International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 / https://doi.org/10.14445/22315381/IJETT-V70I12P218
Volume 70 Issue 12, 170-178, December 2022

Original Article

Transmit Antenna Selection in Massive MIMO: An Energy-Efficient Approach

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Received: 26 August 2022 Revised: 13 November 2022 Accepted: 25 November 2022 Published: 24 December 2022

Abstract - *Massive Multiple Input Multiple Output (MIMO) has the potential to satisfy the requirements of the fifth generation (5G) and beyond networks with regard to factors like high data rate, high efficiency, reliability, better performance, and degree of freedom. However, increasing the number of antennas can lead to design challenges such as hardware complexity, higher cost, and large circuit power consumption. In addition to the parameters mentioned above, Energy Efficiency (EE) also needs to be considered a key parameter to analyze the performance of a cellular network. In this paper, Transmit Antenna Selection (TAS) technique based on the normalized power received by the user is proposed for a single-cell multiuser massive MIMO system. The energy efficiency equation is derived by considering both uplink and downlink communication for Zero Forcing (ZF) technique. The power consumption in the Radio Frequency (RF) chain, channel estimation process, and linear processing of the base station are considered for the analysis. The proposed TAS technique improves EE by 5 Mbit/Joule compared to the conventional massive MIMO system for ZF. This study compares Maximal Ratio Transmission (MRT), Minimum Mean Square Error (MMSE), and Zero Forcing based on energy efficiency performance using transmit antenna selection.*

Keywords - *Energy efficiency, Massive MIMO, Maximal ratio transmission, Minimum mean square error, Transmit antenna selection, Zero forcing.*

1. Introduction

Advances in wireless technology are included after every decade, and these advances are standardized by the International Telecommunication Union (ITU) [1]. The massive MIMO system has been used for the past decade to meet the demand for a more significant data rate in wireless communication while maintaining effective and dependable connections. Improved spectral efficiency is also achieved using massive MIMO by deploying many antennas in the transceiver system [2-4]. Massive MIMO satisfies the requirements of 5G and beyond networks in terms of maximum data rate, high efficiency, reliability, better performance, and degree of freedom [5]. However, increasing the number of antennas causes design challenges such as hardware complexity, cost, large circuit power consumption, and degradation in hardware.

International Mobile Telecommunications (IMT)-2020 radio interface has included more stringent requirements for 5G with energy efficiency as a new metric [6]. Thus, in addition to the parameters mentioned above, energy efficiency also needs to be considered as a key parameter to analyze the performance of the cellular network.

Energy efficiency is defined as:

$$EE\left(\frac{bit}{Joule}\right)=\frac{Data\ Rate\ (\frac{bit}{second})}{Power\ Consumption\ (\frac{Joule}{Second})} \qquad (1)$$

From Equation 1, enhancement in EE is achieved by increasing the data rate and minimizing power consumption. As mentioned earlier, massive MIMO is the best technology for achieving maximum data rate. The total power consumption in a cellular network includes data transmission and circuit power dissipation. By increasing the number of transmit antennas in massive MIMO, the circuit power consumption also increases, and this needs to be considered a significant factor for energy efficiency analysis. Considering this power consumption in the RF chain of individual antennas, the EE of the system initially rises with incrementing antenna count until it achieves its peak value [7]. The EE of massive MIMO decreases further with an increase in antenna count beyond the peak value. Therefore, it is highly essential to maintain the balance between spectral efficiency and EE by controlling the number of active antennas in massive MIMO [23].

The antenna selection technique is proposed for the MIMO system in [9] to address the hardware complexity problem where Channel State Information (CSI) is used to select the subset of the antenna. The transmit antenna selection based on perfect CSI is a popular technique in the MIMO system for improving the quality of reception [10] - [11]. For large-scale green MIMO, the EE maximization based on the random antenna selection technique is proposed in [12]. The exponential correlation model is used for massive MIMO to find the relationship between spectral efficiency and EE [13]. The pilot-based channel estimation is used for CSI assessment in many antenna array systems.

The EE is improved by using a bisection search algorithm to optimize the number of antennas in the massive MIMO [24]. The author considered a single-cell scenario for the uplink of massive MIMO with CSI and circuit power consumption. Optimization of the number of antennas has resulted in an overall increase in EE. An optimal energy-efficient TAS algorithm is proposed in [15] based on an exhaustive search for massive MIMO. The authors used the cross-layer approach based on system capacity and system throughput for energy-efficient antenna selection, which improved the EE of the system. A comparison between the per-subcarrier antenna selection scheme and the bulk antenna selection scheme is presented in [16] for the massive MIMO OFDM system. Upon analyzing the EE, the bulk antenna selection scheme performs better than the per-subcarrier antenna selection system. The hardware degradation effect is also observed over the EE for both algorithms.

