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Research Article

Energy Efficiency Analysis of Antenna Selection Techniques in Massive MIMO-OFDM System with Hardware Impairments

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In massive multiple-input multiple-output (M-MIMO) systems, a large number of antennas increase system complexity as well as the cost of hardware. In this paper, we propose an M-MIMO-OFDM model using per-subcarrier antenna selection and bulk antenna selection schemes to mitigate these problems. Also, we derive a new uplink and downlink energy efficiency (EE) equation for the M-MIMO-OFDM system by taking into consideration the antenna selection schemes, power scaling factor ($g = 0.25,\ 0.5$), and a range of hardware impairments $\{\kappa^{\mathrm{BS}}, \kappa^{\mathrm{UE}}\ \epsilon\ (0, 0.05^2, 0.1^2)\}$. In addition, we investigate a trend of EE by varying various parameters like number of base station antennas (BSAs), SNR, level of hardware impairments, total circuit power consumption, power optimization, antenna selection schemes, and power scaling factor in the proposed M-MIMO-OFDM model. The simulation results thus obtained show that the EE increases with increase in the value of SNR. Also, it increases abruptly up to 100 number of BSA. However, the increase in the EE is not significant in the range of 125 to 400 number of BSA. Further, the bulk antenna selection technique has comparatively more EE than the per-subcarrier antenna selection. Moreover, EE gaps between antenna selection schemes decrease with increase in the value of hardware impairments and power scaling factor. However, as the hardware degradation effect increases, the EE of the bulk antenna selection scheme suffers more degradation as compared to the Per-subcarrier antenna selection scheme. It has also been observed that EE performance is inversely proportional to the total circuit power consumption $(\lambda + \gamma)$ and it increases with the power optimization.

1. Introduction

Today, massive multiple-input multiple-output (M-MIMO) is one of the rising fields in the telecom industry to meet the customer requirement like high date rate, reliability, high efficiency, degree of freedom, and better performance. But, the use of a massive number of antennas in M-MIMO create some challenging design issues like large circuit power consumption, high system complexity, large cost, and hardware performance degradation [1–3]. These challenges limit the increase in EE with increase in the number of BSA. Thus, the use of the antenna selection scheme seems to be a viable solution to counter these challenges in the M-MIMO system [4].

In the past decade, antenna selection schemes have been reviewed mainly for the conventional MIMO systems and very few for the M-MIMO systems using single carrier only. To the best of author's knowledge, no research work has been reported regarding the use of antenna selection schemes for the M-MIMO system using multicarrier OFDM. Therefore, in this paper, we analyze per-subcarrier antenna selection [5, 6] and bulk antenna selection [7] schemes to improve the uplink and downlink EE in the M-MIMO-OFDM system. In the bulk antenna selection, the same antenna among the available antennas is picked every time and each subcarrier is being assigned to it. However, independent antennas are assigned to the subcarriers in the per-subcarrier antenna selection.

Further, the available research literature reveals that the EE of the M-MIMO-OFDM system is mostly analyzed in ideal hardware environment conditions. The effect of hardware impairments due to the additive white Gaussian

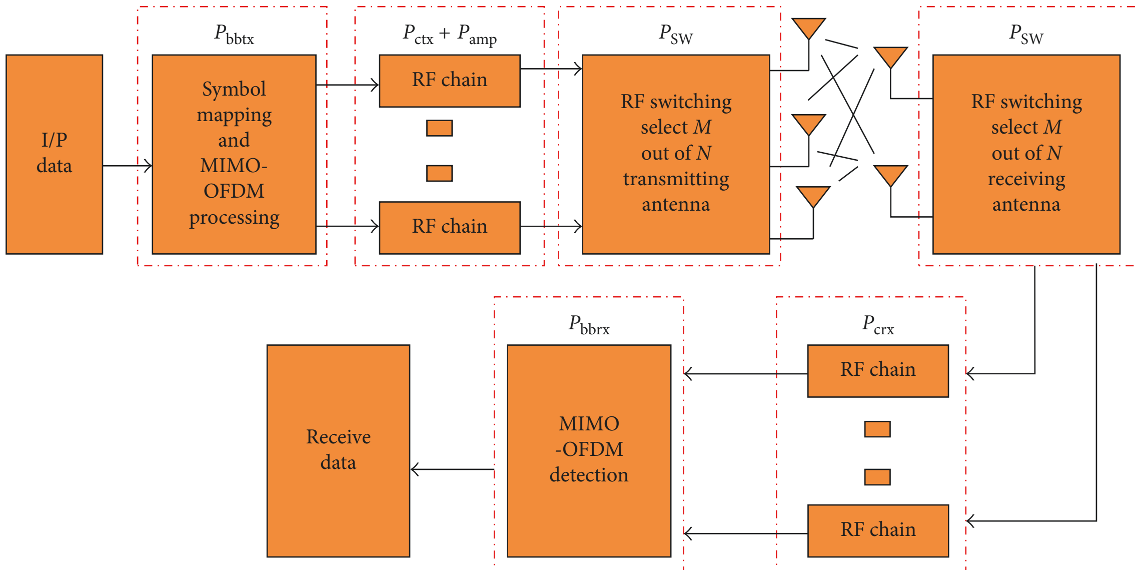

Figure 1: Block diagram of the M-MIMO-OFDM transmitter and receiver with antenna selection.

noise (AWGN) has however been considered in few research papers [8, 9]. Therefore, in this paper, we analyze the EE of the proposed M-MIMO-OFDM model in the nonideal hardware environment by considering the effect of hardware impairments and its degradation.

