Low-Complexity Antenna Selection for Minimizing the Power Consumption of a MIMO Base Station

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***Abstract*—In this paper, we study the problem of Transmit Antenna Selection (TAS) for the minimization of a base station power consumption. We propose an algorithm, which solves this problem when the optimal precoding and power allocation are employed, *i.e.*, when an eigenvalue decomposition is employed with a water-filling algorithm. For that purpose, we derive an approximation for the base station power consumption expression that can be used to compute the number of switched-on antennas. Besides, we show that Norm-Based Selection (NBS) policy can be used for selecting the switched-on antennas. Finally, our numerical results show that the proposed low-complexity algorithm provides optimal power consumption performances.**

Keywords–Multiple-Input Multiple-Output; Transmit Antenna Selection (TAS); Energy-Efficient Wireless Networks.

I. INTRODUCTION

Multiple-Input Multiple-Output (MIMO) is one of the key technology to meet the ever-growing demand for mobile data. However, increasing the number of transmit and receive antennas increases the number of RF chains and, therefore, the energy consumption of base stations. That is why mitigating the energy consumed by MIMO systems is a big challenge for the development of future wireless networks [1].

The base station energy consumption can be reduced by switching-off some of the transmit antennas. This mechanism is called Transmit Antenna Selection (TAS) [2]. This solution has been widely proposed for maximizing the capacity of MIMO systems [3][4] and can also be used for making green wireless communications networks.

Making wireless communication networks green can be done by either maximizing the Energy Efficiency (EE) or by minimizing the base station power consumption under some constraints on the quality of service (e.g., capacity). An algorithm for maximizing the EE of a point-to-point communication with antenna selection has been proposed in [5]. However, this algorithm has a rather high complexity. In [6], the authors proposed a transmit antenna selection algorithm for maximizing the EE of a MISO system with a large number of transmit antennas. Moreover, in [7], the authors proposed to maximize the EE by selecting antennas on both the transmit and receive sides. Unlike [6][7], which focus on the maximization of the EE, in this paper, we focus on the problem of antenna selection for power consumption minimization. This problem has been studied in [8], in this paper the authors proposed an algorithm to solve it in the case where the transmit power is equally distributed over all the eigenvalues. One of the limitations of the algorithms proposed

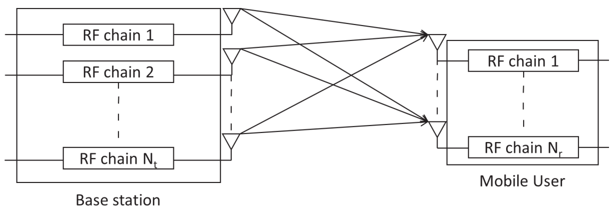

Figure 1. A base station with N_t antennas serves a mobile user with N_r antennas.

in [5]–[8] is the precoding and power allocation. Indeed, in all these papers, the transmit power is equally distributed either over all the antennas or over all the modes. Whereas, in MIMO systems, more efficient performance can be achieved using better precodings. In particular, optimal performance can be achieved using the well-known eigenvalue decomposition and water-filling algorithm [9].

In this paper, we study the problem of transmit antenna selection for the minimization of the power consumption of a base station when the optimal precoding and power allocation is performed. In other words, when the eigenvalue or singular value decomposition is employed with a water-filling algorithm [9]. In addition to improving the performance, the optimal power allocation changes the set of antennas which have to be switched-on to serve the user. We propose a low-complexity two-steps algorithm for the selection of a sub-optimal set of switched-on antennas. For that purpose, we derive an approximation for the base station power consumption and use it for computing N_{on} (the number of switched-on antennas). Moreover, we show that, once this number is known, we can switch-on the N_{on} antennas whose corresponding columns of the channel matrix has the highest norm.