The antenna selection scheme with energy efficiency is proposed in [17] for massive MIMO downlink, which uses the power consumption model for circuit and signal processing power dissipation along with cooling loss. The authors used the global optimal closed-form solution for selecting the number of transmitting antennas. An energy-efficient antenna selection method is proposed for uplinking massive MIMO [25]. The concept of dynamic switching of antennas is used with perfect CSI, where the balance between EE and spectral efficiency is illustrated with the simulations. The authors in [19] proposed an EE-based antenna selection technique for uplinking massive MIMO systems. The authors claim that enhancement in the EE is achieved by switching the RF chains based on the estimated CSI. A novel precoder design that maximizes the EE of a hybrid massive MIMO system is proposed in [20]. The optimization algorithm is implemented to deactivate the number of RF chains. In [21], the authors proposed different antenna selection schemes for deploying the Xl-MIMO system to maximize the EE. The closed-form analytical equations are derived for EE, and a genetic algorithm-based antenna selection scheme is proposed. In [22], massive multiuser MIMO models with accurate and inaccurate CSI are implemented for the analysis of maximization of energy efficiency of single-cell and multi-cell scenarios.

As per the study, Massive MIMO is a key technology used to enhance EE. Because the count of RF chains is more while using massive MIMO, the power consumption also increases. There are two notable methods to achieve an energy-efficient massive MIMO design. The first method is the use of a low complexity algorithm and the second one is to minimize circuit power consumption by reducing RF chain count using transmit antenna selection technique.
As per the literature survey, the process of selecting an antenna is used to achieve better energy efficiency in the massive MIMO system. Existing work primarily focuses on EE analysis of massive MIMO either for uplink or downlink communication using TAS based on perfect and imperfect CSI.

In this work, transmit antenna selection technique based on the normalized power received by the users is proposed for a single-cell multiuser massive MIMO system for both uplink and downlink cases. TAS will select an antenna subset using an uplink and downlink pilot-based approach to estimate perfect CSI. The EE equation is derived by considering both the uplink and downlink communication for ZF linear precoding. The water-filling algorithm is used to minimize data transmission power for optimal power allocation. For the analysis of EE, the base station (BS) linear processing, channel estimation process, and power consumption in RF chains are all taken into account. Thus, using zero-forcing as a low-complexity linear precoding technique and TAS to reduce the count of RF chains will help minimize hardware complexity, which may help reduce power consumption and make the cellular network energy efficient. The last optimization of EE for the proposed system is done by considering the number of antennas and users.

Paper sections are arranged as listed below:
Section 2: System Model.
Section 3: Energy Efficiency of Massive MIMO.
Section 4: Performance Analysis.
Section 5: Conclusion.

2. System Model

Figure 1 shows a single-cell massive MIMO transceiver system for antenna selection. At BS, the data stream is initially mapped with the MIMO-OFDM pre-processing unit and the precoder. The processed data is then passed through a large set of RF chains. A large count of RF chains increases the hardware.