1.1. Problem Formulation. The main contribution of this paper is summarized below:

(a) A new uplink and downlink EE equation has been derived by considering the effect of antenna selection and hardware impairments for the M-MIMO-OFDM system.

(b) In the proposed M-MIMO-OFDM model, the EE of antenna selection schemes like per-subcarrier antenna selection and bulk antenna selection is analyzed by varying the SNR, number of BSA, total circuit power consumption, and levels of hardware impairments.

(c) A trend of EE is analyzed with respect to the power scaling factor ($g = 0.25, 0.5$) and power optimization in the M-MIMO-OFDM system.

The remainder of this paper has been organized as follows. Section 2 gives an overview of the M-MIMO-OFDM system with antenna selection. Section 3 explains the EE for various antenna selection techniques in brief. The simulation results are discussed in Section 4, and finally, the conclusions are drawn in Section 5.

2. M-MIMO-OFDM System with Antenna Selection

In this section, we consider an M-MIMO-OFDM transceiver system with antenna selection, and a block diagram of this system is shown in Figure 1. In Figure 1, initially a stream of input data is mapped and processed by using the MIMO-OFDM system. Then, it passes through a number of radio frequency (RF) chains. This process increases complexity, power consumption, and cost of the system. To overcome this, antenna selection is used for choosing M out of N massive transmit and receive antennas with the help of the RF switching unit at both the transmitter and receiver sides. In the end, a detection unit of MIMO-OFDM is used to recover transmit input data. During the above process, the power consumption takes place at several points like baseband power consumption (P_{bbtx}, P_{bbrx}), per transmit and receive branch power consumption (P_{ctx}, P_{crx}), RF switch power consumption (P_{sw}), and amplifier power consumption (P_{amp}) as shown in Figure 1.

In the M-MIMO-OFDM system, the total power consumption of per-subcarrier antenna selection and bulk antenna selection schemes is given in (1) and (2), respectively [10]:

$$P_{total}^{per} = n_{Tx}\left(P_{amp} + P_{ctx}\right) + n_{Rx}P_{crx} + P_{bbtx} + P_{bbrx}, \quad (1)$$

$$P_{total}^{bulk} = P_{amp} + P_{ctx} + n_{Rx}P_{crx} + P_{bbtx} + P_{bbrx}, \quad (2)$$

where n_{Tx} and n_{Rx} are the number of transmitting and receiving antennas. The total baseband circuit power (P_{bb}) is the sum of the transmitting (P_{bbtx}) and receiving (P_{bbrx}) baseband power. An EE equation in consideration of above two antenna selection schemes and hardware impairments for the M-MIMO-OFDM system has been derived in the next section.

3. Energy Efficiency of M-MIMO-OFDM System with Antenna Selection

In this section, firstly we analyze the EE and derive its value for antenna selection schemes with hardware impairments of the M-MIMO-OFDM system. In the end, a brief introduction of EE optimization and scaling in the M-MIMO-OFDM system is presented.

Table 1: Capacity of the M-MIMO system with the single carrier system with hardware impairments [12].

Serial Number	Capacity
1	$C_{\text{M}-\text{MIMO}}^{\text{uplink}} = T_{\text{data}}^{\text{UL}}/T_{\text{coher}}\text{Log}_2\,(1 + \lvert E\{\varnothing\}\rvert^2 + O(1/\sqrt{N})/(1+\kappa_{\text{t}}^{\text{UE}})E\{\lvert\varnothing\rvert^2\} - \lvert E\{\varnothing\}\rvert^2 + O(1/\sqrt{N} + 1/N^{1-n}))$
2	$C_{\text{M}-\text{MIMO}}^{\text{downlink}} = T_{\text{data}}^{\text{DL}}/T_{\text{coher}}\text{Log}_2\,(1 + \lvert E\{\varnothing\}\rvert^2 + O(1/\sqrt{N})/(1+\kappa_{\text{r}}^{\text{UE}})E\{\lvert\varnothing\rvert^2\} - \lvert E\{\varnothing\}\rvert^2 + O(1/\sqrt{N} + 1/N^{1-n}))$

Energy Efficiency: energy efficiency (bit/Joule/Hz) is defined as the ratio between the capacity (bit/channel use) and total emitted power (Joule/channel use) in the system as shown in the following equation [11]:

$$\text{Energy efficiency}\,(\text{EE}) = \frac{\text{channel capacity}\,(C)}{\text{emitted power}\,(P)}, \tag{3}$$

where C is the maximum information rate for the uplink and downlink single carrier M-MIMO system, which is tabulated in Table 1 [12].

