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# Quad Methodology for Effective Performance Evaluation of Cellular Network

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**Abstract:** The extreme growth in smart mobile users and the demand for higher data rates have paved the way for developing 5G networks. Additionally, increased wireless data traffic implies more power consumption in network equipment. Mobile network service providers are concerned about the energy efficiency (EE) of cellular networks. In this era of advanced wireless communication, Massive multiple input multiple output (MMIMO) technology satisfies the demand for a hyper-connected society. To deal with the problem of increased hardware power consumption and cochannel interference in MMIMO, a quad methodology is proposed to evaluate the performance of a cellular network. This quad package comprises linear precoding (LP), power consumption reduction (PCR), User selection (US), and antenna selection (AS). The proposed quad methodology is used for enhancing the energy efficiency and capacity of a cellular network. Two LP techniques, zero forcing (ZF) and minimum mean squared error (MMSE) are compared to evaluate the EE of MMIMO with antenna selection. It is observed that EE for MMIMO with AS using ZF is three times greater than MMSE. MMIMO system with the suggested quad methodology provides 45% and 20% improvement in capacity and energy efficiency respectively over only the norm US.

**Keywords:** Antenna selection, Capacity, Energy efficiency, Massive multiple input multiple output, Power consumption reduction, User selection.

## 1. Introduction

As per the global survey, there is a fifty percent rise in wireless data traffic every year. 5G and beyond networks are developing to accommodate many users with heavy data rate demand. However, the carbon footprint and energy consumption of networks are increasing. In this smart techno-savvy society of information, green communication is a lifelong solution to improve the energy efficiency of a cellular network [1, 2]. Energy-efficient cellular network's performance is mostly based on the wireless channel environment. Wireless communication systems suffer from a very high level of inter-symbol interference (ISI) because of delay spread and multipath propagation. To address unpredictable wireless channel performance, Orthogonal Frequency Division Multiplexing (OFDM) technique is used to eliminate ISI and to improve spectral efficiency in the early days.

With heavy multimedia interactivity and growing demand for faster networks by smart mobile users, the MIMO technique is recognized as a good technology to achieve a higher data rate and system capacity without deploying additional bandwidth and unnecessary power consumption [3].

Over the years, MIMO has been generally combined with the OFDM technique to combat the effect of frequency selective fading.

Recently, MMIMO is proven to be a branded technology for 5G and beyond wireless networks, as it gives maximum data rate, enhanced throughput, better reliability, and consistent performance. This technology has the advantage to serve a huge number

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of users with enhancement in system sum rate by adding a very large number of antennas at the base station (BS). Consequently, energy efficiency has been listed as a strict measure for 5G, according to the (international mobile telecommunications) IMT-2020 radio interface. [4-7]. EE improvement by reducing power consumption and enhancing system capacity by accommodating maximum users are the main trends of research. Physical EE limits for SISO and MIMO cases are analyzed in [8]. In the case of SISO, EE reaches its upper limit as bandwidth tends to infinity with non-zero transmit power (TP). However, zero TP results in null channel capacity. Energy efficient wireless system with null capacity is worthless. To handle these drawbacks EE analysis is carried out for the MIMO case. MIMO system performance is limited for a single user because of which MMIMO is proven as a successful key enabler for the analysis of EE.

Many researchers worked on the development of energy-efficient MMIMO by maximizing and optimizing EE by increasing data rate and throughput. EE is maximized using active radio frequency (RF) chain selection and hybrid precoding based on random bit allocation for digital to analog converters [9]. In [10], the optimization of EE is explored with optimized BS power transmission conferring to channel quality, user quality of service, and data rate. Authors in [11] discussed the efficient operation of massive MIMO by reducing power consumption using an adaptation of the antenna array configuration depending on the traffic load. The use of a perfect circuit power consumption model [12] and the huge number of antennas [13] with improved data rates are used for maximizing EE. Authors in [14] maximized and optimized EE of multiuser massive MIMO based on perfect CSI with ZF linear precoding considering the power consumption model depends on gross data rate and count of antennas and users.

However, adding more antennas in MMIMO results in design issues such as hardware complexity, expenses, and high circuit power consumption. To deal with the heavy hardware complexity and extensive power consumption challenges of MMIMO, many works have investigated low-complexity LP, and PCR in terms of data transmission and circuit power consumption. Authors in [15] investigated EE in MMIMO with low complexity algorithm for optimal AS, US, and optimal transmit power allocation. EE analysis is done separately for a combination of AS-LP, US-LP, and Power allocation-LP for 100 antennas and 80 users. In [16] EE analysis using LP and PCR in terms of CPC by considering perfect and imperfect CSI. Achieved maximum EE with ZF-perfect CSI by considering 141 antennas. Maximum EE is achieved [17] by reducing CPC with the use of the optimal number of transmit antennas when the transmit power is moderate. EE performance is analysed in terms of CPC [18] and DPC using optimal power allocation using WFA [19] and not considered AS or US.