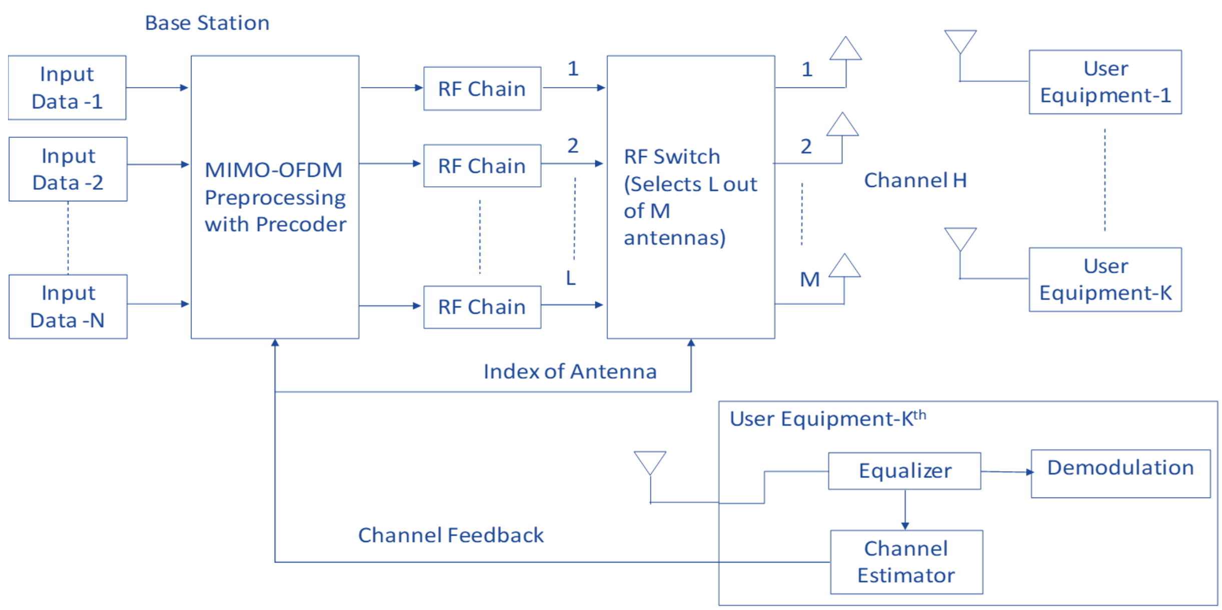

Fig. 1 System Model for TAS in Massive MIMO

The complexity of the system and the overhead of power dissipation decreases the system's energy efficiency. Improved EE can be achieved using a massive MIMO system with transmit antenna selection. As shown in Figure 1, the base station equipped with M massive antennas is communicating to K single antenna User Equipment (UE).

The concept of TAS is implemented by using an RF switch that selects the subset of L antennas from M number of massive antennas depending on CSI estimated at the receiver. The channel between BS and UEs has coherence bandwidth (B_c), coherence time (T_c), and the system operates at the bandwidth B.

Figure 2 shows a single-cell massive MIMO system with multiple users. The base station with M antennas has been positioned at the center of the cell, and K numbers of single antenna UEs are arbitrarily scattered around it. It is assumed that the BS and UEs are operating in perfect synchronization with the time division frame structure, as shown in Figure 2. The uplink frame consists of the uplink pilots with an interval of τ_{ul}, followed by the data. The total uplink symbols are $\zeta_{ul}\, U$. Similarly, the downlink frame has an interval of τ_{dl} between downlink pilots and data. $\zeta_{dl}\, U$ are total downlink symbols. The UE is assumed to be positioned at a distance x_k from the center of the cell. The UEs are randomly distributed, and the selection of antennas is carried out in a round-robin manner. It has been assumed that the same fading channel is present between UEs and all BS antennas. The function $l(x_k)$ is considered the average channel attenuation between K^{th} UE and the BS antenna. The use of pilot transmission ensures the perfect CSI estimation at the receiver in uplink and downlink modes.

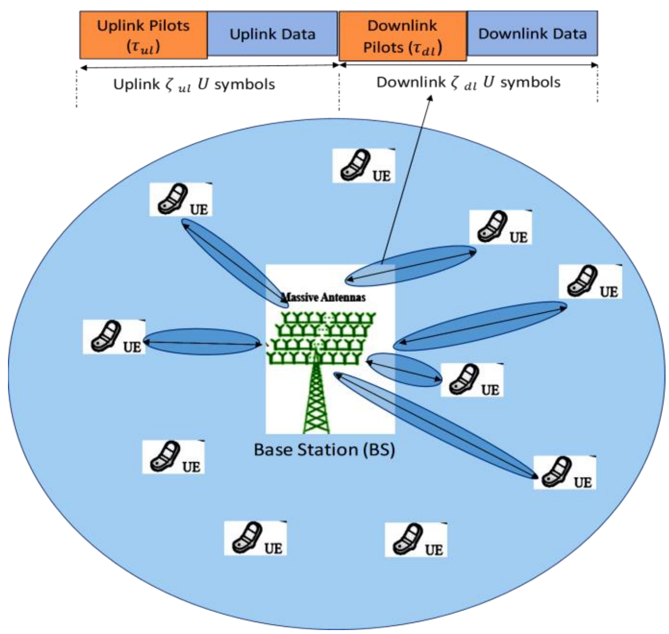

Fig. 2 Massive MIMO System with Multiple Users.

Let H denotes the channel information matrix between K^{th} UE and M^{th} the antenna of the BS. It is assumed that the channel follows the Rayleigh fading distribution. To evaluate the energy efficiency, the first step is calculating the data rate of both the uplink and downlink channels. The zero forcing technique is initially used at the receiver for detection purposes to analyze both the uplink and downlink scenarios. Through linear processing at the uplink, the combining matrix for ZF is defined as

$$G = H\,(H^H H)^{-1} \tag{2}$$

Here, H denotes the channel matrix containing all user channels $[h_1, h_2 \ldots\ldots h_k]$, H^H is the Hermitian matrix of H.

Similarly, the precoding matrix for downlink using ZF is defined as

$$V = H\,(H^H H)^{-1} \tag{3}$$

It is assumed that the combining matrix and precoding matrix given by Equations 2 and 3 are the same to avoid computational complexity.