In Table 1, E is the expectation vector and both terms $O(1/\sqrt{N})$ and $O(1/N^{1-n})$ become zero when number of BSA (N) tends to ∞. κ is the parameter for the hardware impairments and $\varnothing$ is given by the following equation [12]:

$$\varnothing = \frac{(1 + d^{-1}\eta_{\text{t}}^{\text{UE}})\sqrt{\text{tr}\,(R - C)}}{\sqrt{\text{tr}\left(A\left(\lvert d + \eta_{\text{t}}^{\text{UE}}\rvert^2 R + \psi\right)A^{\text{H}}\right)}}, \tag{4}$$

where d is the pilot signal, z is the received signal, R is the channel covariance matrix, $\eta_{\text{t}}^{\text{UE}}$ is the distortion noise, tr is the trace vector, $A = d^{*}RZ^{-1}$ and $\psi = \rho^{\text{UE}}\kappa_{\text{r}}^{\text{BS}}R_{\text{diag}} + S + \sigma_{\text{BS}}^2 I \cdot \rho$ pilot power, σ is the variance of noise, and S is the covariance matrix of noise. In Table 1, the uplink channel capacity and downlink channel capacity are given only for a single subcarrier. If we consider the above channel capacity for the multisubcarrier (M) using the multiplexing with orthogonality, then the proposed uplink channel capacity and downlink channel capacity are given by (5) and (6), respectively:

$$C_{\text{M-MIMO-OFDM}}^{\text{uplink}} = \frac{1}{M}\sum_{j=0}^{M-1}\frac{T_{\text{data}}^{\text{UL}}}{T_{\text{coher}}}\text{Log}_2\left(1 + \frac{\lvert E\{\varnothing(j)\}\rvert^2 + O(1/\sqrt{N})}{(1+\kappa_t^{\text{UE}})E\{\varnothing\lvert(j)\rvert^2\} - \lvert E\{\varnothing(j)\}\rvert^2 + O(1/\sqrt{N} + 1/N^{1-n})}\right), \tag{5}$$

$$C_{\text{M-MIMO-OFDM}}^{\text{downlink}} = \frac{1}{M}\sum_{j=0}^{M-1}\frac{T_{\text{data}}^{\text{DL}}}{T_{\text{coher}}}\text{Log}_2\left(1 + \frac{\lvert E\{\varnothing(j)\}\rvert^2 + O(1/\sqrt{N})}{(1+\kappa_t^{\text{UE}})E\{\lvert\varnothing(j)\rvert^2\} - \lvert E\{\varnothing(j)\}\rvert^2 + O(1/\sqrt{N} + 1/N^{1-n})}\right). \tag{6}$$

In (3), P is the total emitted power and its value for the per-subcarrier antenna selection and bulk antenna selection techniques is given by (1) and (2), respectively. In this, average power (Joule/channel use) consumed by the amplifier (P_{amp}) is defined as the ratio of energy consumed (per coherence period) in the amplifier of transmitters to the total coherence period for the uplink or downlink system as shown in the following equation [12]:

$$P_{\text{amp}} = \frac{E_{\text{amp}}}{T_{\text{coher}}}, \tag{7}$$

where E_{amp} and T_{coher} can be expressed as shown in (8) and (9), respectively [12]:

$$E_{\text{amp}} = \left(T_{\text{pilot}}^{\text{UL}} + T_{\text{data}}^{\text{UL}}\right)\frac{\rho^{\text{UE}}}{\omega^{\text{UE}}} + \left(T_{\text{pilot}}^{\text{DL}} + T_{\text{data}}^{\text{DL}}\right)\frac{\rho^{\text{BS}}}{\omega^{\text{BS}}}, \tag{8}$$

$$T_{\text{coher}} = T_{\text{data}}^{\text{UL}} + T_{\text{pilot}}^{\text{UL}} + T_{\text{data}}^{\text{DL}} + T_{\text{pilot}}^{\text{DL}}. \tag{9}$$

If we put E_{amp} and T_{coher} as given by (8) and (9), respectively, into (7), then we can represent the average power consumed by the amplifier (P_{amp}) as

