding small-scale of fading, hence we assume channel

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between each transmitter antenna and corresponding receiver antenna is chosen as Rayleigh distributed. The parameters used essentially in our basic proposed model for an optimal SE-EE tradeoff analysis of Massive MIMO linear precoding performance evaluation are shown table 1. Besides, those parameters highlighted in table, their values taken by referring or according to [16]. They concern circuit consumption power and relative loss factors values which will be then used essentially to evaluate energy efficiency precoding performance. In all the scenarios, noise power at all receivers' side assumes to one.

Table 1. Parameters settings

Description, Symbol (Parameter)	**Consumed power in Digital/analog convertor,** P_{DAC}	**Consumed power in mixer,** P_{MIX}	**Consumed power in filter at Tx,** P_{FILT}	**Consumed power in LO,** P_{SYN}	**Loss due to feeder of antenna,** σ_{feed}	**Loss due to the direct-current power,** σ_{DC}	**Loss due to main supply power,** σ_{MS}	**Loss due to system cooling,** σ_{Cool}	**Efficiency of PA,** η
Value	15.6mW	30.3mW	20mW	50mW	0.5	0.06	0.07	0.09	0.38

3. Results and Discussion

We present in this section the results of the simulation to confirm our proposed model accuracy regarding massive MIMO performance evaluation linear precodings concept techniques in EE term. That is to say, this section will implement the simulation for massive MIMO technology with MRT/ZF pre-coding schemes under various parameter considerations of the system in perspective essentially to validate our energy-efficiency model and also theoretical analysis, besides we evaluate spectral efficiency achievement performance tradeoff with energy-efficiency regarding performance achievement.

In order so to evaluate precoding performance of proposed model, we provide results based upon simulation of energy-efficiency and also spectral-efficiency as well, and compare different precoders performance and also differ to beliefs that circuit power is a fixed power. To illustrate behavior of EE in contrast to where circuit-power consideration was ignored with very-large BS M-antenna energy-consumption model design in the literature.

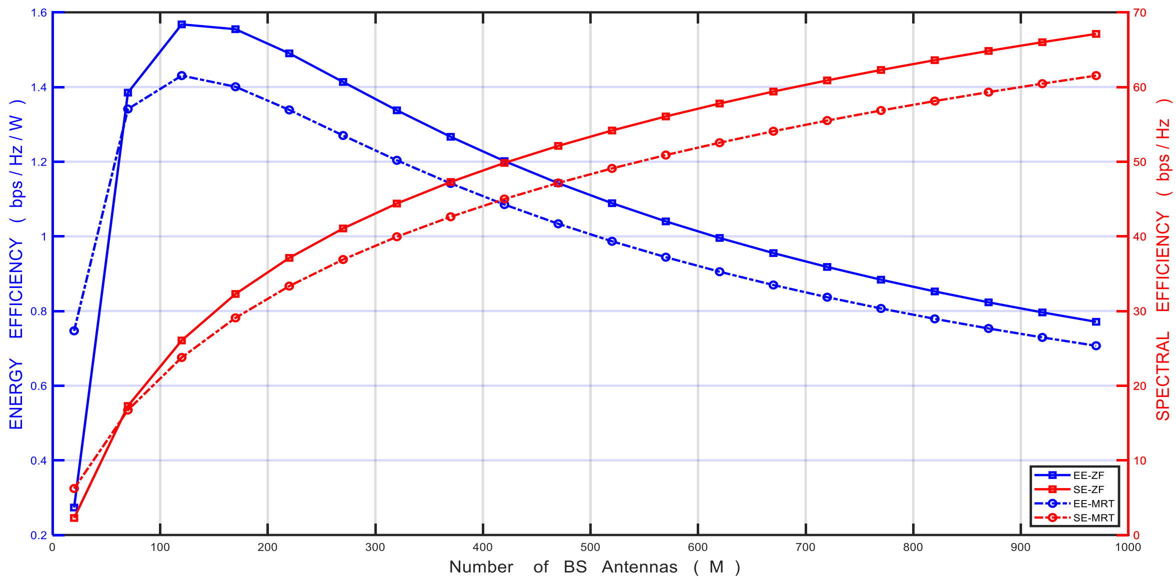

Figure 1. Precoding performance tradeoff EE & SE in terms of BS M-antenna number, nmber of smart users and power allocation under imperfect CSI (K=15, ξ^2 =0.50, ρ_d=$0dB$).