The uplink rate of the K^{th} UE denoted as R_{k-ul} by considering the perfect CSI estimation with the help of uplink pilots can be given as [22]

$$R_{k-ul} = \zeta_{ul}\left[1 - \frac{\tau_{ul}K}{\zeta_{ul}U}\right]\underline{R}_{k-ul} \tag{4}$$

Here, ζ_{ul} is a fraction of the uplink symbol $\zeta_{ul}U$ and τ_{ul} is the pilot overhead. The average data rate $\underline{R}_{k-ul}$ is given as

$$\overline{R}_{k\text{-}ul} = B\log\left(1 + \frac{p_{k\text{-}ul}\,|g_k{}^H h_k|^2}{\sum_{l=1}^{K} p_{l\text{-}ul}\,|g_k{}^H h_l|^2 + \sigma^2\|g_k\|^2}\right) \tag{5}$$

Here, p_{k-ul} is the uplink power allocation vector for K^{th} UE in the numerator by considering the water-filling algorithm, g_k and h_k are K^{th} element of G and H matrix, respectively. σ^2 is noise power and $\|g_k\|^2$ is the square norm of g_k .

By considering the ZF detector with $M \geq K + 1$, the gross data rate is mentioned in Equation 6.

$$\overline{R}_{k\text{-}ul} = B\ \log\big(1 + \rho\ (M - K)\big) \tag{6}$$

Where ρ stands signal to interference noise ratio. Equation 6 is redefined as

$$\overline{R}_{k\text{-}ul} = \frac{BK(U\text{-}\tau_{ul})}{U\ln 2}\ln\left(1 + \frac{\rho^2\,\tau_{ul}(M\text{-}K)}{(\tau_{ul}+K)\rho+1}\right) \tag{7}$$

Similarly, by using ZF, the downlink rate as given by Equation 8

$$R_{k\text{-}dl} = \zeta_{dl}\left[1\text{-}\frac{\tau_{dl}K}{\zeta_{dl}U}\right]\overline{R}_{k\text{-}dl} \tag{8}$$

The average downlink data rate *R_(k-dl)* is given as

$$\overline{R}_{k\text{-}dl} = B\log\left(1 + \frac{p_{k\text{-}dl}\,\frac{|h_k{}^H v_k|^2}{\|v_k\|^2}}{\sum_{l=1}^{K} p_{l\text{-}dl}\,\frac{|h_l{}^H v_l|^2}{\|v_l\|^2} + \sigma^2}\right) \tag{9}$$

Where, p_{k-dl} is the downlink power allocation vector for K^{th} UE in the numerator by considering the water-filling algorithm, v_k and h_k are K^{th} element of matrix V and H, respectively. σ^2 is the variance and $\|v_k\|^2$ is the square norm of v_k .

Similarly, considering the ZF detector with $M \geq K + 1$, the gross data rate for downlink is mentioned in Equation 10.

$$\overline{R}_{k\text{-}dl} = B\ \log\big(1 + \rho\ (M - K)\big) \tag{10}$$

Equation 10 is redefined as

$$\overline{R}_{k\text{-}dl} = \frac{BK(U\text{-}\tau_{dl})}{U\ln 2}\ln\left(1 + \frac{\rho^2\,\tau_{dl}(M\text{-}K)}{(\tau_{dl}+K)\rho+1}\right) \tag{11}$$

Similar equations for MRT and MMSE techniques can be derived. In this work, these equations are considered for simulation purposes.

3. Energy Efficiency of Massive MIMO

The energy efficiency defined in section 1 by Equation 1 is the data rate ratio to the transmission plus circuit power consumption. For a multiuser massive MIMO system, by considering both the uplink as well as the downlink scenarios, energy efficiency is defined as

$$EE = \frac{\sum_{k=1}^{K}\big(E(R_{k\text{-}ul}) + E(R_{k\text{-}dl})\big)}{P_{T\text{-}ul}+P_{T\text{-}dl}+P_C} \tag{12}$$

The following steps are carried out to determine the EE of massive MIMO:

- Evaluate the data rate of uplink and downlink scenarios, described in section 2.
- Consider data transmission power consumption in uplink and downlink.
- Power consumption model wherein circuit power consumption terms which are significantly dependent on the number of antennas that is parameter M are considered for analysis.

To enhance the EE of massive MIMO following steps are carried out.

- Transmit antenna selection technique is proposed for a single-cell massive MIMO system.
- TAS will select the antenna subset depending on the normalized power received by the users.
- The pilot symbols for uplink and downlink are used to estimate the perfect CSI.
- The index of the antenna subset is fed back to the RF switch to select the subset of antennas L from M for transmission purposes.

3.1. Energy Efficiency of Massive MIMO with Data Transmission Power Consumption

Water-filling algorithm as an optimum power allocation technique is used to improve the EE of Massive MIMO. p_{k-ul} and p_{k-dl} are uplink and downlink power allocation vectors considering the water-filling algorithm are used in Equation 5 and Equation 9 while evaluating of data rate for deriving the equation of EE. Massive MIMO is an EE enhancement technique, and a water-filling algorithm is topped up on it as an optimal power allocation technique.