The rest of this paper is organized as follows. The system model is introduced in Section II. In Section III, we recall the expression of the water-filling algorithm and we assess the performance of the antenna selection policy. In Section IV, we propose an approximation for the base station power consumption and we use this approximation for selecting the number of switched-on antennas. Some numerical simulations are conducted in Section V and Section VI concludes this paper.

II. SYSTEM MODEL

We consider a point-to-point MIMO system in which a base station with N_t transmit antennas serves a mobile user with N_r receive antennas. As illustrated in Fig. 1, each of the N_t antennas of the base station is linked to an RF chain.

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Instead of using all its antennas, the base station switches-off some of them and the corresponding RF chains in order to save energy. We denote $\mathscr{S}_{on}$ the set of switched-on antennas and N_{on} is the cardinal of this set, i.e., the number of switched-on RF chains. Moreover, for the analysis of the base station power consumption, we focus on the power consumed in the RF chains whose power consumption can be modeled as [5] [10]:

$$P = \frac{1}{\eta_a} P_{T_X} + N_{on} P_{ct}, \quad (1)$$

where P is the total base station power consumption, P_{T_X} is the transmit power used to serve the user. This transmit power must be lower than a maximum value denoted $P_{\max} = 20W$. $\eta_a = 0.35$ denotes the efficiency of the power amplifiers, and $P_{ct} = 120$ mW is the static power consumed by each switched-on RF chain. In other words, P_{ct} is the power which can be saved by switching-off an antenna.

In this paper, we suppose that the base station has a perfect Channel State Information (CSI). We denote $\mathbf{H} \in \mathbb{C}^{N_r \times N_{on}}$ the channel matrix when N_{on} antennas are switched-on. Moreover, $\mathbf{h}_k$ denotes the k^{th} column of the matrix $\mathbf{H}$ and $||\mathbf{h}_k||_2$ denotes its Euclidian norm. Furthermore, L denotes the pathloss between the base station and the user and σ^2 denotes the noise power. We denote by $\mathbf{Q}$ the input covariance matrix [9], which verifies $\text{Tr}(\mathbf{Q}) = P_{T_X}$, where Tr(.) denotes the trace operator. With the notations introduced herein, the channel capacity can be written as:

$$C = \log_2 \left(\det \left(\mathbf{I}_{\mathbf{N_{on}}} + \frac{L}{\sigma^2} \mathbf{Q} \mathbf{H}^* \mathbf{H} \right) \right), \quad (2)$$

where $\mathbf{I}_{\mathbf{N_{on}}}$ denotes the identity matrix of size N_{on}, det(.) is the matrix determinant and $\mathbf{H}^*$ denotes the conjugate transpose of $\mathbf{H}$.

In our numerical simulations, we consider Rayleigh fading channel, in such case, the elements of the channel matrix are independent identically distributed (i.i.d.) zero mean complex Gaussian variables with variance one. Moreover, we compute the pathloss with the Winner II 'C1' pathloss model [11] with a 2 GHz central frequency. The thermal noise is equal to $\sigma^2 = k_B T B$, where k_B is the Boltzmann constant, T is the temperature in Kelvin and $B = 1$ MHz is the bandwidth. A $2dB$ noise figure is considered.

Our objective is to minimize the base station power consumption while providing to the user a given quality of service in term of capacity. The optimization problem can be written as:

$$\min_{\mathscr{S}_{on}, P_{T_X}} \frac{1}{\eta_a} P_{T_X} + N_{on} P_{ct}, \quad (3a)$$

$$\text{S.t. } C_c \leq \log_2 \left(\det \left(\mathbf{I}_{\mathbf{N_{on}}} + \frac{L}{\sigma^2} \mathbf{Q} \mathbf{H}^* \mathbf{H} \right) \right). \quad (3b)$$

$$P_{T_X} \leq P_{\max} \quad (3c)$$

In (3b), C_c denotes the capacity constraint of the user. Please note that, this constraint is written as an inequality, however, it is easy to see that the base station power consumption is minimum when this constraint is an equality, i.e., when $C_c = C$. Equation (3c) makes sure that the transmit power is not higher than the maximum transmit power of the base station. In the following, we propose an algorithm to solve the problem of (3).