US and AS approach is also helpful in the upgradation of EE and capacity of the MMIMO system.

Improvement in energy efficiency and capacity using norm-based US and norm-based AS with LP for multiuser MIMO is achieved in [20]. This method is implemented by considering only 8 antennas and 100 users in multiuser MIMO. Low complexity AS algorithm in MMIMO [21] and AS in OFDM-MIMO [22] is implemented to reduce the hardware complication which helps to achieve PCR. In [23], compared norm AS and random AS and analysed random AS is effective for improvement in EE and norm-based AS is better for capacity enhancement with 200 antennas and 100 users.

Many researchers worked on various AS methods and algorithms to improve the EE of MMIMO. Authors in [24] used only AS method, similarly, in [25] AS with power model and [26] used only AS with 200 antennas for improvement in EE. EE maximization is done by joint parameter selection and joint optimization of parameters [27, 28]. In [29, 30] only a combination of AS and power allocation and in [31]a pack of US, power allocation with precoding is used for the analysis of EE. Authors in [32] used LP- US- AS for analysis of capacity. Only US-AS [33] is used to evaluate the capacity of MMIMO by varying antenna count from 8 to 100 with 4 users.

Improved capacity can be achieved with a top-up of joint US and AS on energy-efficient MMIMO. Authors of [34] focused only on the maximization of capacity using the LP methods. MMIMO channel capacity modeling in [35] and capacity estimation in [36] are carried out. Authors in [37] discussed the improvement of capacity in distributed MMIMO, which is a rising solution of 5G limitations.

To summarize the literature survey, improvement of EE in the MMIMO cellular network is carried out by combining any two or three methods like AS-US, AS-LP, AS-power allocation, and AS-US-LP. For analysis of capacity, US-AS-LP is used without considering the power consumption model.

Thus, the gap analysis of existing work is that a combined analysis of EE and capacity in MMIMO has not been done before using four methodologies LP, PCR, US, AS together. Also, existing work

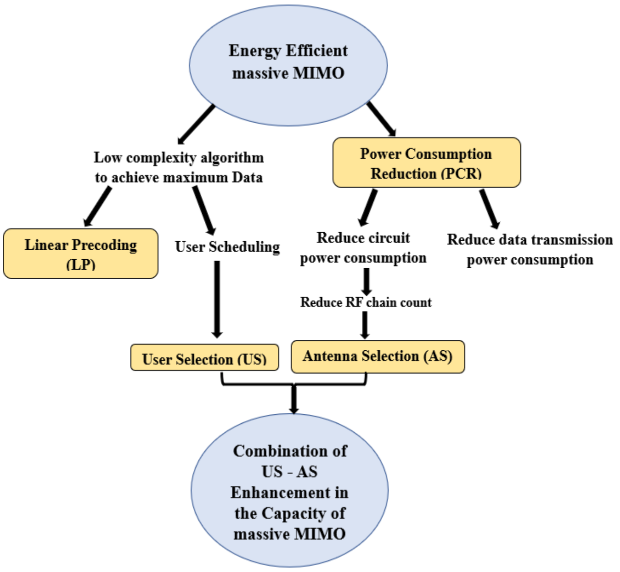

Figure. 1 Quad method to enhance EE and capacity

considered a maximum of 200 antennas and 100 users.

This paper presents the performance evaluation of a cellular network in terms of EE and capacity together by combining four methods LP, PCR, US, and AS for 220 antennas and 120 users. Three cases SISO, MIMO, and MMIMO are discussed to analyze enhancement in EE and capacity of the cellular network.

The proposed quad methodology norm user selection (NUS), norm antenna selection (NAS) with ZF linear precoding (LP) employing PCR, framed as NUS-NAS-LP-PCR is used to enhance EE and capacity of the MMIMO system.

The key contribution of this paper is

- Identified four methods: linear precoding, power consumption reduction, user selection, and antenna selection to estimate a cellular network's performance.
- Achieved three times more EE for the MMIMO system with AS using zero-forcing LP in comparison to the MMSE.
- Proposed pack of quad method NUS-NAS-LP-PCR is applied on MMIMO to enhance EE and capacity.
- Achieved improved EE and capacity for MMIMO system using a quad methodology NUS-NAS-LP-PCR in comparison with the existing model [20].