3.2. Energy Efficiency of Massive MIMO with Circuit Power Consumption

Accurate modeling of power consumption is essential while dealing with the energy efficiency analysis of a cellular network. Performance analysis of a single-cell massive MIMO is carried out by considering circuit power consumption. In Equation 12, P_{T-ul} and P_{T-dl} are data transmission power terms of uplink and downlink, respectively and P_C is total circuit power consumption given as

$$P_C = P_X + P_{RC} + P_{C\text{-}D} + P_{BH} + P_{CE} + P_{LP} \tag{13}$$

Here, P_X represents the power consumption for the backhaul network and control signaling, which is assumed to be fixed, P_{RC} stands the RF chain power consumption, P_{C-D} stands the power consumption in coding-decoding of the channel, P_{BH} is the power consumption load-dependent backhaul, P_{CE} represents power loss during the process of channel estimation, P_{LP} is power loss in the linear processing of the BS. By using the equations presented in [22], the power consumption in the RF chain is given as

$$P_{RC} = (M\,P_{BS} + P_{LO} + KP_{UE}) \tag{14}$$

Here, P_{BS} stands for power consumed by the mixer, converter, and other circuit components, P_{LO} stands the local oscillator and P_{UE} stands user equipment power consumption. The channel coding-decoding power consumption P_{C-D} is given as

$$P_{C\text{-}D} = \sum_{k=1}^{K}\big(E(R_{k\text{-}ul}) + E(R_{k\text{-}dl})\big) + (P_{cod} + P_{dec}) \tag{15}$$

Here, P_{cod} is the coding power, which is the same as P_{dec} decoding power.

The power consumption of backhaul P_{BH} is specified as

$$P_{BH} = \sum_{k=1}^{K}\big(E(R_{k\text{-}ul}) + E(R_{k\text{-}dl})\big) + P_{BT} \tag{16}$$

Here, P_{BT} Stands the traffic power of the backhaul network.

The P_{CE} is uplink and downlink power for channel estimation and is given as

$$P_{CE} = \frac{2BMK^2\tau_{ul}}{UL_{BS}} + \frac{4BK^2\tau_{dl}}{UL_{UE}} \tag{17}$$

Here, L_{BS} and L_{UE} are complex-valued terms.
The P_{LP} is given as

$$P_{LP} = B\left(1 - \frac{K(\tau_{ul}+\tau_{dl})}{U}\right)\frac{2MK}{L_{BS}} + P_{LP\text{-}C} \tag{18}$$

Here, P_{LP-C} is the power consumed to compute the matrix *G* and *V*.

Looking at Equation 14 to Equation 18, it is observed that the power consumption terms P_{RC}, P_{CE} ad P_{LP} are mainly dependent on the parameter M that is, the number of massive antenna elements. Therefore, selecting all such antenna elements will significantly increase the power dissipation, and interns will decrease the EE of the system.

3.3. Energy Efficiency of Massive MIMO with TAS

To improve the EE of the massive MIMO system, It is suggested to utilize a TAS technique that will choose a subgroup of antennas depending on the normalized power users receive. The pilots used for uplink and downlink are utilized to estimate the perfect CSI. The antenna subset is selected based on the maximum value of CSI, and then the antenna index is feedback to the RF switch.
To select the subset of the antenna, the parameter ϑ_m is computed as

$$\vartheta_m = \sum_{k=1}^{K}\frac{l_{m,k}}{\sum_{j=1}^{M} l_{j,k}} \tag{19}$$

Here, $l_{m,k}$ is the fading coefficient parameter between m^{th}antenna and K^{th} user. The antenna subset is selected with the highest value of ϑ_m. The pilot-based approach is used to find out the ϑ_m value for all the antenna elements. The antenna element has the highest value of ϑ_m are arranged in descending order and selected with the highest value of ϑ_m.

3.4. Maximization of Energy Efficiency

Evaluating the maximum value of the EE defined by Equation 12, the power consumption terms with a significant value of M are considered. Therefore, rewriting Equation 12 as

$$EE \approx \frac{\sum_{k=1}^{K}\big(E(R_{k\text{-}ul}) + E(R_{k\text{-}dl})\big)}{P_{T\text{-}ul} + P_{T\text{-}dl} + P_{RC} + P_{CE} + P_{LP}} \tag{20}$$

Equation 20 with detailed power consumption terms is given as

$$EE \approx \frac{\sum_{k=1}^{K}\big(E(R_{k\text{-}ul}) + E(R_{k\text{-}dl})\big)}{P_{T\text{-}ul} + P_{T\text{-}dl} + (M\,P_{BS} + P_{LO} + KP_{UE}) + \frac{2BMK^2\tau_{ul}}{UL_{BS}} + \frac{4BK^2\tau_{dl}}{UL_{UE}} + B\left(1 - \frac{K(\tau_{ul}+\tau_{dl})}{U}\right)\frac{2MK}{L_{BS}} + P_{LP\text{-}C}} \tag{21}$$