$$\begin{aligned}
P_{\text{amp}} &= \frac{\left(T_{\text{pilot}}^{\text{UL}} + T_{\text{data}}^{\text{UL}}\right)(\rho^{\text{UE}}/\omega^{\text{UE}}) + \left(T_{\text{pilot}}^{\text{DL}} + T_{\text{data}}^{\text{DL}}\right)(\rho^{\text{BS}}/\omega^{\text{BS}})}{T_{\text{coher}}}, \\
&= \left[\frac{T_{\text{pilot}}^{\text{DL}}}{T_{\text{coher}}}\left(\frac{\rho^{\text{BS}}}{\omega^{\text{BS}}}\right) + \frac{T_{\text{pilot}}^{\text{UL}}}{T_{\text{coher}}}\left(\frac{\rho^{\text{UE}}}{\omega^{\text{UE}}}\right)\right] + \left[\frac{T_{\text{data}}^{\text{DL}}}{T_{\text{coher}}}\left(\frac{\rho^{\text{BS}}}{\omega^{\text{BS}}}\right) + \frac{T_{\text{data}}^{\text{UL}}}{T_{\text{coher}}}\left(\frac{\rho^{\text{UE}}}{\omega^{\text{UE}}}\right)\right], \\
&= [\alpha_{\text{UL}} + \alpha_{\text{DL}}]\left[\frac{T_{\text{pilot}}^{\text{DL}}}{T_{\text{coher}}}\left(\frac{\rho^{\text{BS}}}{\omega^{\text{BS}}}\right) + \frac{T_{\text{pilot}}^{\text{UL}}}{T_{\text{coher}}}\left(\frac{\rho^{\text{UE}}}{\omega^{\text{UE}}}\right)\right] + \left[\frac{T_{\text{data}}^{\text{DL}}}{T_{\text{coher}}}\left(\frac{\rho^{\text{BS}}}{\omega^{\text{BS}}}\right) + \frac{T_{\text{data}}^{\text{UL}}}{T_{\text{coher}}}\left(\frac{\rho^{\text{UE}}}{\omega^{\text{UE}}}\right)\right],
\end{aligned} \tag{10}$$

where $\alpha_{UL} + \alpha_{DL} = 1$ and α_{UL} and α_{DL} are the ratios of uplink and downlink transmission as shown in (11) and (12), respectively [12]:

$$\alpha_{UL} = \frac{T_{data}^{UL}}{T_{data}^{UL} + T_{data}^{DL}}, \quad (11)$$

$$\alpha_{DL} = \frac{T_{data}^{DL}}{T_{data}^{DL} + T_{data}^{UL}}. \quad (12)$$

Also, the average uplink and downlink power consumed by the amplifier (P_{amp}) can be equated from (7) and is represented by (13) and (14) [12]:

$$P_{amp}^{UL} = \alpha_{UL}\left[\frac{T_{pilot}^{DL}}{T_{coher}}\left(\frac{\rho^{BS}}{\omega^{BS}}\right) + \frac{T_{pilot}^{UL}}{T_{coher}}\left(\frac{\rho^{UE}}{\omega^{UE}}\right)\right] + \frac{T_{data}^{UL}}{T_{coher}}\left(\frac{\rho^{UE}}{\omega^{UE}}\right), \quad (13)$$

$$P_{amp}^{DL} = \alpha_{DL}\left[\frac{T_{pilot}^{DL}}{T_{coher}}\left(\frac{\rho^{BS}}{\omega^{BS}}\right) + \frac{T_{pilot}^{UL}}{T_{coher}}\left(\frac{\rho^{UE}}{\omega^{UE}}\right)\right] + \frac{T_{data}^{DL}}{T_{coher}}\left(\frac{\rho^{UE}}{\omega^{UE}}\right). \quad (14)$$

Table 2: Proposed EE expression of the M-MIMO-OFDM system with per-subcarrier and bulk antenna selection schemes.

Serial Number	Energy efficiency
1	$E_{bulk}^{uplink} = C_{M\text{-}MIMO\text{-}OFDM}^{uplink}/n_{Tx}P_{amp}^{DL} + P_{ctx} + n_{Rx}P_{crx} + (\lambda + N\gamma)$
2	$E_{bulk}^{downlink} = C_{M\text{-}MIMO\text{-}OFDM}^{downlink}/n_{Tx}P_{amp}^{DL} + P_{ctx} + n_{Rx}P_{crx} + (\lambda + N\gamma)$
3	$E_{per}^{downlink} = C_{M\text{-}MIMO\text{-}OFDM}^{downlink}/n_{Tx}P_{amp}^{DL} + n_{Tx}P_{ctx} + n_{R}xP_{crx} + (\lambda + N\gamma)$
4	$E_{per}^{uplink} = C_{M\text{-}MIMO\text{-}OFDM}^{uplink}/n_{Tx}P_{amp}^{DL} + n_{Tx}P_{ctx} + n_{Rx}P_{crx} + (\lambda + N\gamma)$