This research article is structured as follows:

Section 2: Quad methodology
Section 3: Use cases
Section 4: Performance analysis of EE and capacity in MMIMO using Quad Methodology
Section 5: Conclusion

## 2. Quad methodology

Four methods: linear precoding, power consumption reduction, user selection, and antenna selection (highlighted in squares as shown in Fig. 1.) are the key roots to enhance the EE and capacity of the MMIMO cellular network. These methods are discussed in the following sections.

### 2.1 Linear precoding (LP)

The use of low-complexity algorithms for BS operations to achieve maximum data rate is the most effective method to enhance EE. Two linear precoders ZF and MMSE are discussed and compared to evaluate the performance of EE with the antenna selection method.

ZF is responsible for maximizing the received signal-to-interference ratio, minimizing ISI, neglecting the effect of noise, or even enhancing it.

ZF works best with perfect Channel State Information (CSI). ZF matrix with H as the channel Information matrix and $H^H$ as Hermitian matrix, is mentioned in Eq. (1).

$$\text{ZF Matrix} = H(H^H H)^{-1} \tag{1}$$

MMSE is responsible for maximizing signal interference plus noise ratio (SINR), minimizing error in the received signal, and decreasing the noise. It fails to nullify ISI perfectly and is more complex as compared to ZF. MMSE matrix is mentioned in Eq. (2).

$$\text{MMSE Matrix} = (H^H H + 1/\text{SNRI})^{-1}\ H \tag{2}$$

In conclusion, ZF is the best precoding technique for the analysis of EE and MMSE is more effective for the analysis of bit error rate. ZF gives high EE because of active interference suppression at affordable complexity. ZF is proven to be the best low-complexity precoding technique for the analysis of EE.

### 2.2 Power consumption reduction (PCR)

To implement the concept of green communication, the reduction in power consumption of cellular networks is a key aspect that needs to be taken into consideration for enhancing EE.

The energy efficiency equation is given as

$$\text{Energy Efficiency (bits/Joule)} = \frac{\text{Data Rate (bits/s)}}{\text{Power Consumption (Joule/s)}} \tag{3}$$

Power consumption in Eq. (3) includes circuit power consumption and data transmission power consumption.

PCR is achieved by minimizing data transmission power consumption (DPC) and circuit power consumption (CPC). DPC reduction using optimum power allocation by water filling algorithm (WFA) is discussed for MIMO- SVD case in section 3.2.

Eq. (3) in terms of CPC and DPC is mentioned as

$$\mathrm{EE}=\frac{\text{Data Rate}}{\mathrm{DPC}+\mathrm{CPC}} \tag{4}$$

Perfect analysis of EE is done by considering CPC. Eq. (5) describes the CPC at base station.

$$\mathrm{CPC}=P_{\mathrm{Backhaul+Control}}+P_{\mathrm{RFch}}+P_{\mathrm{Codec}}+P_{\mathrm{LoadBackhul}}+P_{\mathrm{ChEst}}+P_{\mathrm{Lpc}} \tag{5}$$

Here, $P_{\mathrm{Backhaul+Control}}$ represents fixed power dissipation in the backhaul network and control signaling, $P_{\mathrm{RFch}}$ is the RF chain, $P_{\mathrm{Codec}}$ is coding-decoding of the channel, $P_{\mathrm{LoadBackhul}}$ is load-dependent backhaul power consumption. $P_{\mathrm{ChEst}}$ and $P_{\mathrm{Lpc}}$ represent power loss during the process of channel estimation and linear processing of the BS respectively. Only those terms which are reliant on the number of antennas are taken into account for a reduction in CPC, which helps to improve EE.

Eq. (4) is redefined as

$$\mathrm{EE}=\frac{\text{Data Rate}}{\mathrm{DPC}+P_{\mathrm{RFch}}+P_{\mathrm{ChEst}}+P_{\mathrm{Lpc}}} \tag{6}$$

CPC terms $P_{\mathrm{RFch}}$ , $P_{\mathrm{ChEst}}$ and $P_{\mathrm{Lpc}}$ are dependent on the count of antennas. Reduction in the number of RF chains by using antenna selection (AS), as presented in Fig. 1., helps in reducing $P_{\mathrm{RFch}}$ and enhances the EE.

### 2.3 User selection (US)

User selection with linear precoding helps with the enhancement of data rate in massive MIMO systems. Improved data rate boosts EE and capacity of the wireless network.

User selection algorithms like random US, Round Robin US, SINR US, and capacity-based US has no feedback information from users to the BS. Practically feedback-based US algorithm helps in maximizing the throughput of the selected user.