Equation 21 is maximized to evaluate the optimum number of selected antennas by considering,

$$P_{T-ul} + P_{T-dl} = \frac{B\sigma^2 \rho S_x}{\eta} K$$

and

$$\sum_{k=1}^{K} \left(E(R_{k\text{-}ul}) + E(R_{k\text{-}dl}) \right) = K\bar{R} \left(1 - \frac{K(\tau_{ul}+\tau_{dl})}{U} \right)$$

Where $B\sigma^2$ is total noise power, ρ stands signal to interference noise ratio, $S_x = E\{(l_x)^{-1}\}$, l_x is a model of large-scale fading, η is PA efficiency at the BS, U is Total symbols, and K is user count.

The EE for TAS in multiuser massive MIMO can be given as

$$EE \approx \frac{K\bar{R}\left(1-\frac{K(\tau_{ul}+\tau_{dl})}{U}\right)}{\frac{B\sigma^2\rho S_x}{\eta}K + \sum_{i=0}^{3} C_i K^i + M\sum_{i=0}^{2} D_i K^i + AK\bar{R}\left(1-\frac{K(\tau_{ul}+\tau_{dl})}{U}\right)} \quad (22)$$

Here, C_i and D_i denotes the coefficients of various power terms defined in Equation 14 to Equation 18.

Equation 22 is the maximized value of EE by considering the ZF combining technique. Similar to this maximized value of EE for the MRT technique can also be derived.

4. Performance Analysis

Performance evaluation of a single-cell massive MIMO system is carried out for the ZF precoding technique with and without TAS cases. The proposed system is a single-cell massive MIMO with TAS, and the conventional system is without TAS.

The comparison of ZF with MRT and MMSE is also implemented in the proposed system. The parameters used for the simulation are listed in Table 1.

Table 1. Simulation parameters of the proposed system

Parameter	Value	Parameter	Value
M	220	K	150
Kappa (Path loss component)	3.56/5.5	τ_{ul}, τ_{dl}	1
B	20MHz	B_C	180KHz
$B\sigma^2$	-96dBm	U	1800
ζ_{dl}	0.6	ζ_{ul}	0.4

Figure 3 shows the simulated result of a single-cell massive MIMO with TAS and without TAS using ZF for two different values of path loss component (Kappa). By increasing the antennas at the BS beyond 200, the proposed TAS system gives improved EE by 5 Mbit/Joule compared to the conventional massive MIMO system for the path loss component of 3.56 and 5.5. Thus, the massive MIMO with the TAS system's performance is better than the conventional massive MIMO system.

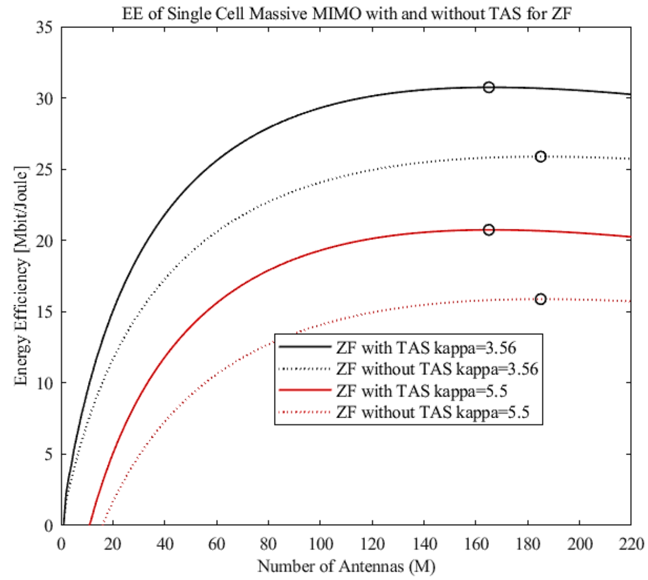

Fig. 3 EE of Single-cell Massive MIMO with and without TAS for ZF

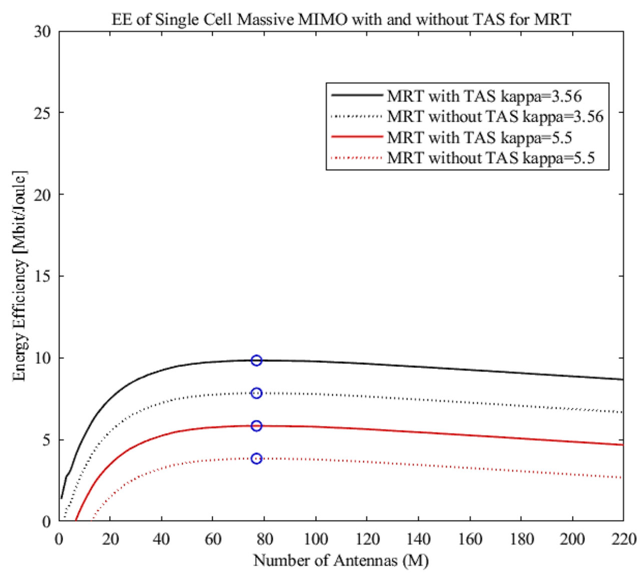

Fig. 4 EE of Single-cell Massive MIMO with and without TAS for MRT

Figure 4 shows the application of the proposed TAS system for MRT. The proposed TAS system has also improved energy efficiency compared to the conventional massive MIMO for MRT. An analogous performance is observed for a higher value of the path loss component of 5.5.