III. ANTENNA SELECTION POLICY

In this section, we first recall the optimal MIMO precoding and power allocation. Besides, we assess the performance of the employed antenna selection policy.

A. MIMO precoding

We assume, here, that a set of $\mathscr{S}_{on}$ antennas has been switched-on and we recall the MIMO precoding which minimizes the power consumption. When the set of switched-on antennas has been chosen, minimizing the base station power consumption aims at minimizing the transmit power. Looking at the capacity, finding the optimal MIMO precoding means deriving the matrix $\mathbf{Q}$ which minimizes the transmit power while providing to the user its capacity constraint. It is well-known that the matrix $\mathbf{Q}$ is optimal when the eigenvalue decomposition of $\mathbf{H}^*\mathbf{H}$ is performed [9]. In other words, $\mathbf{Q}$ and $\mathbf{H}^*\mathbf{H}$ must have the same eigenvectors. In that case, the capacity constraint becomes:

$$C_c = \sum_{k=1}^{N} \log_2 \left(1 + \frac{L}{\sigma^2} \mu_k \lambda_k \right), \quad (4)$$

where λ_k denotes the k^{th} eigenvalue of $\mathbf{H}^*\mathbf{H}$, μ_k is the k^{th} eigenvalue of $\mathbf{Q}$ and $N = \min(N_{on}, N_r)$. Then, the eigenvalues μ_k which minimize the transmit power are computed with the well-known water-filling algorithm:

$$\mu_k = \frac{\sigma^2}{L} \left(\frac{2^{\frac{C_c}{N'}}}{\left(\prod_{k=1}^{N'} \lambda_k \right)^{\frac{1}{N'}}} - \frac{1}{\lambda_k} \right)^{\dagger}, \quad (5)$$

where $(.)^{\dagger} = \max(., 0)$ and N' is the number of non-zero eigenvalues of $\mathbf{Q}$. With this optimal power allocation over the eigenvalues of the system, the total transmit power can be expressed as:

$$P_{T_X} = \frac{\sigma^2}{L} \left(\frac{N' 2^{\frac{C_c}{N'}}}{\left(\prod_{k=1}^{N'} \lambda_k \right)^{\frac{1}{N'}}} - \sum_{k=1}^{N'} \frac{1}{\lambda_k} \right) \quad (6)$$

B. Norm-Based Selection

In this section, we answer the following question: if we want to switch-on N_{on} antennas, which ones must be selected? A good solution for antenna selection lies in switching-on the N_{on} antennas whose corresponding columns of the channel matrix have the highest norm. This solution is called Norm-Based Selection (NBS). This approach has been proposed in [12] for capacity maximization with equal power allocation over the antennas. It has been proven to be optimal at low Signal-to-Noise Ratio (SNR) and in the Multiple-Input Single-Output (MISO) case [13]. Recently, this solution has also been shown to provide near-optimal performance even when the columns of the channel matrix are correlated [14].

In this paper, we propose to use NBS with the optimal power allocation for the purpose of power consumption minimization. In order to assess the performance of NBS, we consider a base station with $N_t = 12$ antennas and we suppose that the capacity constraint is equal to 5 bits/s/Hz. We compare:

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- The minimum base station power consumption with NBS. Which is obtained by computing the power consumption with the N_t possible antenna configurations with NBS and by finding the one that minimizes the power consumption.
- The minimum base station power consumption which is computed with an exhaustive search. I.e., by evaluating the base station power consumption for the $2^{N_t} - 1$ possible antenna configurations and by finding the optimal one.

We compute the average base station power consumption, with these two strategies, as a function of the distance between the user and the base station. The results are presented in Fig. 2. They show that, with the selected simulation parameters, NBS and the iterative search provide the same results. As a consequence, this antenna selection strategy provides optimal performance. That is why we can use NBS as a solution for transmit antenna selection.

