# Optimal Transmit Antenna Selection for Massive MIMO Systems

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**Abstract.** Antenna selection in Multiple input Multiple Output (MIMO) is a signal processing method in which the elements of Radio Frequency (RF) chain are switched to their corresponding subset of antennas. Due to the large number of RF transceivers, antenna selection resolves the complexity and power consumption. In this paper, a sub-optimal antenna selection algorithm that combines two selection techniques is proposed. The algorithm leverages the use of minimum signal to noise ratio (SNR) at the cell edge and dynamic channel condition due to mobility. To apply fractional transmit power re-allocation at sub 6 GHz and mmWave frequencies, the same number of RF components are set to be active and the rest to sleep mode after adaptive selection. As a result, the branch in the array with the best signal quality is chosen and applied in iteration until the desired value is reached however re-selection boosts EE at the expense of total rate. In comparison to complete array consumption and random selection, the results show that the algorithm outperforms random selection and achieves higher energy efficiency. Furthermore, capacity loss due to selection is offset by using nonlinear precoding at the expense of complexity.

**Keywords:** Antenna selection · Energy efficiency · Massive MIMO · mmWave · Precoding

## 1 Introduction

Massive MIMO (mMIMO) is a large-scale MIMO device that is becoming more common in wireless communications. It potentially scales up traditional MIMO by orders of magnitude. Itconsiders multi-user MIMO, in which a base station has hundreds of thousands of antennas supporting multiple single-antenna users in the same time-frequency resource [1,2]. A device with a large number of base sta- tion antennas will increase connection reliability, spectral quality, and radiated energy efficiency [3]. Each antenna element is linked to a single RF


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chain at the base station, which comprises an amplifier, an analog-to-digital converter (ADC), and mixers. RF chains are generally expensive and power-hungry as a result of these characteristics. Furthermore, because of the high power consumption, increasing the number of antennas at the base station will result in physical restrictions, complexity, and expense. RF chains, in particular, are responsible for 50–80% of total transceiver power consumption [4]. As a result, antenna selection could be a viable option for ad- dressing the inherent hardware complexities of massive MIMO while still taking advantage of the increased degrees of freedom provided by the base station's antenna excesses.

For the classic MIMO, a variety of antenna selection standards and algorithms have been investigated over the last few decades. In [5], basic selection algorithms for realistic detectors were used to investigate error-rate directed antenna selection. Many studies promoted capacity-oriented selection criteria like the greedy algorithm and convex optimization [6–8]. The author of [9] presented an antenna selection technique (AS) with a minimal level of complexity that picks antennas that minimize constructive user interference. When used in conjunction with a simple matched filter (MF) precoder at the transmitter, the suggested AS algorithm outperformed systems that used a more complicated channel inversion method (CI). The work in [10,11] aimed to remove the destructive portion of interference, which was established by the connection between the sub streams of a modulated MIMO PSK transmission.

The authors in [12] presented a distance based selection algorithm with spatial modulation in the process of optimization. The algorithm uses a singular value decomposition in order to minimize complexity and symbol error rate compared to the exhaustive search. In this article, the down-link massive MIMO system's transmit antenna selection is considered. The procedure is divided into three parts: first, the EE of a full array device is evaluated at the cell edge using an equivalent power allocation technique, and then an optimal number of BS antennas that retains the optimal value is calculated. Second, minimum threshold SNR is cal- culated using the optimum number of antennas (M*) as a benchmark to further reduce M*. For each mobile terminal, free space path-loss (FSPL) and Close-In (CI) path-loss (PL) models are used, with adaptive power allocation based on PL and minimum obtained power at the edge. Finally, after re-identifying M*, the antenna elements with best gains are employed, and EE is assessed at various frequency ranges using spatial selectivity. The rest of the work is structured as follows: A system model for mMIMO antenna selection is defined in section two. In sections three and four, the proposed technique's sum rate and EE are tested, and the effects are then illustrated in Sect. 5. In Sect. 6, the overall work is summarized and conclusions are drawn.

## 2 System Description

There are two sections of the system description. A signal model for a downlink large MIMO device is presented with antenna selection. Then the mathematical formulations for the selection is analyzed and simulated with different scenarios.

### 2.1 System Model

This channel model uses only free space LoS transmission between the BS and user terminals. The BS has a ULA with a $\lambda$ spaced M antennas, where $\lambda$ is the signal wavelength and the mutual resonance effect between antenna element is ignored. Inside the cell, there are K single-antenna devices that transmit data to the BS at the same time using the same time-frequency resources. Furthermore, it is believed that all of the K devices served by the BS are located at different angles on the antenna array's far-field and experience large and small scale fading. The downlink For a single- cell massive MIMO structure, Mo RF chains associated with $K(K \leq MoM^o)$ are considered.

### 2.2 Mobile Location Positioning

In today's cellular networks, identifying a mobile position is a critical problem. Angle of Arrival (AoA), Time of Arrival (ToA), and GPS are among the techniques used. In general, there are three methods for determining the location of a mobile terminal: satellite positioning, cellular network-based positioning, and indoor positioning. The trilateration method is used to calculate a mobile's location using the relative position of a base station (BS). Unlike the triangulation process, which requires the angle of each user for position tracking, only the distance between the BS and each user is needed in this case.