Table 2. EE Comparison of ZF, MMSE, and MRT on proposed TAS massive MIMO system

Precoding Technique	Energy Efficiency (Mbit/Joule)
ZF	30.52
MMSE	8.85
MRT	0

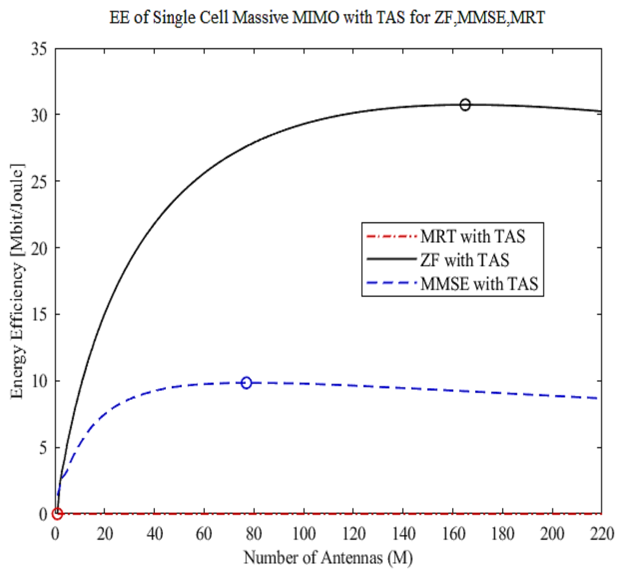

Fig. 5 EE of Single-cell Massive MIMO with TAS for ZF, MMSE, and MRT

Figure 5 shows the EE performance comparison of the proposed TAS massive MIMO system for ZF, MMSE, and MRT. It has been observed that the proposed TAS system has given very high EE by using ZF as compared to MMSE and MRT techniques. The observations for 200 antennas at BS give EE = 30.52 Mbit/Joule using ZF, whereas for the same count of antennas, MMSE gives only 8.85 Mbit/Joule, and MRT is very close to 0 Mbit/Joule. The values presented are for one set of random generations of parameters and can vary in every iteration. Thus, the ZF technique has given significantly high EE compared to MMSE and MRT, as per the values in Table 2.

A comparison is presented in [22] between the proposed system using massive MIMO TAS for ZF and the existing system. In the existing system, analysis of EE is based on perfect and imperfect CSI is carried out. The proposed massive MIMO system with TAS depending on normalized power received by the users for ZF has given around 5% improvement in EE compared to the current work. Achieved 5% improved EE values are listed in Table 3 for 64, 128, and 200 antennas at the base station.

Table 3. Improvement in EE for ZF with TAS

Number of Antennas	EE (Mbit/Joule) Proposed System ZF with TAS	EE (Mbit/Joule) Existing System [22]	Improvement in EE (%) of Proposed Model
64	26.15	25	4.60
128	30.34	29	4.62
200	30.52	29	5.24

Optimized EE in single-cell massive MIMO for ZF with TAS is shown in Figure 6 (a) and Figure 6 (b) without TAS. Along with EE and the number of antennas, the number of users is also considered to analyze multiuser scenarios. As shown in Figure 6 (a) and values listed in Table 4, it has been observed that 30.8 Mbit/Joule optimum EE is obtained at $M = 150$ and $K = 100$. Similarly, the optimum EE = 25 Mbit/Joule without TAS case is obtained at $M = 160$ and $K = 110$ as shown in Figure 6 (b), and values listed in Table 5 as per the achieved results, the proposed TAS system gives improved EE even in the case of multiuser scenario.