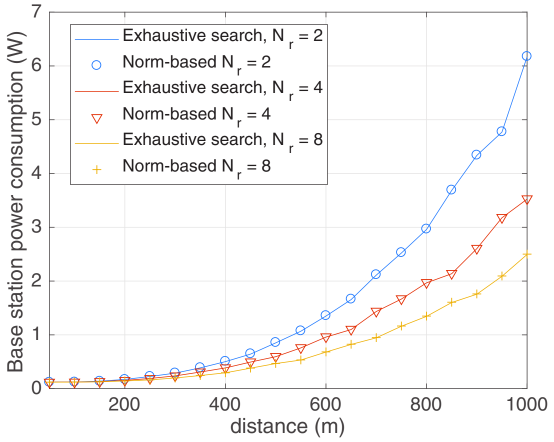

Figure 2. Comparison of NBS with an exhaustive search.

IV. Sub-Optimal Number of Switched-on Antennas

In this section, we propose a method to compute N_{on}, the number of switched-on antennas.

A. Number of antennas

In the previous section, we have shown that with an optimal power allocation, NBS is an optimal antenna selection policy. We, now, have to focus on the number of switched-on antennas. Indeed, with NBS, we have N_t possible antenna configurations (one for each number of switched-on antennas). In order to find the one which minimizes the base station power consumption, we can compute the power consumption of the base station for each of them and select the optimal one. However, this iterative computation requires N_t matrix diagonalizations and as many water-filling algorithms. This is too much. That is why, in the following, we derive an approximation for the base station power consumption when N_{on} antennas are switched-on. Once this approximation has been derived, the proposed algorithm can compute the value of N_{on} which minimizes our approximation in order to provide a sub-optimal value for the number of switched-on antennas.

In order to approximate the base station power consumption, we first insert the expression of the transmit power of (6) in (1). We obtain the following expression:

$$P = \frac{\sigma^2}{L\eta_a}\left(\frac{N' 2^{\frac{C_c}{N'}}}{\left(\prod_{k=1}^{N'} \lambda_k\right)^{\frac{1}{N'}}} - \sum_{k=1}^{N'} \frac{1}{\lambda_k}\right) + N_{on} P_{ct}. \quad (7)$$

In the following, in order to make our derivation clearer, we denote α_k the normalized eigenvalue of $\mathbf{H}^*\mathbf{H}$:

$$\alpha_k = \frac{\lambda_k}{\sum_{n\in\mathscr{S}_{on}} ||\mathbf{h}_n||_2^2}, \quad \forall k \in [\![1; N]\!]. \quad (8)$$

With this notation $\sum_{k=1}^{N} \alpha_k = 1$. The base station power consumption becomes:

$$P = \frac{N'\sigma^2}{L\eta_a S}\left(\frac{2^{\frac{C_c}{N'}}}{\left(\prod_{k=1}^{N'} \alpha_k\right)^{\frac{1}{N'}}} - \frac{1}{N'}\sum_{k=1}^{N'} \frac{1}{\alpha_k}\right) + N_{on} P_{ct}, \quad (9)$$

where $S = \sum_{n\in\mathscr{S}_{on}} ||\mathbf{h}_n||_2^2$. In order to derive an approximation for the base station power consumption, we consider the case where the matrix $\mathbf{H}^*\mathbf{H}$ has exactly N non-zero eigenvalues and where all these eigenvalues are considered in the water-filling algorithm. In other words, we consider the case $N' = N$. In this situation, all the eigenvalues are beneficial to satisfy the user's capacity constraint. This is the best case.