### 2.3 Close-In(CI) Path Loss Model

The CI model is based on Friis and Bullington's fundamental radio propagation concepts, wherein the PLE gives insight into route loss dependant on environment. Previous UHF models applied 1–100 m as CI reference distance since BS tower was tall and inter-site distances for certain frequency bands were many kilometers [14]. The CI 1m reference distance, as proposed in [15], is a suitable recommended norm that relates the real path loss to a practical CI distance of 1m. Standardization to a 1m reference distance simplifies dimension and model comparisons, provides a consistent description for the PLE, and allows for simple and quick route loss estimates without the need of a calculator. In a given situation, the CIPL model is a generic frequency model that explains large scale transmission path loss at all relevant frequencies. The equation for the CI model is as follows: simpler, gives a consistent description for the PLE, and allows for intuitive and quick path loss computation without the need of another computations. There will be few users within a few meters of the base station antenna in emerging mmWave mobile systems, and close-in users in the near field will have strong signals or be power-controlled compared to typical users much farther from the transmitter and so that any path loss error in the near field will be much smaller than the dynamic range of signals. The general formula for CIPL according to [14] is given by

$$PL_{dB}^{CI} = FSPL_{dB} + 10nlog_{10}(d) + \chi_a^{CI} \tag{1}$$

where $n = \dfrac{\sum(DA)}{\sum(D^2)}$ , $A = PL^{CI}(f, d)_{dB} - FSPL(f, 1m)$, $10log_{10}d$ indicates the single model criterion, the path loss exponent (PLE), with 10n defining path loss in dB in terms of decades of distances starting at 1m (making power over distance very easy to compute and the loss model for free space is stated as

$$FSPL_{dB} = 20log10(4\pi/\lambda) \tag{2}$$

This is worth noting as the CI model is described on the basis of an inherent frequency dependent path loss contained into 1 m FSPL as a single parameter to optimize opposed to the ABG model. Table 1 shows the frequency ranges to be used in CI pathloss model in urban micro for street canyon (UMi-SC) and open space (UMi-OS) at line of sight (LOS) and non line-of-sight (NLOS) environments respectively [15]. As shown in the table, the CI model provides path loss exponent (PLE) of 2.0 and 1.9 in LOS, which approaches the FSPL.

**Table 1.** Parameters for CI path loss model [41].

| Scenarios | Frequency (GHz) | Distance (m) | PLE/$\alpha$ | $\sigma_{dB}^{CI}$ |
|---|---|---|---|---|
| UMi-SC LOS | 2–73.5 | 5–121 | 2.0 | 2.9 |
| UMi-SC NLOS | 2–73.5 | 19–272 | 3.1 | 8.0 |
| UMi-OS LOS | 2–60 | 5–88 | 19 | 4.7 |
| UMi-OS NLOS | 2–73.5 | 8–235 | 2.8 | 8.3 |
| UMa LOS | 2–73.5 | 58–930 | 2.0 | 4.6 |
| UMa NLOS | 2–73.5 | 45–1429 | 2.7 | 10.0 |

### 2.4 Trilateration Based Antenna Selection

The number of antennas to be chosen is determined by adjusting an appropriate amount of transmit power to be radiated by only the selected number of antennas during the selection process. Trilateration is used to pinpoint a user's position so that the main beam can focus only on the target region, reducing leakage. The transmit power adapts when the user's location changes as a function ofdistance due to user mobility. In this case, instead of using all arrays and wasting resources, the number of transmit antennas can be decreased adaptively as the consumer gets closer to the center of the BS, using the minimum SNR at the cell edge as a threshold value. In comparison, when allocating maximum transmit power based on edge distance, the BS only allocates power proportional to the reduced distance, resulting in only a few antennas being activated, as described in (3). After that, using factorial permutations as $\binom{M}{N} = \dfrac{M!}{N!(M-N)!}$, the antennas with the best channel gains are chosen from the list.

$$N = (\frac{M * \sum_{i=1}^{K} p_t/K}{P_T}) \tag{3}$$

where $p_t$ is the transmit power adjusted for each user based on path loss, $P_T$ is the total transmit power and $N = M^o$ is the number of RF chain components. The selection process for the whole system is stated in a sub optimal algorithm I below.