Now, if we put P_{total}^{bulk} and $C_{M\text{-}MIMO\text{-}OFDM}^{UL}$ as given by (2) and (5), respectively, into (3), then we can express the uplink EE of the M-MIMO-OFDM system for the bulk antenna selection by the equation below:

$$\begin{aligned} E_{bulk}^{uplink} &= \frac{1/M\sum_{j=0}^{M-1} T_{data}^{UL}/T_{coher}\text{Log}_2\left(1 + \left(\left|E\{\varnothing(j)\}\right|^2 + O(1/\sqrt{N})\right)/\left(\left(1+\kappa_t^{UE}\right)E\left\{\left|\varnothing(j)\right|^2\right\} - \left|E\{\varnothing(j)\}\right|^2 + O\left(1/\sqrt{N} + 1/N^{1-n}\right)\right)\right)}{n_{Tx}P_{amp}^{UL} + P_{ctx} + n_{Rx}P_{crx} + P_{bb}}, \\ &= \frac{1/M\sum_{j=0}^{M-1} T_{data}^{UL}/T_{coher}\text{Log}_2\left(1 + \left(\left|E\{\varnothing(j)\}\right|^2 + O(1/\sqrt{N})\right)/\left(\left(1+\kappa_t^{UE}\right)E\left\{\left|\varnothing(j)\right|^2\right\} - \left|E\{\varnothing(j)\}\right|^2 + O\left(1/\sqrt{N} + 1/N^{1-n}\right)\right)\right)}{n_{Tx}P_{amp}^{UL} + P_{ctx} + n_{Rx}P_{crx} + (\lambda + N\gamma)}, \\ &= \frac{C_{M\text{-}MIMO\text{-}OFDM}^{UL}}{n_{Tx}P_{amp}^{UL} + P_{ctx} + n_{Rx}P_{crx} + (\lambda + N\gamma)}, \end{aligned} \quad (15)$$

where

$$C_{M\text{-}MIMO\text{-}OFDM}^{uplink} = \frac{1}{M}\sum_{j=0}^{M-1}\frac{T_{data}^{UL}}{T_{coher}}\text{Log}_2\left(1 + \frac{\left|E\{\varnothing(j)\}\right|^2 + O(1/\sqrt{N})}{\left(1+\kappa_t^{UE}\right)E\left\{\left|\varnothing(j)\right|^2\right\} - \left|E\{\varnothing(j)\}\right|^2 + O\left(1/\sqrt{N} + 1/N^{1-n}\right)}\right). \quad (16)$$

In above equation (15), the baseband circuit power (P_{bb}) is expressed as $\lambda + N\gamma$, where N represents the number of baseband antennas and λ and γ both are the circuit power parameters. In the similar fashion, other uplink and downlink EE equations of the M-MIMO-OFDM system with per-subcarrier selection and bulk antenna selection schemes can be derived. These equations are summarized in Table 2.

Now, we also consider the impact of power optimization and hardware degradation on the above EE equations of the M-MIMO-OFDM system. Here, the power is optimized for a range of power x using the minimum scalar function of EE as shown in the following equation [11, 12]:

$$\text{Power}_{opt} = \min \text{EE}(x), \quad 0 < x < 1. \quad (17)$$

Also, the hardware degradation effect on the EE is analyzed through various values of the scaling factor g ($g \cdot \varepsilon$ {0, 1/4, and 1/2}) and by using the power scaling law as shown in the following equation [11, 12]:

$$\text{Power}_{scaled} = \text{Power}_{opt} \times \frac{1}{N^g}. \quad (18)$$

In (18), the scaling factor (g) increases with increase in the value of hardware degradation.

4. Results and Discussion

In this section, firstly the EE of the M-MIMO-OFDM system is analyzed with respect to the number of BSA using a range of hardware impairments (kappa = 0, 0.05^2, and 0.1^2) for optimized power. Here, we also examine the EE with respect to antenna selection schemes like per-subcarrier selection and bulk antenna selection. The simulation results are shown in Figures 2 and 3. Secondly, we analyze the EE with respect to