In (9), we have a weighted difference between the geometric and arithmetic means of $\frac{1}{\alpha_k}$, $\forall k \in [\![1; N']\!]$. The geometric mean is always lower than the arithmetic mean and we have an equality in the case where all the α_k are equals to $\frac{1}{N}$. As a consequence, we can approximate the base station power consumption of the base station by its value in the case where all the eigenvalues are equals. We derive:

$$P \approx N_{on} P_{ct} + \frac{N^2\sigma^2}{L\eta_a \sum_{n\in\mathscr{S}_{on}} ||\mathbf{h}_n||_2^2}\left(2^{\frac{C_c}{N}} - 1\right). \quad (10)$$

Please, note that, the evaluation of the power consumption with (10) does not require any matrix diagonalization. Moreover, this approximation allows to verify if the constraint on the maximum transmit power of (3c) is satisfied. Indeed, for a given number of switched-on antennas, the transmit power of the base station is approximated by:

$$P_{Tx} \approx P_{Tx}^{\text{app}} = \frac{N^2\sigma^2}{L\eta_a \sum_{n\in\mathscr{S}_{on}} ||\mathbf{h}_n||_2^2}\left(2^{\frac{C_c}{N}} - 1\right). \quad (11)$$

For a number N_{on} of antennas, if the approximation of (11) is higher than the maximum transmit $P_{\max}$, the value of P_{Tx} will probably be higher than $P_{\max}$. As a consequence, we can eliminate the antenna configurations for which the transmit power is higher than $P_{\max}$ by eliminating the values of N_{on} for which $P_{Tx}^{\text{app}} \geq P_{\max}(1-\epsilon)$, where ϵ is a security margin which can be equal to 0.05.

Finally, we can find N_{on}^*, the sub-optimal value for the number of switched-on antennas, by finding the value of N_{on} which minimizes (10):

$$N_{on}^* = \underset{N_{on}}{\operatorname{argmin}}\ N_{on} P_{ct} + \frac{N^2\sigma^2}{L\eta_a \sum_{k=1}^{N_{on}} ||\mathbf{h}_k||_2^2}\left(2^{\frac{C_c}{N}} - 1\right). \quad (12)$$

1 Sort the columns of the channel matrix by descending order of their norm, $||\mathbf{h}_k||_2$;
2 Eliminate the values of N_{on} for which $P_{Tx}^{\text{app}}(N_{on}) \geq P_{\max}(1-\epsilon)$;
3 $N_{on}^* = \underset{N_{on}}{\text{argmin}}\ N_{on}P_{ct} + \frac{N^2\sigma^2}{L\eta_a \sum_{k=1}^{N_{on}} ||\mathbf{h}_k||_2^2}\left(2^{\frac{C_c}{N}} - 1\right)$;
4 Diagonalize the matrix $\mathbf{H}^*\mathbf{H}$ which contains the N_{on}^* column which have the highest norm;
5 Apply the water-filling algorithm of (5);

Figure 3. Proposed algorithm

B. *Algorithm in full*

The observations done in the previous sections show that NBS policy provides optimal performance, and that we can provide an approximation for the base station power consumption. So, the antenna selection can be done by first ordering the columns by descending order of their norm. Then, for each value of N_{on}, we can evaluate the base station power consumption with (10) and find the value N_{on}^* for which it is minimum. Finally, the base station can make the eigenvalue decomposition and apply the water-filling algorithm.

The whole algorithm introduced in this paper is summarized in Fig. 3. It is interesting to note that among the five steps of the algorithm, the first three are used for antenna selection and the last two are used for precoding and power allocation. Besides, this algorithm has a low complexity. Indeed, the step with the highest complexity is the matrix diagonalization which is part of the precoding.

V. Simulation Results

In this section, we use numerical simulations in order to analyze the effect of the proposed antenna selection policy and of the power allocation on the base station power consumption.

A. *Performance of the proposed policy*

We first conduct some numerical simulations in order to assess the performance of the proposed algorithm. For that purpose, we compare four different policies:

- The proposed policy.
- The optimal policy with NBS, in which we compute the power consumption for the N_t possible configurations and select the one which consumes the less power.
- A policy in which all the RF chains are switched-on.
- A policy in which the number of antennas is computed using the method proposed in [8].