**Algorithm I: Sub Optimal Algorithm**

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1. Initialize: R, M, K, $Cap_i \leftarrow 0$, $\gamma$ $P_t$, B, $p_{amp}$, $p_{bb}$, $p_{syn}$, $p_{dac}$, $p_{mix}$, $p_{filt}$
2. **For** l = 1 : length (M) **do**
3. $p_{tot} \leftarrow p_{amp} + (p_{bb} + p_{syn}) + (\ell * (p_{dac} + p_{mix} + p_{filt}))$
4. $H \leftarrow (randn(K, \ell) + j * randn(K, \ell))$
5. $R(\ell) = log_2(real(det(I + (\frac{\gamma_{sel}}{\ell}) * HH')))$
6. $EE \leftarrow \frac{R(\ell)}{P_{total}(\ell)}$
7.End **for**
8. $M^* \leftarrow \ell(find(EE == max(EE)))$
9. Find r of $k_x$ using trilateration and $\Gamma(R)$ for cell edge user
10. $P_{rmin} \leftarrow P_{tmax}/\Gamma(R)$
11. $Pt_r \leftarrow \Gamma_r * Pr_{min}$
12. $M_1^o = \frac{M * \sum_{i=1}^{K} P_t/K}{P_T}$
13. $M_2^o \leftarrow round(\sum(\Gamma(r))/K) * M/\Gamma(R)$
14. **If** $M^o \neq M^o$ **goto** 9
15. Else $M^o \leftarrow M_1^o$ ; Selecting $M^o$ best branches among M.
16. **For** $\gamma = 1 : M^o$ **do**
17. $H = (rand(K; M) + j * rand(K, M))/\sqrt{M^o})$;
18. **For** $M_i^o = 1 : M^o$
19. $H_c = [H :; [MoiM - i]]$.... Select column with maximum capacity.
20. $C(m) = log_2(real(det(I + \gamma * H_c * H_c')))$
21. End **for**
22. $C_{max} = max(C(m))$; Calculating maximum Capacity.
23. $M_i^o \leftarrow find(C = Cmax)$
24. End **for**
25. $C(\gamma) \leftarrow C$
26. End **if**

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In the algorithm, $\Gamma(r)$, $\Gamma(r)$ and is SNR in dB at cell edge and at reduced distance respectively..

## 3 Sum Rate Evaluation

There are M antennas on the base station, and each antenna has its own transceiver chain. The N matching transceivers are turned on when N antennas are selected, while the other $M - N$ are turned off. In the same time-frequency resources, this base station with N operational antennas and transceivers supports K single-antenna users. With massive MIMO, $M \gg K$ and N should be within the range of K to M. Where N, K is the number of antennas to be selected and the total number of single antenna user terminals. The received signal at the BS can be stated as

$$\hat{y}_l = \sqrt{\rho K} H_l^{(N)} \hat{z}_l + \hat{n}_l \tag{4}$$

where $H_l^N$is a KxN channel vector at carrier $\ell$ and the superscript N shows that antennas are selected such that $H_l^N$ are chosen from the KxM full vector or matrix $H_l$. The components of $H(N)l$ are normalized such that they have the same size, same energy across all sub-carriers, antennas, and K user terminals. The Nx1 transmit vector over the N chosen antennas is thus $z_l$, which satisfies $\mathbb{E}\{||z_l||^2\} = 1$. The transmit power is represented by the factor $\rho_K$. The transmit power per user is managed using the rules in [16]. As a result, the overall transmission power rises with uplink terminals and unaffected by N. The normalized transmit SNR per user is represented by the parameter $\rho$. The average per-user received SNR with random antenna selection is $\rho N$ and enhances the number of chosen antenna elements N owing to higher branch gains. If only a limited number of RF chains are activated and the number of users K changes, the average peruser received SNR stays unchanged, as does the average peruser rate (ignoring interference).

Because the "best" antennas are picked, the resulting SNRs should be greater with smart antenna selection than with random antenna selection. To prevent favoring users with a sufficient average gain, normalization of the array matrix is utilized to combat the impacts of pathloss and large scale obstructions [15]. Normalization is conducted when users are both far and close to the base station. However, since channel differences among antennas are crucial for selection scenario, they should never be put on an equal basis.

### 3.1 Dirty Paper Coding Sum Capacity($C_{DPC}$)

The down-link sum capacity for DPC is [7]:

$$C_{DPC_l} = \max_{P_l} \log_2 det\left(I + \rho K (H_l^{(N)})^H P_l H_l^{(N)}\right) \tag{5}$$

which is achieved using dirty-paper coding (DPC) [9]. The diagonal optimal control matrix $Pl, i$ in (5) has $Pl, i$ I = 1, 2,...K. The optimization is also done with the total power restriction $sumi = 1KPl, i = 1$ in mind. This convex optimization issue may be addressed with iterative water filling technique to sum power. In practice, DPC is quite difficult to execute. However, there are inferior linear precoding methods that are significantly less complicated and work rather well for large MIMO, such as zero-forcing (ZF) precoding.

### 3.2 Zero Forcing Sum Capacity($C_{ZF}$)

For ZF linear precoder, the total rate is given by [16]

$$\hat{C}_{ZF,l} = \max_{\hat{Q}_l} \sum_{i=1}^{K} log_2(1 + \rho K \hat{Q}_{l,i}), \tag{6}$$

The received signal of various user terminals are represented by $\hat{Q}_l, i$, and the maximizing is done under the total power restriction.

$$\sum_{i=1}^{K} \hat{Q}_{l,i} \left[ \left( H_l^{(N)} \left( H_l^{(N)} \right)^H \right)^{-1} \right] = 1 \tag{7}$$

$\hat{Q}_l$ is a diagonal matrix with i=1, 2,...,K, as illustrated in (6) and (7) and the diagonal, with $[.]i, i$ denoting the $i^{th}$ diagonal elements $\left( H_l^{(N)} \left( H_l^{(N)} \right)^H \right)^{-1}$ which represent the power penalty of removing the interferences.