Norm US is a feedback-based scheme wherein, every user computes the squared Frobenius norm of the scalar channel information matrix and sends feedback to the BS. Afterward BS orders these users based on this feedback and selects a subset of users with the highest channel norm. NUS is used to enhance EE and capacity of MMIMO system in section 4.2

### 2.4 Antenna selection (AS)

Antenna selection helps in reducing the number of RF chains thus reducing the CPC and making MMIMO energy efficient.

Antenna selection algorithms like random AS, norm AS, and SINR-based AS are used for improving the performance of massive MIMO systems, and it offers several benefits in terms of spectral efficiency, energy efficiency, computational complexity, hardware costs, and system reliability.

For NAS the squared Frobenius norm of each antenna's channel information matrix is determined. The antenna with the highest norm value is chosen after these values are sorted. The use of NAS boosts the MMIMO system's capacity and EE.

## 3. Use cases

### 3.1 Single-input single-output

SISO system with perfect CSI, having bandwidth (BW) B, total transmit power P, and $N_0$ as the noise power spectral density is given by

$$y = hx + n \tag{7}$$

Where y is the received signal, x is the transmit signal with power P, h is the channel information matrix for SISO, and $n = BN_0$ is Additive White Gaussian Noise (AWGN).

As per assumption, the perfect CSI is available, so channel capacity is equal to the maximum data rate. The channel capacity is specified by

$$C=B\log_2\left(1+\frac{P\beta}{BN_0}\right) \tag{8}$$

Where, the channel gain is $\beta = |h|^2$

Eq. (9) provides an upper limit of EE when the transmit power is the only aspect taken into account while calculating the power consumption.

$$\text{Energy Efficiency} = \frac{B\log_2\left(1+\frac{P\beta}{BN_0}\right)}{P} \tag{9}$$

When P and B are viewed as design factors, EE is maximized as P/B tends to zero. This can be done by using conditions such as P = 0, B tends to ∞, or a

Table 1. The upper limit of EE by varying transmit power at various channel gain

| **Transmit Power P (dBm)** | **Channel Gain β (dB)** | **Frequency at maximum EE limit is reached (GHz)** | **Energy Efficiency Gbit/Joule** |
|---|---|---|---|
| 10 | -110 | 0.1 | 3 |
| | -90 | 10 | 337 |
| | -70 | 10000 | 3.3 x $10^4$ |
| 20 | -110 | 1 | 3 |
| | -90 | 100 | 331.1 |
| | -70 | 10000 | 3.3 x $10^4$ |
| 40 | -110 | 100 | 3 |
| | -90 | 10000 | 331.1 |
| | -70 | 1000000 | 3.3 x $10^4$ |

combination of both.

From an EE perspective, if these conditions are considered, it won't cause a problem but would give null capacity. From Eq. (8), it is observed that practically any communication system with zero capacity is meaningless. So, to achieve an upper limit of energy efficiency, transmit power is considered non-zero.

By considering non-zero transmit power, the following are the observations of the SISO system to enhance EE and capacity are

- EE increases with an increase in the channel gain.
- Energy efficiency reaches its upper limit as BW tends to infinity. To reach the maximum EE limit, 100 times more BW is required every time if the channel gain is increased by 20 dB.
- As TP is increased, EE decreases and the maximum EE limit is achieved at the higher bandwidth as compared to low TP. These results are displayed in Table 1.
- The above explanation demonstrates that there will be a loss of communication as BW tends to infinity. By considering zero transmit power, channel capacity is zero but a zero-capacity wireless system is practically insignificant, even though it is energy efficient. To tackle these limitations of the SISO system, the MIMO technology is discussed in section 3.2.

### 3.2 Multiple input multiple output

MIMO with singular value decomposition (SVD) is considered for analysis of MIMO capacity.

MIMO system model with M X N antennas is given as

$$y = H\,x + n \tag{10}$$

Where, MIMO channel information matrix is H, n is the AWGN with zero mean, and $\sigma^2$ is the variance.

SVD ensures spatial multiplexing in MIMO and helps to avoid interference, SVD is given as

$$H = U \sum V^H \tag{11}$$

Where, H is the channel information matrix, U and V are left and right singular vector unitary matrices respectively, and Σ is a rectangular diagonal matrix containing singular values of H.