Table 4. EE with TAS using ZF

M	*K*	Energy Efficiency (Mbit/Joule)
150	100	30.8
200	50	15
220	150	35

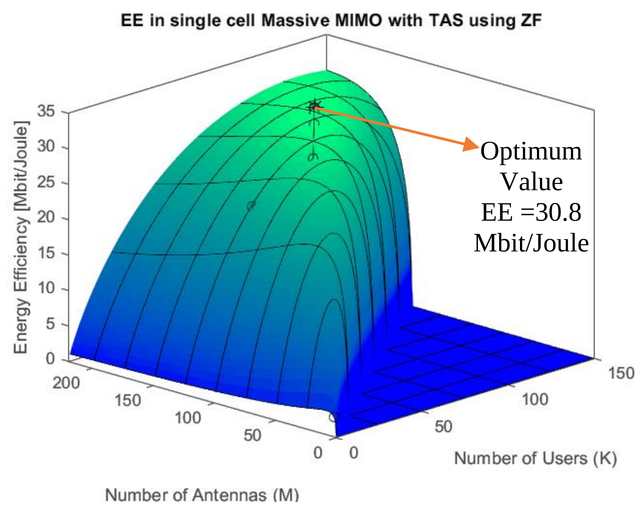

Fig. 6 (a) EE of Single-cell Multi-user Massive MIMO with TAS using ZF

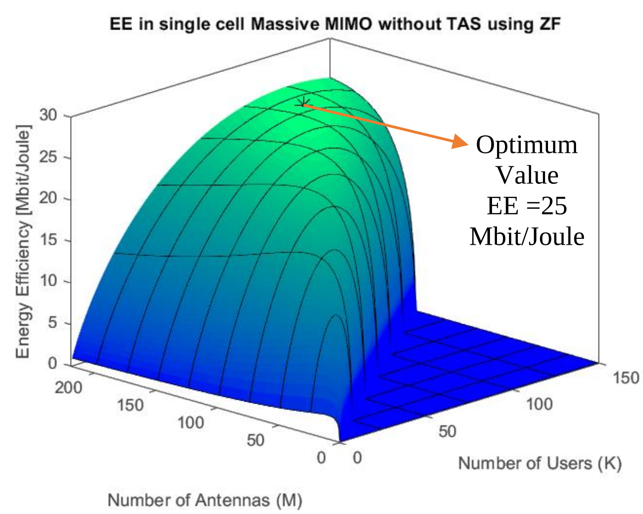

Fig. 6 (b) EE of Single-cell Multi-user Massive MIMO without TAS `using ZF

Table 5. EE without TAS using ZF

M	*K*	Energy Efficiency (Mbit/Joule)
150	100	22
160	110	25
50	50	14

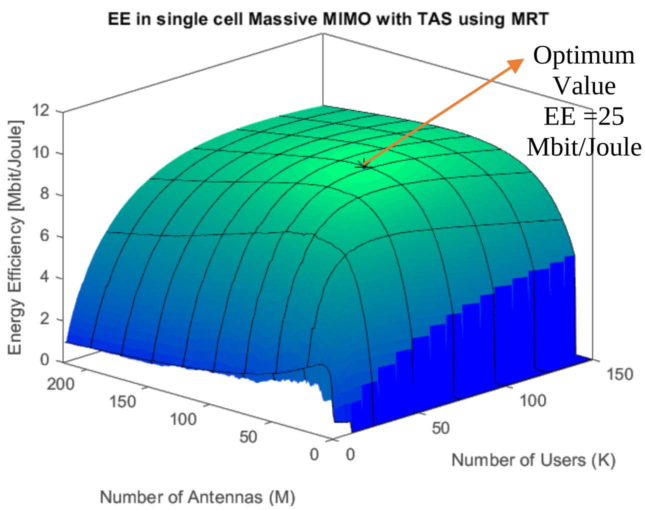

Fig. 7 EE of Single-cell Multi-user Massive MIMO with TAS using MRT

Figure 7 shows the optimum EE of massive MIMO for MRT using the proposed TAS technique. MRT also achieved the optimum value of EE = 10 Mbit/Joule at *M* = 80 and *K*=60 as per the results listed in Table 6. Thus, with an increase in the user count, the proposed TAS system also improves EE for MRT.

Table 6. EE with TAS using MRT

M	*K*	Energy Efficiency (Mbit/Joule)
100	100	11
80	60	10
100	50	8

5. Conclusion

Transmit Antenna Selection technique depending on normalized power received by the users is proposed in this work for a single-cell multiuser massive MIMO system. The energy efficiency equations are derived for uplink and downlink communication for the zero forcing combining technique. The power consumption in the RF chain, channel estimation process, and linear processing of the BS are considered for the perfect energy efficiency analysis. The proposed TAS technique improved EE by 5 Mbit/Joule compared to the conventional massive MIMO system for ZF. Also, the proposed TAS for the multiuser scenario gives optimum EE = 30.8 Mbit/Joule at *M* = 150 and *K* = 100 for ZF and optimum EE = 10 Mbit/Joule at *M* = 80 and *K* = 60 for MRT. The EE performance of the proposed TAS massive MIMO is much better for the ZF case than MRT and MMSE. Efforts have been put into energy efficiency improvement by using low complexity ZF linear precoding and minimizing power consumption in RF chains using the proposed TAS in a massive MIMO system.

Future work

In the future, the system can be upgraded to enhance energy efficiency for multi-cell massive MIMO systems using the proposed transmit antenna selection technique.

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