The detected SNRs at users are influenced by the precoding method and channel condition in general. The received SNR in the single-user scenario, for example, is $\rho N$. In the multi-user case with zero-forcing precoding, the peruser received SNR is $\rho N / Tr \left( H_l^{(N)} \left( H_l^{(N)} \right)^H \right)^{-1}$, where Tr{.} represents the trace of a matrix. When the user channels are orthogonal, $H_l^{(N)} \left( H_l^{(N)} \right)^H$ is diagonal, and the average per-user received SNR reaches the upper bound given by the single-user case, i.e., $\rho N$. When the number of base station antennas increases under "favorable" situations or contexts, the user channels get orthogonal, and the average received SNR approaches this absolute limit.

The DPC sum-capacity is used as the foundation for antenna selection algorithms. However, in relevant circumstances, the performance of the resultant selection will also be assessed in terms of ZF sum-rate. On various subcarriers, different antenna configurations may be optimum. Though in a real MIMO systems, all subcarriers should use the same antennas. As a result, the DPC throughput will be enhanced through selecting the antennas only with better gains after iteration over all possible combinations. In selection process of those columns from full array of $H_l$, $M * M$ matrix $\Delta$ with binary diagonal element has been introduced.

$$\Delta_i = \begin{cases} 1, & Select \\ 0, & \text{otherwise} \end{cases} \tag{8}$$

showing whether the $i^{th}$ element is chosen, and achieving $\sum_{i=1}^{L} = N$. According to Sylvester's identity, det (I+UJ) = det (I+JU), DPC total rate can be rewritten as in (5) as

$$C_{DPC_l} = \max_{P_l} \ \log_2 det(1 + \rho K P_l H_l \Delta (H_l)^H) \tag{9}$$

where $\sum_{i=1}^{K} P_{l,i} = 1$. The desired $\Delta$ is discovered by increasing the average DPC sum rate,

$$\mho opt = \underset{\mho}{\text{argmax}} \ \frac{1}{L}\sum_{l=1}^{L} \log_2 det\Big(I + \rho K P_l H_l \mho (H_l)^H\Big) \tag{10}$$

The corresponding sum rate of ZF after selection is

$$C_{ZF,l} = \max_{Q_l} \sum_{i=1}^{K} log_2(1 + \rho K Q_{l,i}), \tag{11}$$

subject to

$$\sum_{i=1}^{K} Q_{l,i}\left[\left(H_l^{(N)}\left(H_l^{(N)}\right)^H\right)^{-1}\right]_{i,i} = 1 \tag{12}$$

Despite $\mho_{opt}$ could not be optimal for ZF, using a more realistic precoding scheme than DPC helps in achieving efficient antenna selection. Conversely, if the throughput is to be more affected due to minimized number of antennas, DPC compensates by leveraging the loss in capacity. Moreover, although an extensive search of all available permutations of N antennas would definitely produce the optimal $\mho$, as described above, such a search is very complicated and infeasible for massive MIMO. From (11) and (12), it can be seen that in ZF, zeroing the upper and lower matrix elements consumes more power, but it is still easier to process than DPC, which has no additional power penalty but is more complex.

## 4 Energy Efficiency Evaluation

The total energy efficiency of the system can be evaluated as [16]

$$EE = \frac{\sum_{k=1}^{K}\Big(E\{R_k^{ul}\} + E\{R_k^{dl}\}\Big)}{P_{Tx}^{dl} + P_{Tx}^{ul} + P_{CP} + P_{fix}} \tag{13}$$

where $P_{total} = P_{amp} + P_{CP}$ , $P_{CP} = P_{bb} + P_{syn} + M^o(P_{dac} + P_{mix} + P_{filt})$ and $P_{CP}$ accounts for the circuit power consumption. The amount of power provided by various analog components and other digital processors is referred to as $P_{amp}$. Baseband signal processing ($P_{bb}$) and synchronization ($P_{syn}$) are unaffected by the number of BS antennas in $P_{CP}$, while digital to analogue conversion power ($P_{dac}$), mixing ($P_{mix}$), and filtering ($P_{filt}$) power linearly increase with the number of BS antennas. Table 2 lists the parameters that will be used for simulation in the evaluation of EE in accordance with (13).