Decoupling of the MIMO channels is facilitated by the use of SVD. MIMO system model with SVD is given by Eq. (12).

$$y' = H\,x' + n' \tag{12}$$

MIMO–SVD with $\sigma_{1,}$ $\sigma_{2,}$ $\sigma_{3,}$ ……… $\sigma_M$ decreasing ordered singular values of the channel is mentioned as

$$\begin{bmatrix} y'_1 \\ y'_2 \\ y'_3 \\ \vdots \\ y'_N \end{bmatrix} = \begin{bmatrix} \sigma_1 & \cdots & \\ \vdots & \sigma_2 \;\ddots & \vdots \\ & \cdots & \sigma_M \end{bmatrix} \begin{bmatrix} x'_1 \\ x'_1 \\ x'_1 \\ \vdots \\ x'_M \end{bmatrix} + \begin{bmatrix} n'_1 \\ n'_2 \\ n'_3 \\ \vdots \\ n'_N \end{bmatrix} \tag{13}$$

Signal to Noise Ratio (SNR) of $k^{th}$ parallel channel is

$$SNR = \frac{\sigma_k^2 P_k}{\sigma_n^2} \tag{14}$$

Where $\sigma_n^2$ is noise Power, $\sigma_k^2$ singular value, $P_k$ is power allocated to $k^{th}$ channel.

The capacity of $k^{th}$ parallel channel is

$$C = \log_2\left(1 + \frac{\sigma_k^2 P_k}{\sigma_n^2}\right) \tag{15}$$

Net MIMO Capacity is

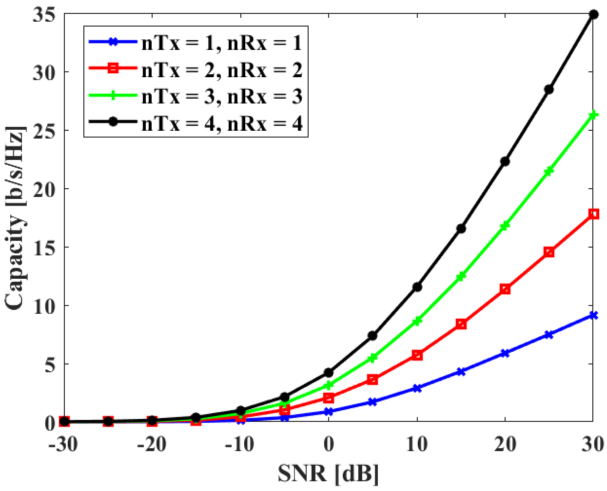

Figure. 2 Capacity of MIMO system

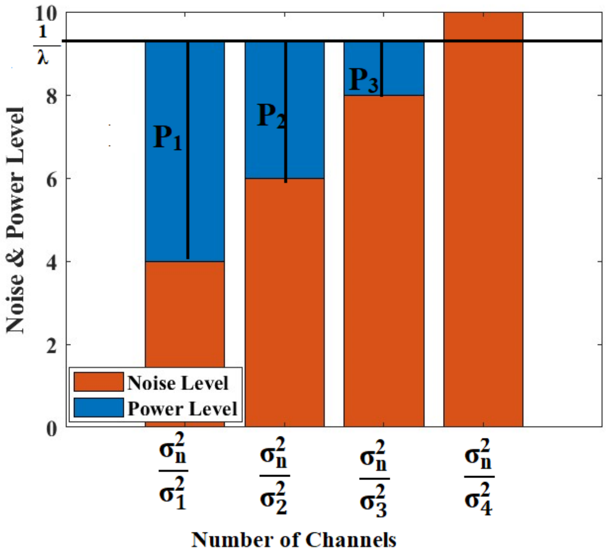

Figure. 3 Optimum power allocation using WFA

$$C_{MIMO}=\sum_{k=1}^{M}\log_2\left(1+\frac{\sigma_k^2 P_k}{\sigma_n^2}\right) \tag{16}$$

Thus, MIMO capacity is given by

$$C_{MIMO}=M \times B \log_2 (1+SNR) \tag{17}$$

MIMO-SVD helps to remove interference at the receiver antennas. Spatial multiplexing has the benefit of increased linear capacity. The simulation result of MIMO capacity enhancement is shown in Fig. 2. It has been noted that at 20dB SNR capacity is increased in proposition to the antenna count.

EE enhancement in MIMO-SVD is carried out by considering one of the quad methodologies PCR in terms of DPC using WFA as follows. Eq. (18) represents maximum channel capacity with optimal power allocation.

$$C_{Maximum} = \max \sum_{k=1}^{M}\log_2\left(1+\frac{\sigma_k^2 P_k}{\sigma_n^2}\right) \tag{18}$$

Power constraints such as the need for the sum of assigned power to be equal to the total power and that the given power to be non-negative is taken into account by considering the Lagrange multiplier λ to determine assigned power.

Optimal Power allocation $P_K$ is

$$P_K = \frac{1}{\lambda} - \frac{\sigma_n^2}{\sigma_k^2} \tag{19}$$

From Eq. (4) denominator, DPC is managed and minimized with optimum power allocation techniques. Equal power allocation and water filling algorithm (WFA) are the most popular power allocation methods. WFA is the best suited solution for energy-saving optimum power allocation. WFA allocates less power to channels with higher noise levels in favour of channels with higher SNR. A channel with noise greater than water level 1/ λ will not receive any power. Fig. 3. shows the power allocation to four channels using WFA for MIMO-SVD. From the above discussion and results, WFA is one of the optimal techniques of PCR from a quad methodology which helps to enhance EE.