For each of the antenna selection policies compared here, NBS is applied and after selecting the number of antennas, the base station computes the transmit power with the water-filling algorithm. We consider the simulation parameters introduced in Section II and we suppose that the base station has N_t = 32 antennas, that the user has N_r = 8 antennas, and that the capacity constraint of the user is equal to 20 bits/s/Hz.

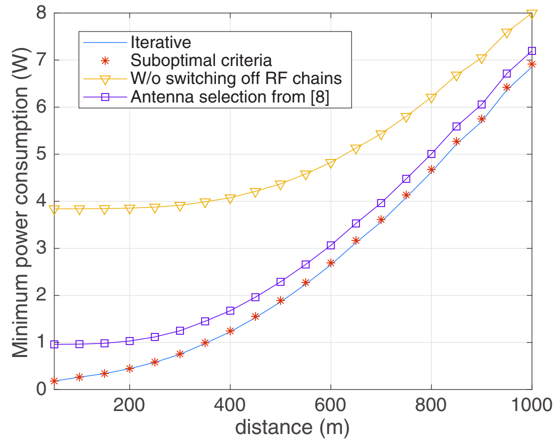

Figure 4. Comparison of the base station power consumption with several antenna selection policies.

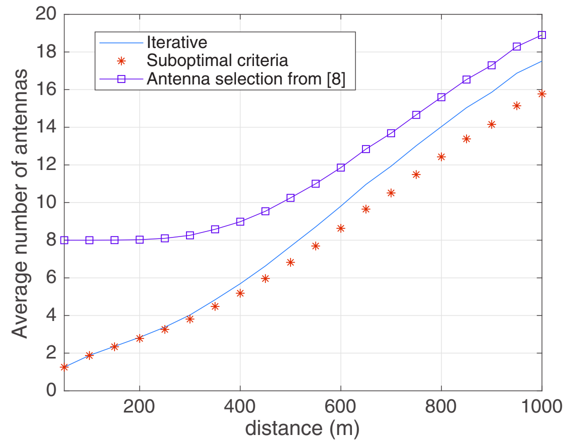

Figure 5. Comparison of the number of switched-on antennas with several antenna selection policies.

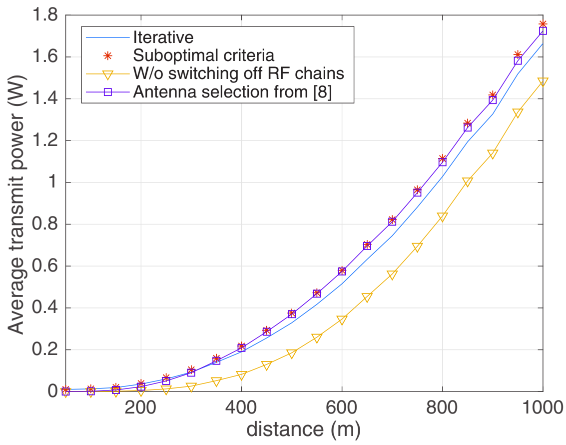

Figure 6. Comparison of the average transmit power with several antenna selection policies.

We display in Fig. 4 the average base station power consumption with the four compared policies. We can see in this figure that the proposed policy provides optimal performance. We first compare the base station power consumption with the proposed policy and with the policy without antenna selection. We can see that the highest gain is obtained when the user is near the base station. In such situation, the base station power consumption is reduced from 4 W to 0.2 W. Moreover, we can see, in Fig. 5, that the number of switched-on antennas is low when the user is near the base station and increases with the distance. Indeed, when the user is near the base station, the transmit power used to serve him is low. In such case, the part of the power consumption which is dependent on the transmit power ($\frac{1}{\eta_a} P_{T_X}$) is low. As a consequence, switching-on an antenna increases more the power consumption than increasing the transmit power and, consequently, only one antenna is switched-on. On the contrary, when the user is far from the base station, the part of power consumption which is proportional to the transmit power is high compared to the power needed to switch-on an antenna. In that case, it is beneficial to switch-on more antennas.