**Table 2.** Simulation parameters.

| Parameter | Value | Description |
|---|---|---|
| $P_{tx}$ | 5 mW | Transmission power |
| $P_{mix}$ | 0.033 | Mixing consumption |
| $P_{fil}$ | 0.02 | Filtering consumption |
| $P_{bb}$ | 0.03 | Base band signal processing power |
| $P_{syn}$ | 0.05 | Synchronization power |
| $P_{dac}$ | 0.015 | Digital to analogue conversion power |
| $P_{amp} = \frac{p_{tx}}{\eta}$ | $\eta = 0.01$ | Amplier powerr |
| $f_s$ | 2.5 GHz | Sub 6 Ghz frequency |
| $f_m$ | 37 GHz | mmWave band |

## 5 Results and Discussion

Figure 1 depicts the ergodic capacity of various MIMO configurations for the iid (independent identically distributed) channel. The capacity of massive MIMO

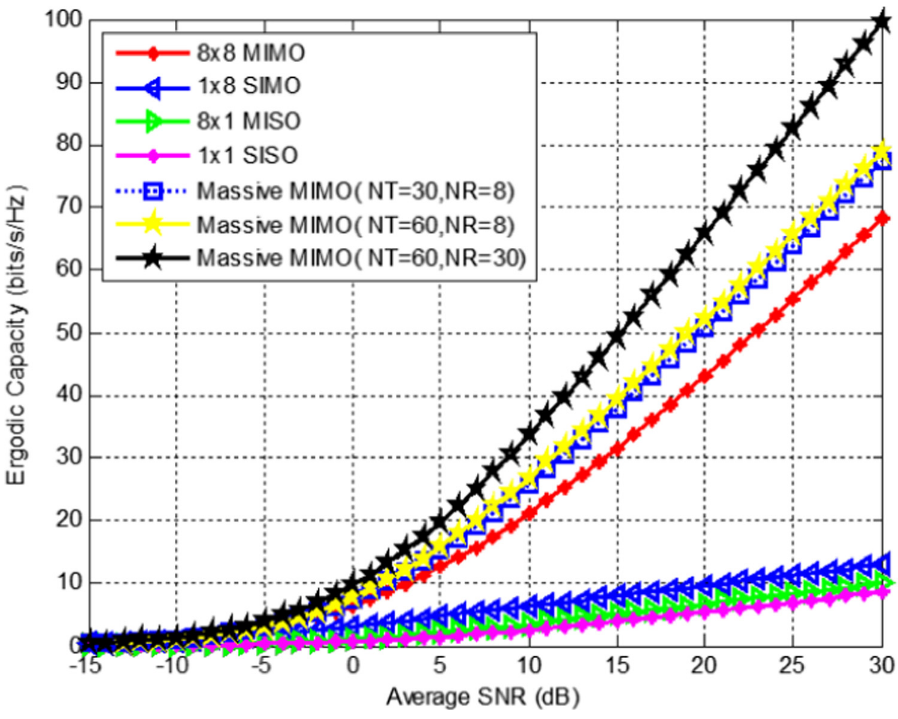


**Fig. 1.** Ergodic capacity for i.i.d. Rayleigh fast fading channel in different MIMO configurations.

systems with different number of antenna configurations is higher than classical MIMO systems as shown in the figure. Nevertheless, the difference is much smaller at lower SNR levels and can be ignored. However, as the number of BS antennas grows, so does the SNR, indicating that the system's power grows as well.

The effect of randomly selected transmit antennas on system energy efficiency is depicted in Fig. 2. The energy efficiency rises with the number of transmit antennas (M) at first, then drops abruptly after reaching an optimal point. This is because an increase in BS antennas is directly proportional to an increase in the corresponding radio frequency chain elements, which account for the majority of the system's power consumption. The optimal number of antennas ($M^* = M^o$) is also dependent on the number of user terminals (K), as shown in the diagram. For K = 5, 10, 15 and 20, M* = 5, 7, 8 and 9 respectively. This is the point at which the increase in the system's total power consumption exceeds the increase in the total rate. As a result, the number of antennas chosen should not surpass this point in order to preserve EE; however, due to processing difficulty, finding the optimal point presents its own set of challenges.