Observations of MIMO SVD are:

- MIMO-SVD gives an improvement in the channel capacity with additional antennas at the transmitter and receiver. However, it is only applicable to a single user.
- For single user MIMO, the complexity lies at the receiver. The data must be separated into several received data streams and some complex computations must be performed such as; determining the inverse of H. This process consumes a lot of energy. If the receiver is mobile, it will suffer from excessive battery consumption. To tackle this drawback MMIMO is discussed in section 3.3. For multiuser MIMO, the complexity is at the BS, whose computational power is more. At the receiver, there is no need to tackle the multiuser spatial layer separation as the data is received independently from the other users with an improved signal to noise inference ratio.
- MIMO-SVD also gives EE enhancement by minimizing power consumption while transmitting data using WFA.

### 3.3 Massive MIMO

According to the findings from SISO and MIMO use cases, massive MIMO is recognized as the best technology for the analysis of EE and capacity. MMIMO itself is an energy efficient technology and the adoption of the proposed four methods provides extended capacity. This study achieves expanded EE and capacity employing LP, PCR, US, and AS quad techniques in MMIMO.

Norm user selection (NUS) helps to improve the energy efficiency of the system, as it allows for more effective use of the available resources, and also increases the overall system capacity by reducing interference. Norm antenna selection (NAS) helps to improve the capacity of the system, as it allows for better signal quality and reduced interference.

Combining these two techniques can result in even greater energy efficiency and capacity improvements for massive MIMO systems. By selecting both the strongest users and strongest antennas for transmission, the system can achieve more efficient use of resources and reduced interference, leading to increased capacity and energy savings.

Consider a single cell massive MIMO transceiver with bandwidth = 20 MHz, antenna count M = 220 and user count R =120 and H is channel information matrix.

Norm user selection (NUS): Frobenius norm is calculated for each user with the channel matrix $H_R$

$$\| H_F^2 \| = \text{trace}\,( H_R H_R^H ) \tag{20}$$

Norm antenna selection (NAS): Each antenna calculates the squared Frobenius norm of its channel matrix $H_n$

$$\| H_F^2 \| = \text{trace}\,( H_n H_n^H ) \tag{21}$$

A combination of NUS and NAS with zero forcing is implemented for enhancing EE and the capacity of MMIMO by employing PCR in section 4.2.

## 4. Performance analysis of EE and capacity in MMIMO using quad methodology

### 4.1 EE of MMIMO with AS-LP-PCR

Two linear precoders ZF and MMSE are compared to evaluate the performance of EE with the antenna selection.

Antenna selection dependent on the normalized power received by user in the MMIMO system with ZF and MMSE is considered for analysis of EE with power consumption reduction. PCR by considering the terms which are reliant on the number of antennas are taken into account for a reduction in CPC, which improves EE as described in section 2.2.

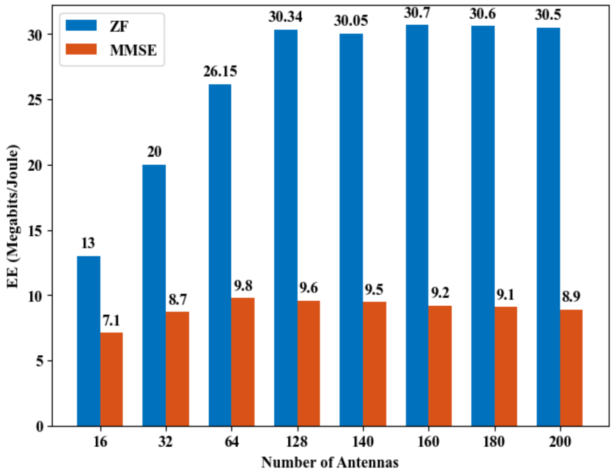

Figure. 4 EE Vs Number of antennas for ZF and MMSE

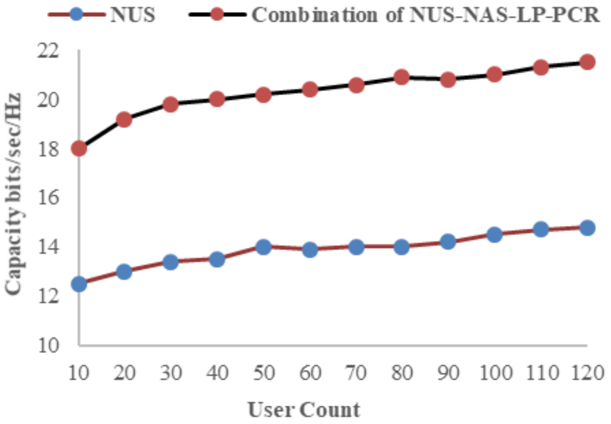

Figure 5. Comparison of capacity for combination of NUS-NAS-LP-PCR and only NUS

Fig. 4. shows massive MIMO energy efficiency performance evaluation for antenna selection with ZF and MMSE. It has been noted that AS in MMIMO with ZF system has provided around three times more EE in comparison to MMSE approach.