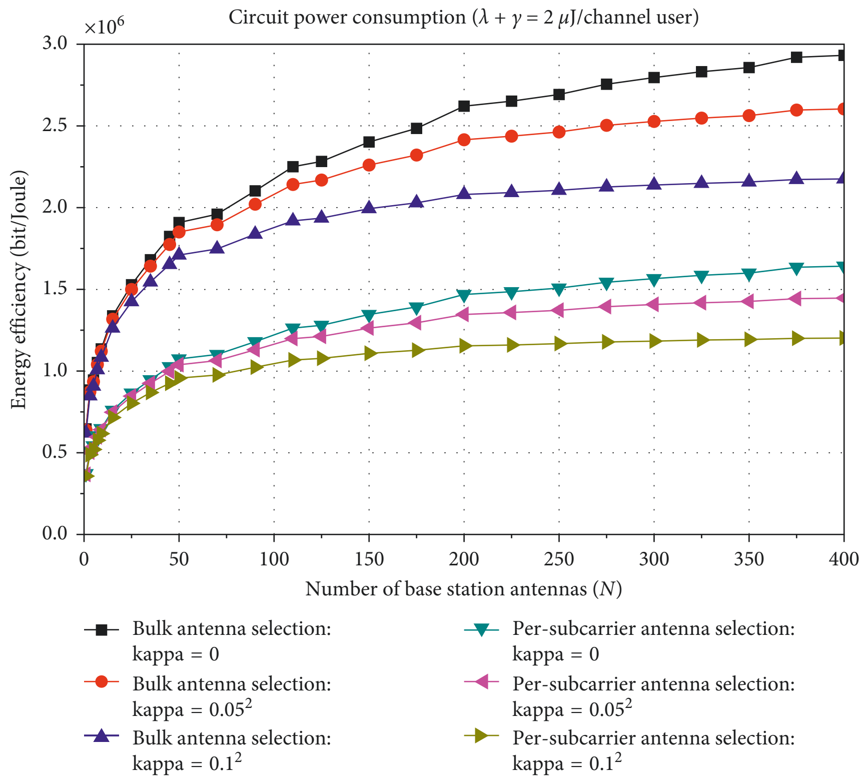

FIGURE 2: Energy efficiency of the massive MIMO-OFDM channel versus the number of BSA for per-subcarrier selection and bulk antenna selection techniques using various hardware impairments (kappa = 0, 0.05^2, and 0.1^2) at total circuit power ($\lambda + \gamma = 2\ \mu$J/channel user).

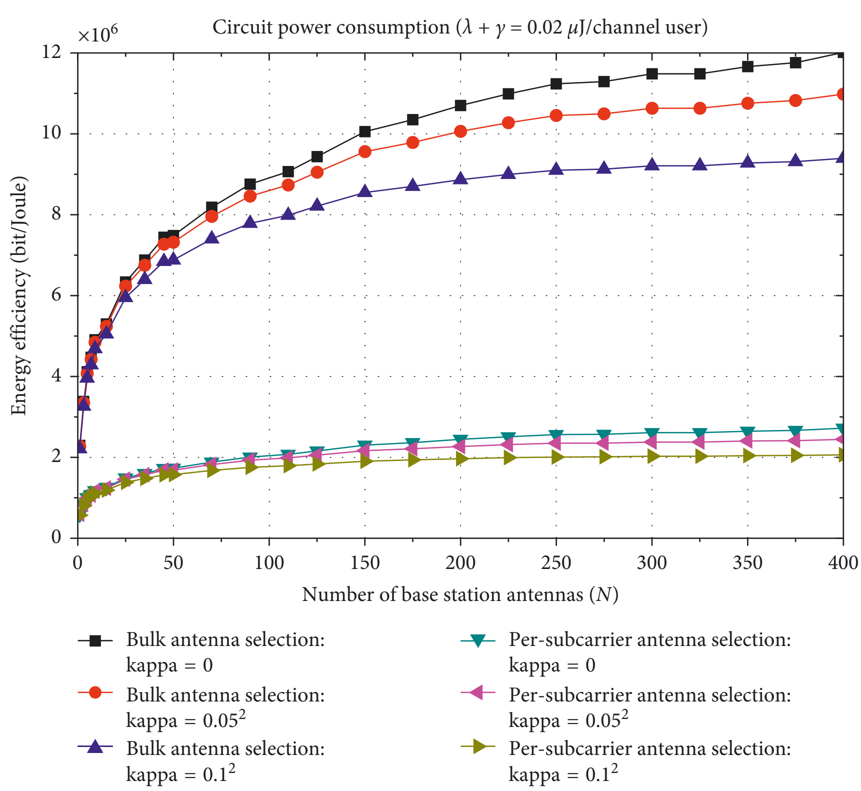

FIGURE 3: Energy efficiency of the massive MIMO-OFDM channel versus the number of BSA for per-subcarrier selection and bulk antenna selection techniques using various hardware impairments (kappa = 0, 0.05^2, and 0.1^2) at total circuit power ($\lambda + \gamma = 0.02\ \mu$J/channel user).