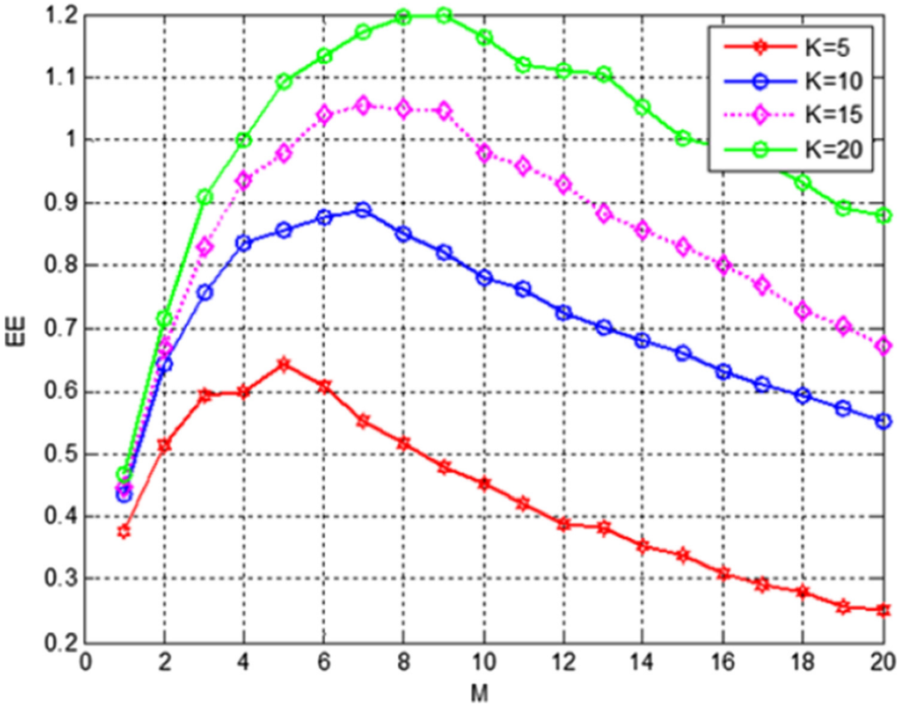


**Fig. 2.** EE at different users and BS antenna settings.

Figure 3 depicts the relationship between energy efficiency, K, and M in a massive MIMO system with statistical and instantaneous SNR values. For cell edge users in LoS conditions, the outcome is evaluated using procedures 1 to 9 of algorithm I. While the energy efficiency increases with the increase of M at first, it begins to decline at some point as M continues to increase, according to the simulation.

Furthermore, when comparing statistical and instantaneous or fixed SNR for the same K, it has been demonstrated that fixed SNR outperforms for small M and underperforms for large M. It has also been shown that EE increases as the number of user terminals increases, and that due to random channel conditions, EE exhibits different optimal points. Figure 3 depicts the optimal number of antennas ($M^o$) and maximum total power for the mmwave band at statistical, instantaneous, or fixed SNR.

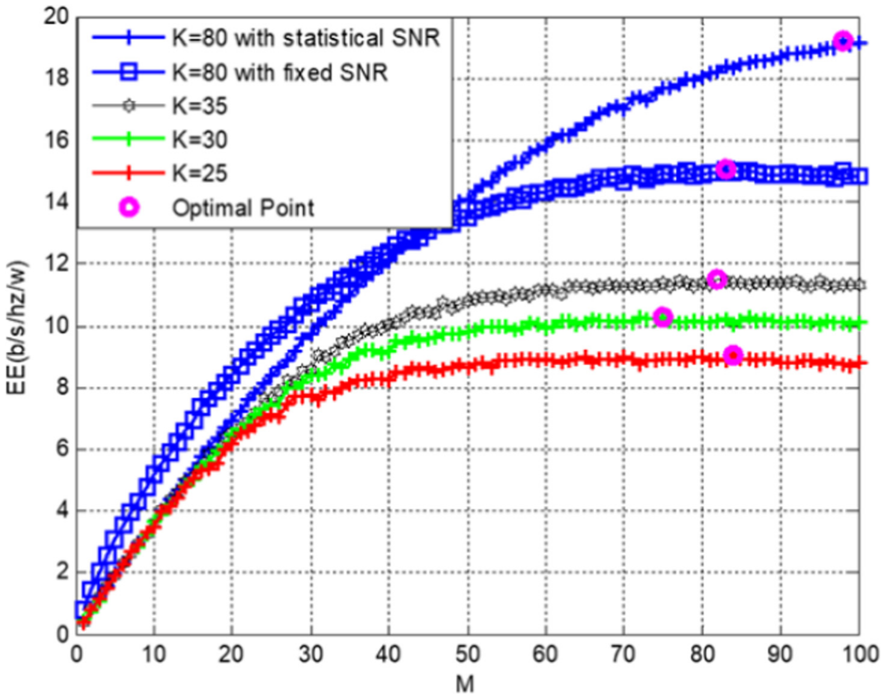


**Fig. 3.** EE for statistical and xed SNR at sub 6 Ghz.

In Fig. 4, the effect of channel variation on total power and optimal number of antennas to be selected is shown. When statistical channel variation is considered, the SNR varies and therefore both total power and M* grow large to combat small scale fading by adaptively allocating desired amount of power. With fixed SNR, smaller number of antennas can achieve optimal level than statistical SNR. From the figure, evaluation with statistical SNR accounts for more total power consumption than instantaneous SNR assumption which is 20 mW and nearly 19 mW for statistical and fixed SNR respectively.

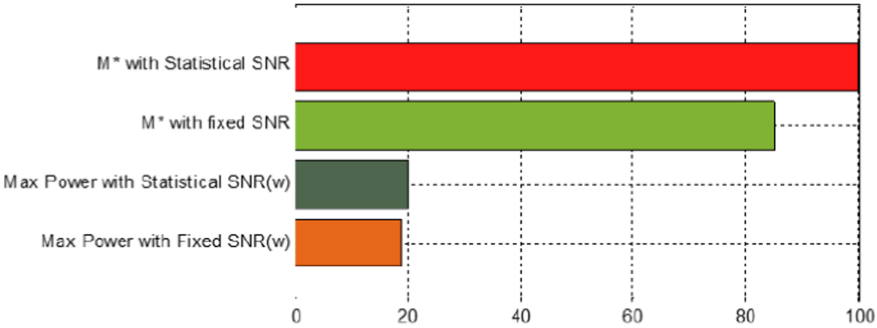


**Fig. 4.** Optimal number of antennas and maximum power for statistical and xed SNR.

Figure 5 depicts minimum SNR based antenna selection using linear and nonlinear precoders and also compares with EE at full array implementation with no any precoders. After finding an optimal number of antennas as figure5, it applies (3) to recalculate a new optimal point which depends on the current position or distance of the users and adaptive reduction of M instead of transmit power. In this case the optimal $M^*$ which was found in full array implementation