### 4.2 Capacity and EE of MMIMO with NUS-NAS-LP-PCR

Capacity and EE of massive MIMO system are determined using a combination of NUS and NAS with ZF as LP by considering PCR.

As per the comparison displayed in Table I. in the existing work, either analysis of EE or capacity is carried out with a combination of any two or three methods, using maximum 200 antennas and 100 users. Moreover, in the proposed work a pack of quad methodology is used for the analysis of EE and

Table 2. Comparison of Methodologies based on analysis of EE and capacity

| **Reference** | **Methodology** | **Antenna Count** | **User Count** | **Analysis of EE** | **Analysis of Capacity** |
|---|---|---|---|---|---|
| [15] | US-LP | 100 | 100 | ✓ | X |
| | AS-LP | | 100 | | |
| | PCR -LP | | 20 | | |
| [16] | PCR-LP | 141 | 100 | ✓ | X |
| [20] | NUS-NAS-LP | 8 | 100 | ✓ | ✓ |
| [23] | AS | 200 | 100 | ✓ | X |
| [25] | TAS-ZF-PCR | 220 | 100 | ✓ | X |
| [32] | UA-AS | 100 | 4 | X | ✓ |
| Proposed | NUS-NAS-LP-PCR | 220 | 120 | ✓ | ✓ |

Table 3. Performance analysis of capacity and EE with NUS-NAS-LP-PCR and only NUS

| **Model** | **Technology** | **Methodology** | **User count** | **Improvement in capacity over only NUS (%)** | **Improvement in EE over only NUS (%)** |
|---|---|---|---|---|---|
| Proposed model | Massive MIMO | NUS-NAS-LP-PCR | 120 | 45 | 20 |
| Existing Model [20] | Multiuser MIMO | Norm based US<br>Norm based AS | 100 | 43 | 19 |

Table 4. Summary of EE and capacity enhancement for three use cases

| **Use Cases** | **Methodology** | **Energy Efficiency** | **Capacity** |
|---|---|---|---|
| SISO | Power Consumption Reduction<br>Channel Gain<br>Bandwidth<br>Transmit Power | EE increases with an increase in channel gain.<br>EE reaches its upper limit as bandwidth tends to infinity.<br>As transmit power is increased, EE decreases and the maximum EE limit is achieved at the higher bandwidth.<br>Loss of communication as BW tends to infinity. | With zero transmit power, channel capacity is zero.<br>Even though a wireless system with zero capacity is energy-efficient, it is insignificant. |
| MIMO | Data Rate Improvement.<br>Power Consumption Reduction | EE increases as MIMO is a proven technology for max data rate. | MIMO-SVD boosts the channel capacity. However, it is only applicable to a single user. |
| MMIMO | TAS-ZF<br>Quad methodology:<br>LP- PCR- US -AS | MMIMO itself is energy-efficient technology. The use of LP, PCR, US, and AS helps in the additional enhancement of EE. | Energy-efficient MMIMO with quad methods also expands capacity. A combination of NUS-NAS-LP-PCR is a value addition for expanded capacity. |

capacity together considering 220 antennas and 120 total users.

Simulation results of the proposed combination of NUS-NAS-LP-PCR in MMIMO are compared with the existing model in [20]. Reference [20] is preferred for comparative analysis as it is based on both EE and capacity analysis. However, it is based on multiuser MIMO with NUS – NAS system considering only 8 total BS antennas and 100 users.

MMIMO system with the suggested quad methodology NUS-NAS-LP-PCR provides 45% and 20% improvement in capacity and energy efficiency respectively over only the NUS for 120 users. Fig. 5. shows comparison of capacity for combination of NUS-NAS-LP-PCR and only NUS. Comparison of EE for combination of NUS-NAS-LP-PCR and only NUS is shown in Fig. 6. Thus, the proposed combination provides extended EE and capacity performance as displayed in Table 3.