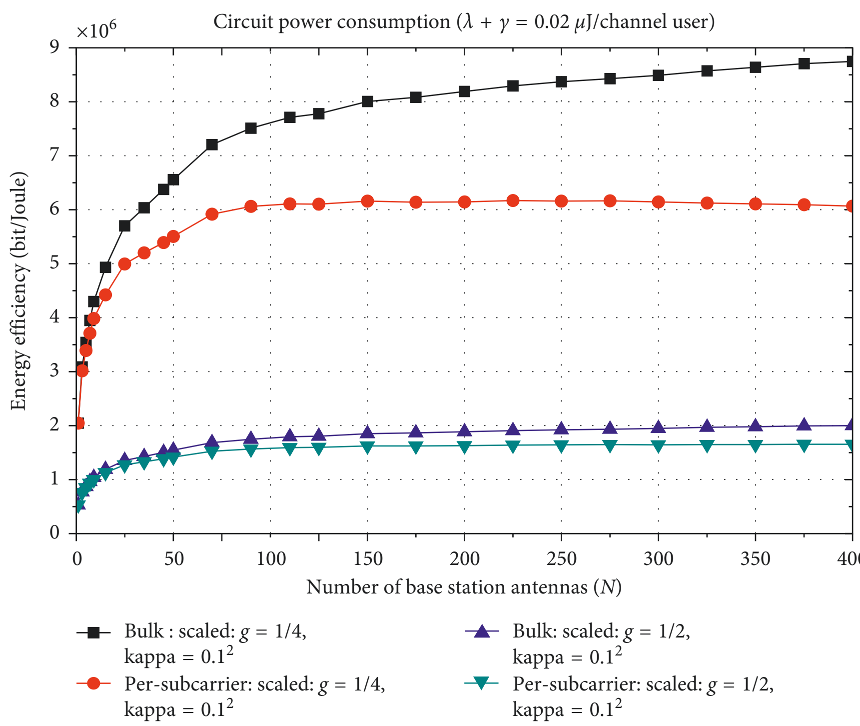

FIGURE 4: Energy efficiency of the massive MIMO-OFDM channel versus the number of BSA for per-subcarrier selection and bulk antenna selection techniques using various power scaling factors ($g = 0.25$ and $t = 0.5$) at hardware impairments ($\text{kappa} = 0.1^2$) and total circuit power ($\lambda + \gamma = 0.02\,\mu$J/channel user).

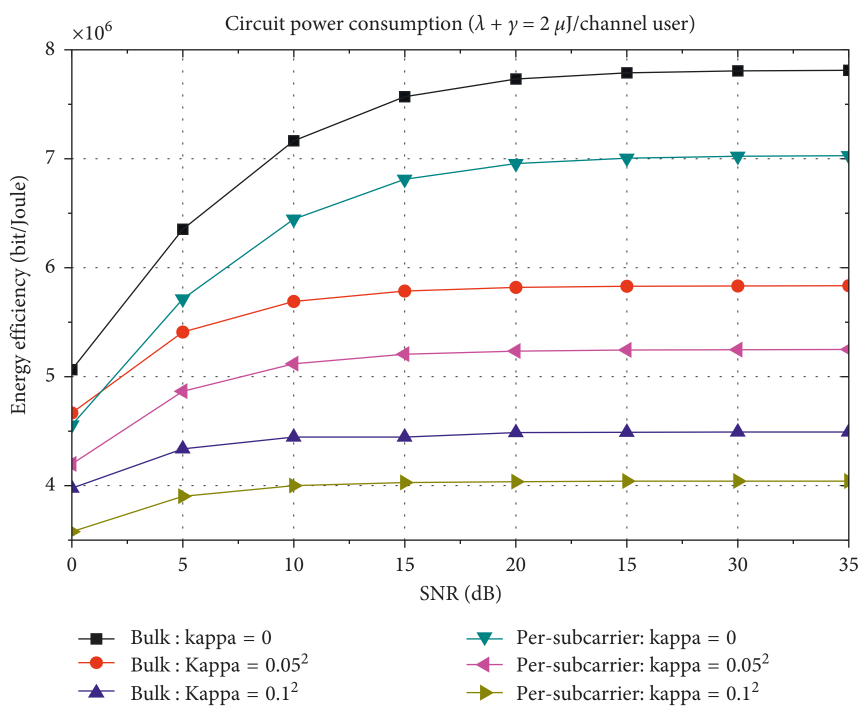

FIGURE 5: Energy efficiency of the massive MIMO-OFDM channel versus the SNR for per-subcarrier selection and bulk antenna selection techniques using various hardware impairments ($\text{kappa} = 0, 0.05^2$, and 0.1^2) at total circuit power ($\lambda + \gamma = 2\,\mu$J/channel user).

the number of BSA for the various power scaling factors, that is, $g = 0.25$ and $t = 0.5$, in Figure 4. In the last, we analyze the EE with respect to the SNR using various parameters like antenna selection and hardware impairments for the total circuit power consumption $(\lambda + \gamma)$ $2\,\mu$J/channel user and $0.02\,\mu$J/channel user in Figures 5 and 6, respectively.