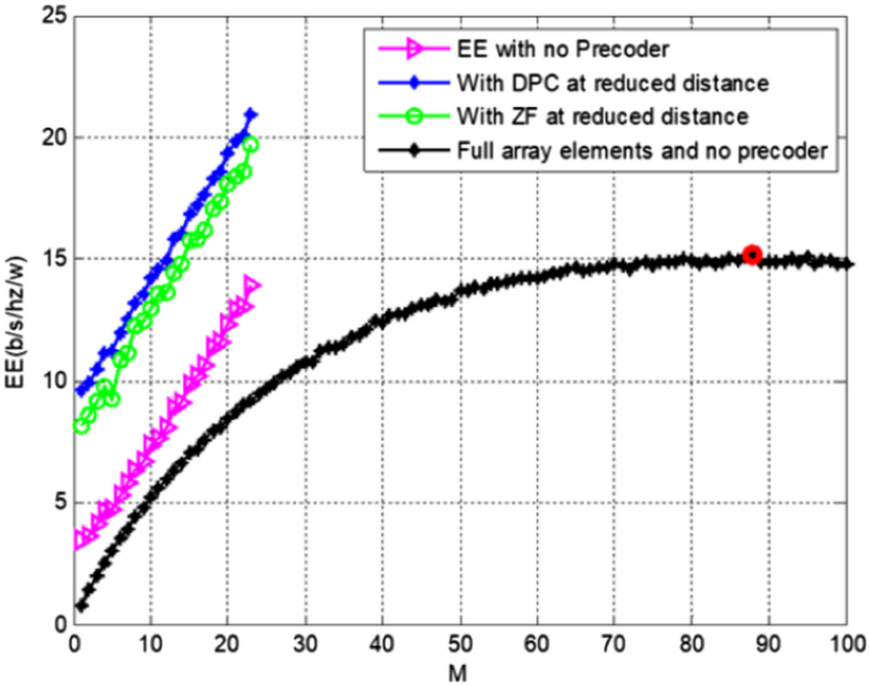


**Fig. 5.** Minimum SNR based selection.

is used as M to re-searching new optimal value $M^o$ as in (3). Despite reduction in total rate when the number of antennas reduced, the reduction in total power consumption compensates in maintaining EE. Finally applying precoders in general and nonlinear DPC in particular boost total rate of the system and EE as well. It is observed that EE of a proposed selection is larger even without any precoders compared to full RF implementation at fixed SNR.

Figure 6 presents the results according to the proposed algorithm by combining the three scenarios and compares the performance of each at CI and FSPL using mmWave and sub 6 Ghz frequency ranges. The first scenario is finding $M^*$ from full array at indoor cell edge, finding $M^o$ according to (3) and finally selecting $M^*$ and $M^o$ data rate values by factorial combination ${}^M P_{M^*}$ and ${}^M P_{M^o}$.

Accordingly, it has been observed that after finding $M^o$ using minimum SNR scenario at mmWave range, EE becomes higher than all with the same number of BS antennas. Due to the fact that mmWave reduces the range of communication and wave length, it leads to either the adaptive reduction of branch's transmit power or $M^o$ BS antennas. In this case, the minimum received power is maintained to a threshold which is the minimum received power at the cell edge and other parameters are varied. Furthermore, adaptive EE in mmWave using DPC according to (9) and found to be better than that of at sub 6 GHz at the same environment.