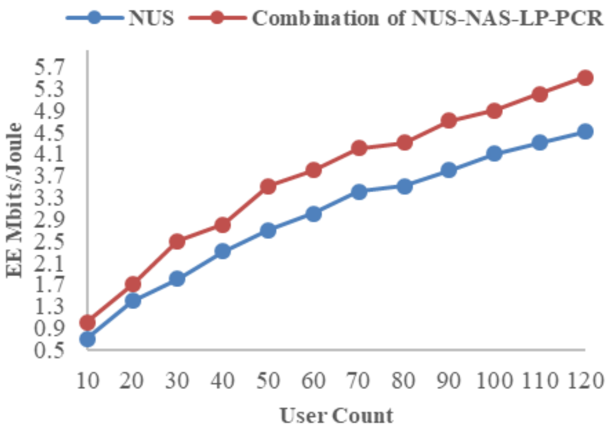

Figure 6. Comparison of EE for combination of NUS-NAS-LP-PCR and only NUS

To conclude, the performance of EE and capacity for three use cases are summarised in Table 4.

## 5. Conclusion

Leading towards green communication and coping with the advances in wireless communication, massive multiple input multiple output is proven to be a brand technology. Energy efficiency and capacity improvement are the main goals associated with green cellular networks. Quad methodology linear precoding, power reduction, user selection, and antenna selection are identified as key roots and used to estimate an MMIMO cellular network's capacity and energy-efficiency performance.

Antenna selection in MMIMO with zero forcing linear precoding has resulted in three times improved EE in comparison to MMSE. Thus, ZF is identified as a low-complexity LP. PCR is achieved by reducing circuit power consumption and data transmission power consumption. CPC is evaluated using AS and DPC with WFA as the optimal power allocation method. Energy-efficient MMIMO also gives expanded capacity by combining NUS-NAS. MMIMO system with the suggested quad methodology NUS-NAS-LP-PCR provides 45% and 20% improvement in capacity and energy efficiency respectively over only the norm US. In the future, the deep learning-based quad methodology can be used to evaluate the performance of massive MIMO.

## Conflicts of interest

The authors declare no conflict of interest.

## Author contributions

Conceptualization, methodology, software, validation, formal analysis, investigation, resources, writing—original draft preparation, writing—review and editing, visualization is done by S. R. Danve; supervision by M. S. Nagmode, and S. B. Deosarkar.

## Nomenclature and abbreviations

| **Nomenclature** | |
|---|---|
| B | Bandwidth |
| β | Channel gain |
| C | Channel Capacity |
| $C_{MIMO}$ | Capacity of Multiple Input Multiple Output System |
| h, H | Channel Information Matrix |
| $H^H$ | Channel Information Hermitian matrix |
| $\|\| H_F^2 \|\|$ | Frobenius norm of Channel Information Matrix |
| k | Number of channels |
| M | Total count of antennas at Transceiver |
| $n = BN_0$ | Additive White Gaussian Noise (AWGN) |
| $n'$ | Noise with SVD |
| P | Total transmit power |
| $P_k$ | Power allocated to $k^{th}$ channel |
| $P_{Backhaul+Control}$ | Fixed power dissipation in the backhaul network and control signaling. |
| $P_{RFch}$ | RF chain power consumption |
| $P_{Codec}$ | Power consumption in coding-decoding of the channel |
| $P_{LoadBackhul}$ | Load-dependent backhaul power consumption |
| $P_{ChEst}$ | Channel estimation power consumption |
| $P_{Lpc}$ | Linear processing power consumption |
| R | Total count of users |
| x | Transmitted signal |
| $x'$ | Transmitted signal with SVD |
| y | Received signal |
| $y'$ | Received signal with SVD |
| λ | Lagrange multiplier |
| $\sigma_n^2$ | Noise Power |
| $\sigma_k^2$ | Singular value of $k^{th}$ channel |
| **Abbreviations** | |
| AS | Antenna selection |
| BS | Base Station |
| CPC | Circuit Power Consumption |
| CSI | Channel State Information |
| DPC | Data Transmission Power Consumption |

| | |
|---|---|
| EE | Energy Efficiency |
| ISI | Inter Symbol Interference |
| LP | Linear Precoding |
| MIMO | Multiple Input Multiple Output |
| MMSE | Minimum Mean Square Error |
| MMIMO | Massive Multiple Input Multiple Output |
| NAS | Norm Antenna selection |
| NUS | Norm User selection |
| OFDM | Orthogonal Frequency Division Multiplexing |
| PCR | Power Consumption Reduction |
| RF | Radio frequency |
| SNR | Signal to Noise Ratio |
| SINR | Signal to Interference Noise Ratio |
| TP | Transmit Power |
| US | User selection |
| UE | User Equipment |
| ZF | Zero Forcing |

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