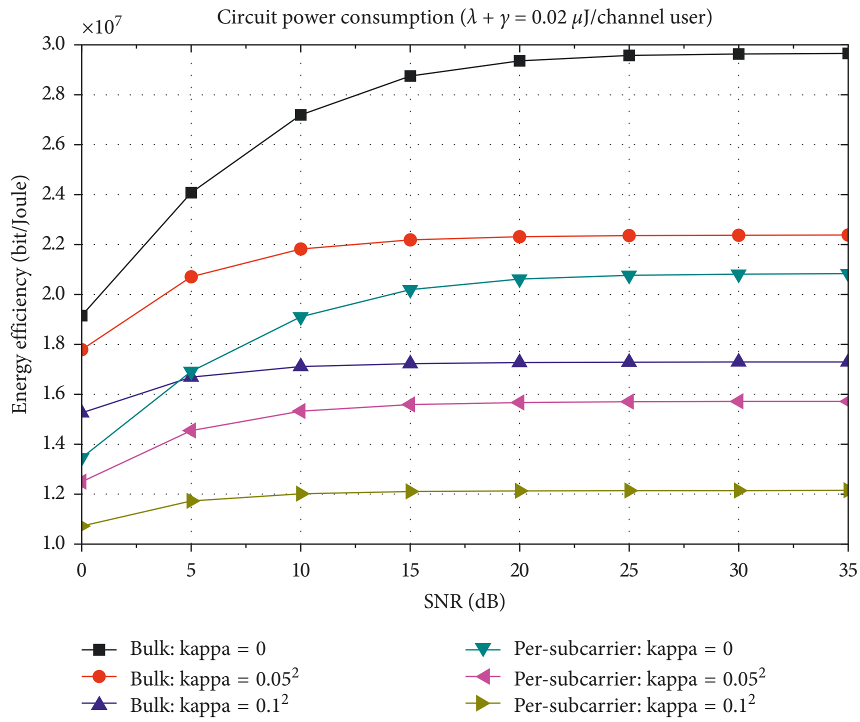

FIGURE 6: Energy efficiency of the massive MIMO-OFDM channel versus the SNR for per-subcarrier selection and bulk antenna selection techniques using various hardware impairments (kappa = 0, 0.05^2, and 0.1^2) at total circuit power ($\lambda + \gamma = 0.02\,\mu$J/channel user).

4.1. Energy Efficiency versus Number of Base of Station Antenna. Figures 2 and 3 depict the EE of the M-MIMO-OFDM system with respect to the number of BSA using power optimization for the total circuit power ($\lambda + \gamma$) $2\,\mu$J/channel user and 0.02 μJ/channel user, respectively. Here, the power optimization provides a required minimum power for examining the EE using the minimum scalar function as defined in (16). As we compare Figures 2 and 3, it is observed that the EE is almost 75% more for the lower value of circuit power consumption ($\lambda + \gamma$), that is, $0.02\,\mu$J/channel user. Also, the bulk antenna selection technique has comparatively more EE than the per-subcarrier antenna selection, and the EE increases with the increase in the value of the number of BSA. But the EE decreases with the increase in the value of the hardware impairments (kappa = 0, 0.05^2, and 0.1^2).

In Figure 4, we analyze the EE of the M-MIMO-OFDM system for bulk antenna selection and per-subcarrier antenna selection techniques with respect to the number of BSA using various power scaling factors, that is, $g = 0.25$ and $t = 0.5$. Here, the power scaling factor increases with increase in the hardware degradation. In the simulation result, it is observed that the EE increases with the increase in the value of the number of BSA, and the bulk antenna selection technique is again found to be more energy efficient than the per-subcarrier antenna selection. However, the EE decreases with the increase in the value of the power scaling factor.

4.2. Energy Efficiency versus SNR. Here, the EE of the M-MIMO-OFDM system is analyzed with respect to the SNR for the total circuit power consumption ($\lambda + \gamma$) $2\,\mu$J/channel user and $0.02\,\mu$J/channel user in Figures 5 and 6, respectively. The results in Figures 5 and 6 show that the EE increases very sharply with the increase in the value of the SNR from 0 to 15 dB. However, it remains almost constant during higher SNR values, that is, 15 to 35 dB. However, it decreases with the increase in the value of hardware impairments (kappa = 0, 0.05^2, and 0.1^2). Also, it is noticed that the EE gap between the antenna selection schemes decreases with the increase in the value of hardware impairments. As we compare Figures 5 and 6, it is again concluded that the EE is more for the lower value of circuit powers, that is, ($\lambda + \gamma$) $0.02\,\mu$J/channel user consumption.

5. Conclusion

In this paper, we have investigated the EE of the M-MIMO-OFDM system for antenna selection schemes like bulk antenna selection and per-subcarrier antenna selection using a range of hardware impairments (kappa = 0, 0.05^2, and 0.1^2). The EE is affected by several important parameters such as SNR, number of BSA, antenna selection schemes, total circuit power consumption, power optimization, power scaling factor, and level of hardware impairments. In the M-MIMO-OFDM system, hardware complexity and its cost is a biggest challenge to the researcher. Also, it increases with an increase in the number of BSA. To mitigate the hardware cost and complexity problem, an M-MIMO-OFDM system was proposed with antennas selection schemes like bulk antenna selection and per-subcarrier antenna selection and a new EE equation has been derived by considering antenna selection and hardware impairments. The simulation results prove that the EE increases with the increase in the value of the SNR and the number of BSA. However, at high SNR values, hardware impairments limit EE, and the EE decreases with the increase in the value of hardware impairments and the power scaling factor ($g = 0.25$ and $t = 0.5$). If we further compare both the antenna selection schemes, then our results show that the bulk antenna selection technique has comparatively more EE than the per-subcarrier antenna selection. It has also been observed that the EE gap between the antenna selection technique decreases with the increase in the value of hardware impairments. Furthermore, it has been observed that the EE is 75% more for the lower value of circuit power ($\lambda + \gamma$), that is, $0.02\,\mu$J/channel user consumption as compared to $2\,\mu$J/channel user circuit power consumption.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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