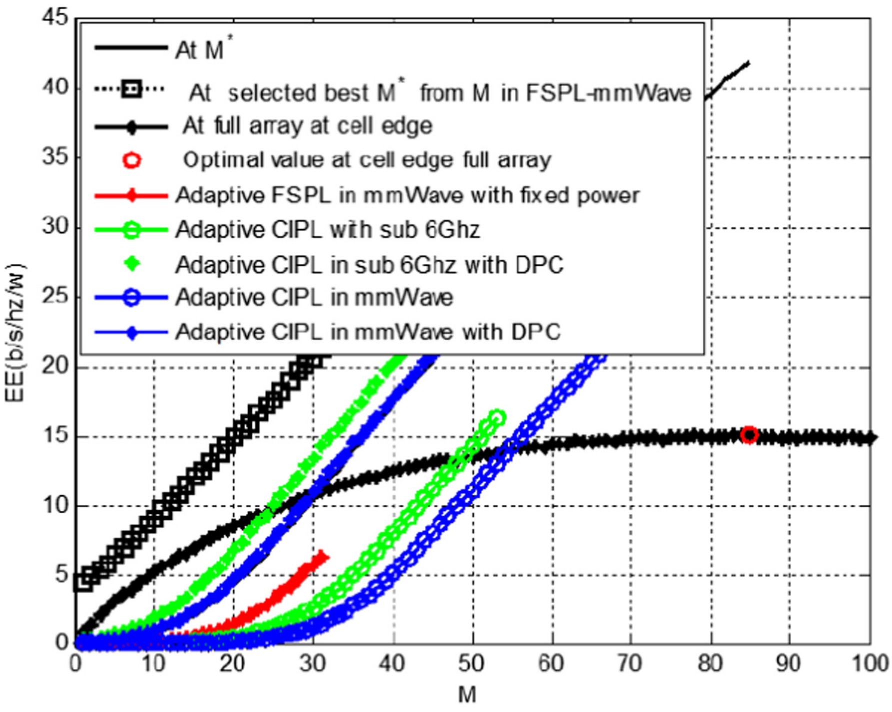


**Fig. 6.** Antenna Selection with the proposed algorithm at k = 35, pt = 5 mw and R = 0.5 km.

## 6 Conclusions

This work has focused on the problem of massive MIMO system's energy effi ciency due large number of antenna elements to be installed on a single BS in the upcoming wireless communication era. Adaptive antenna selection technique has been proposed as a novel strategy in resolving substantial amount of power consumption and complexity as a result of power-hungry RF elements which grow with antenna elements. The selection has been done for cell edge users with full array at fixed power allocation and minimum SNR based selection for cell center users. Both cases are used to achieve optimal number of antennas at which EE becomes maximum. The key idea of the proposed algorithm is to minimize the number of RF chains and performance evaluation has been done at several scenarios by applying precoders at different frequency ranges. The numerical results show that the proposed antenna selection algorithm performs better than full utilization of the array while finding some computational complexity when applying nonlinear precoders to compensate the total rate whilst selection gets negative effects.

## References


1. Larsson, E.G., Tufvesson, F., Edfors, O., Marzetta, T.L.: Massive MIMO for next generation wireless systems, CoRR, vol. abs/1304.6690 (2013)
2. Auer, G., Van der Perre, L.: Challenges and enabling technologies for energy aware mobile radio networks. IEEE Commun. Mag. **48**(11), 6672 (2010)
3. Heath, R.W., Sandhu, S., Paulraj, A.: Antenna selection for spatial multiplexing systems with linear receivers. IEEE Commun. Lett. **5**(4), 142–144 (2001)
4. Correia, L., et al.: Challenges and enabling technologies for energy aware mobile radio networks. IEEE Commun. Mag. **48**(11), 66–72 (2010)
5. Gharavi-Alkhansari, M., Gershman, A.B.: Fast antenna subset selection in MIMO systems. IEEE Trans. Signal Process. **52**(2), 339–347 (2004)
6. Dua, A., Medepalli, K., Paulraj, A.J.: Receive antenna selection in MIMO systems using convex optimization. IEEE Trans. Wireless Commun. **5**(9), 2353–2357 (2006)
7. Wang, B., Hui, T., Leong, M.S.: Global and fast receiver antenna selection for IMO systems. IEEE Trans. Common. **58**(9), 2505–2510 (2006)
8. Xu, Z., Sfar, S., Blum, R.S.: Analysis of MIMO systems with receive antenna selection in spatially correlated Rayleigh fading channels. IEEE Trans. Veh. Technol. **58**(1), 251–262 (2009)
9. Masouros, C., Alsusa, E.: Dynamic linear precoding for the exploitation of known interference in MIMO broadcast systems. IEEE Trans. Wireless Commun. **8**(3), 1396–1404 (2009)
10. Gesbert, M.: Soft linear precoding for the downlink of DS/CDMA communication systems. IEEE Trans. Veh. Technol. **59**(1), 203–215 (2010)
11. Xiang, G., Edfors, O., Liu, J., Tufvesson, F.: Antenna selection in measured massive MIMO channels using convex optimization. In: IEEE GLOBECOM Workshop, Atlanta, Georgia, United States (2013)
12. Gao, X., Edfors, O., Rusek, F., Tufvesson, F.: Massive MIMO performance evaluation based on measured propagation data. IEEE Trans. Wireless Commun. **14**(7), 3899–3911 (2015)

13. Rappaport, T.: Wireless Communications: Principles and Practice, 2nd ed, Prentice Hall, Upper Saddle River (2002)
14. Molisch, A.F., Win, M.Z., Winters, J.H.: Capacity of MIMO systems with antenna selection. IEEE Trans. Wireless Commun. **4**(4), 1759–1772 (2005)
15. Rappaport, T.: Wideband millimeter-wave propagation measurements and channel models for future wireless communication system design. IEEE Trans. Commun. **63**(9), 3029–3056 (2015)
16. Guthy, C., Utschick, W., Honig, M.: Large system analysis of sum capacity in the gaussian MIMO broadcast channel. IEEE J. Sel. Areas Commun. **31**(2), 149–159 (2013)