Figure 1 illustrates tradeoff phenomenon between EE/SE of technology massive MIMO with respect so to different numbers of BS M-antenna with CSI imperfect assuming (ξ^2 = 0.50) for estimation error channel and 0dB for transmit-power. Firstly, figure 1 illustrates that serving 15 autonomous user terminals with CSI imperfect, it is remarkable from the curves that results have given reason to massive MIMO, i.e., SE can improve with increasing BS M-antenna number. We observe our MRT precoding performance proposed takes its advantages whenever the range ratio of $\alpha=M/K$ smaller whenever number BS station M-antenna is smaller compare to K smarts terminals whereas famous ZF precoding performance will be better whenever the range ratio of $\alpha=M/K$ larger or within a bigger range number BS M-antenna compare to number autonomous K terminals. We interestingly note as BS antennas M increases the performance gap between two pre-coders increases in ZF favor pre-coder that means ZF scheme works well in a single-cellular massive MIMO scheme.

In addition, according to relationship between SE and total amount power consumed that represents EE. Hence, need of future generation networks is to enhance this SE but this action may be a tradeoff phenomenon leading EE to decrease as shown expected EE by figure 1. In this scenario, we observe the advantages of each pre-coder with respect to size of BS station M-antenna number where MRT pre-coder takes its advantages over ZF pre-coder in a small number BS M-antenna (small $\alpha=M/K$), while ZF pre-coder outperforms MRT pre-coder by benefiting large BS number M-antenna (large $\alpha=M/K$). Phenomenon of EE-SE tradeoff is clearly then visible from curves. At first, both tradeoff EE-SE performance increase, but so when EE performance one achieves optimal value therefore it ends up decreasing while SE performance is continuously or gradually increasing. The cause is that circuit consumption power increases with

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BS M-antenna. It is also observable that advantage of MRT pre-coder is vanishing as M-antenna increases, which confirms that performance of MRT precoder works well under certain poor condition channel or region of low-SNR over the ZF. Moreover, the results illustrate the highest EE of ZF/MRT that are higher compared to so their SE respectively. While the highest SE of ZF/MRT are also higher compare to their EE respectively, this explains the tradeoff phenomenon. Additionally, the EE and the SE for ZF precoding have better performance at higher ratio $\alpha=M/K$ while the EE and the SE for MRT precoding are the better choice performance at small ratio $\alpha=M/K$.

Furthermore, both MRT/ZF are suitable for the performance improvement massive MIMO as shown from results of EE/SE tradeoff curves. In which the highest EE and the highest SE belong to ZF that performs better appreciably than MRT at bigger ratio $\alpha=M/K$. However, when the ratio $\alpha=M/K$ is small then MRT would be best choice performance.

4. Conclusion

We locate the tradeoff phenomenon between spectral efficiency (SE) and energy efficiency (EE) even though they coincide at the starting time however later their interests end up conflicting and divergent then leading the energy efficiency (EE) to so progressively decrease while spectral efficiency (SE) persevering with growing logarithmically. As illustrated nearly one hundred provider BS M-antenna used so as to be able to serve tenth of autonomous smarts terminals simultaneously shows that spectral efficiency (SE) and energy efficiency (EE) schemes cannot be done at a low SNR, so however in region in which an appropriate interference-canceling processing, ZF precoding is suitably appropriate over limited-interference processing, MRT pre-coding. We further end up that in a single-cellular massive m-MIMO multiuser downlink system that the ZF pre-coding method is the appropriate scenario to achieve higher pre-coder performance.

Acknowledgments

Firstly, I would honorably like addressing my thanks to all my previous schools, from Mali (ENI-ABT) to china (HUST), professors and particularly my sincere gratitude and thanks to my undergoing PhD school EDSTM (USTTB) in Mali, and supervisors for their helpful guidance to this paper. Without their beneficiary supports, constructive criticisms in addition so to their motivations this paper could not really be reached as far. My final thanks to my own school (ENETP) for providing and supporting me during this manuscript preparation work.

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