By comparing the number of switched-on antennas with the proposed and with the optimal policies, we can see, in Fig. 5, that the number of switched-on antennas is slightly lower with the proposed policy. However, we can see in Fig. 4 that, the error committed on the number of antennas does not have any effect on the power consumption as the water-filling algorithm counterbalances this error by adjusting the transmit power. In other words, when the power is allocated with the water-filling algorithm, it compensates the error committed on the number of antennas. Besides, as the proposed solution uses a little less antennas than the optimal strategy, it requires a little more power to serve the user. This result is shown in Fig. 6.

Furthermore, with the solution proposed in [8], the number of switched-on antennas is computed considering that the transmit power P_{T_X} is equally distributed over all the eigenvalues. With such hypothesis, more antennas are required to serve the users. As more antennas are switched-on, the base station power consumption is higher. This extra-power consumption causes performance loss when the user is near the base station and the transmit power low. That is why, our solution outperforms the one proposed in [8]. When the distance increases, the transmit power increases and the impact of the error in the number of antennas has less impact on the base station power consumption.

B. Impact of the power allocation

We now analyze the impact of the power allocation. For that purpose, we still consider that the base station has 32 antennas and that the user has 8 antennas. We consider three different power allocations: the water-filling one, an equal power transmission over the transmit antennas and an equal power transmission over the eigenvalues. For this evaluation, we suppose that the capacity constraint is equal to 10 bits/s/Hz and we do not consider the constraint on the maximum transmit power. The results are displayed in Fig. 7. It is important to note that, with equal power transmissions (over the transmit antennas or over the eigenvalues of $\mathbf{H}^*\mathbf{H}$) the value of the transmit power which satisfies the capacity constraint of the user has to be computed using an iterative algorithm such as the bisection method.

This figure shows that the water-filling algorithm outperforms the two others power allocations. More precisely, the water-filling algorithm provides a large gain compared to the allocation where the RF power is equally distributed over all the antennas. Besides, even if the water-filling algorithm provides a small gain compared to the power allocation with equal transmit power over the eigenvalues, both solutions require perfect CSI and the water-filling algorithm is more convenient for antenna selection as we can more easily express the base station power consumption.

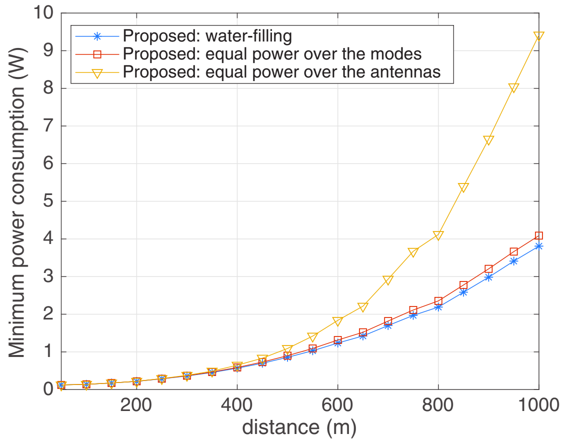

Figure 7. Base station power consumption with different power allocations.

VI. Conclusion

In this paper, we studied the problem of transmit antenna selection with an optimal precoding, *i.e.*, with the eigenvalue decomposition and a water-filling algorithm. We proposed a low-complexity algorithm for minimizing the base station power consumption. Our results show that, when the water-filling algorithm is employed, a small error in the number of switched-on antennas has no effect on the base station power consumption. This result highlights the possibility to reach optimal performance with simple algorithms. For our future work, we plan to study the combination of antenna selection and Cell Discontinuous Transmission.

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