Near Optimal Antenna Selection Model for MIMO Systems

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Abstract. Recently it has been shown that Multiple Input Multiple Output (MIMO) Systems offer great advantages over Simple Input Simple Output (SISO) systems particularly in terms of capacity. By increasing the number of antennas at both transmitter and receiver. Unfortunately, when the MIMO System are physically deployed, it has the disadvantages of increasing the implementation costs and the complexity involved due the increase of RF chains. However, there are several algorithms proposed to overcome such challenges. One of them consists in the selection of a sub-set of antennas with the main objective of maintaining the benefits of MIMO at an affordable trade-off among complexity and implementation cost. This article proposes a novel model for antenna selection which is able to achieve similar results to the optimal selection in terms of performance and significantly surpassing other algorithms in both performance and capacity, low cost complexity.

Keywords: Multiple Input Multiple Output (MIMO), Simple Input Simple Output (SISO), Radio Frequency (RF), Correlation Based on the Method (CBM), Improvement Correlation Based on the Method (ICBM), Line of Sight (LOS).

1 Introduction

There are several characteristics that make MIMO wireless systems very attractive. Among them find: near optimal capacity, increase in coverage area, growth of data rate, etc. Such characteristics are possible due the spatial-diversity exploitation directly size of the antenna array. Unfortunately, if the MIMO array is too large, it generates a considerable increase in the implementation cost. Thus, in the simplest case, when transmitting a signal, we require an antenna (or more if MIMO) and a RF chain. The RF chain is mainly composed of communications hardware such as analog to digital converters, filters, amplifiers and some other circuits that do not follow Moore's law [1] and hence increasing the implementation cost.

One clever way to improve the benefits of the MIMO systems is to increase the number of antennas at the receiver, providing a greater space diversity, while keeping the number of RF chains lower than the number of the antennas. Furthermore, we can make use of an *antenna selection algorithm* which selects a sub-set of antennas (i.e., the ones with better channel conditions) according to the same number of RF chains

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that exist at the receiver. Thus, we take advantage of the space diversity while keeping the low cost of the MIMO system in terms of antennas and RF chains.

Ideally, the optimal method of antenna selection makes an exhaustive search to find the best L antennas of the N in an array of size $\binom{N}{L}$. The increase in capacity and performance is substantial compared to MIMO array antennas without increasing the array at the receiver [2], [3]. However, since the calculation of this combination of antennas is too complex and computationally prohibitive [4], [5], there are several algorithms that have been proposed to face this problem [6], [7] that will be briefly described in the following sections.

On this paper, we present a novel model for antenna selection in MIMO systems. Different from the existing models, it is able to achieve similar results than the optimal selection model in terms of performance and significantly surpassing other algorithms in both performance and capacity. Performance tests show that our model is able to achieve satisfactory results under Rician fading channel and Correlation channel which are very unfavorable for MIMO systems.

This paper is organized as follows. Section 2 describes a few antenna selection algorithms and channels used along this document. In Section 3.1 is described how the optimal selection works and in Section 3.2 the proposed model is presented and described, Section 4 explain how was calculated the complexity cost. Finally, the performance results are shown in Section 5 including valuable conclusions presented in Section 6.

2 MIMO Antenna Selection and Channels

2.1 Algorithms

Correlation Based on the Method (CBM) This algorithm presented in [6] assumes full knowledge of the channel by the receiver and it works as follows: if the channel matrix **H** has two lines equal, one of them must be eliminated because if one of them is not in the matrix there is no loss of information. If they have different powers, the selected row shall be the one with the highest power (the square of the norm of the vector). When any row is not identical, the correlation is applied among them eliminating the row yielding the highest value of this operation. The objective of this algorithm is to create a channel matrix with unique vectors and with the higher value of power.

Improvement Correlation Based on the Method (ICBM) A substantial improvement to the CBM algorithm was developed in [7]. Here, the algorithm calculates the correlation and non-correlation. The channel matrix is filled incrementally and does not require to know all the signals. This difference respect CBM allows to ICBM to achieve a faster antenna selection process since does not require to make the correlation with all the vectors of the channel.

CBM and ICBM were designed to work under slow Rayleigh fading channel conditions. Thus, when they work in different or faster channels, CBM and ICMB tend to decrease their effectiveness and in consequence there is a substantial loss of performance and capacity.

2.2 The Fading Channel

Rayleigh fading channel is rich in scattering and does not have a line of sight (LOS) path between transmitter and receiver, something that suits to the MIMO systems. However, there are other channels that the MIMO systems may encounter, environments that are not suitable for them but very similar to everyday wireless communications situations, e.g. absence of multi path (Rician) and sameness in the received signal (correlation).

Therefore, for sake of simplicity and generalization, we define the MIMO channel that will be used thorough this paper as a Rayleigh fading represented by a $N_R \times N_T$ antenna number at R_x and T_x respectively, $\mathbf{H}$ matrix, $\mathbf{H} = [\mathbf{h}^{(1)}, \ldots, \mathbf{h}^{(N_R)}]^T$, $\mathbf{h}^{(k)} = [h_{k,1}, \ldots, h_{k,N_T}]$, unless specified otherwise. Additionally, indexes $(\cdot)^T$ and $(\cdot)^H$ stand for transpose and conjugated transpose respectively.

Rician fading Channel When the transmitter and receiver have a LOS path, the channel follows the Rice distribution. In this case the spread is decreasing, affecting the performance of MIMO systems. This degree of affectation is determined by the K Rician Factor (KF) which is the radius of the power of the LOS component of the channel to the power in the fading component [8].

Thus, for the presence of LOS between the transmitter and receiver, the MIMO channel can be modeled as the sum of a fixed component and a scattered component, thus we have

$$\mathbf{H} = \sqrt{\frac{KF}{1+KF}}\mathbf{H}_{LOS} + \sqrt{\frac{1}{1+KF}}\mathbf{H}_w \tag{1}$$

where $\sqrt{\frac{KF}{1+KF}}\mathbf{H}_{LOS} = \mathrm{E}\{\mathbf{H}\}$ is the LOS component and the faded component is calculated as $\sqrt{\frac{1}{1+KF}}\mathbf{H}_w$, which assumes uncorrelated fading. Therefore, when $KF = 0$ corresponds to a Rayleigh fading channel while $KF = \infty$ corresponds to a non-fading channel.

Correlated Channel Another real-world phenomena that affects the MIMO systems is the correlation. This problem occurs when the separation between the base station antennas is not sufficient to allow the signals to take different paths. The order of this separation is in centimeters while the distance between base station(BS) and mobile device is the order of kilometers. Thus, when the base station antennas receive a signal from a mobile device, and if it is very close to the BS, the result is the presence of the correlation effect. A model that is widely used to define a correlation matrix is defined by

$$\sum\mathbf{H} = \sum\mathbf{R} \otimes \sum\mathbf{T}, \tag{2}$$

where $\otimes$ represents the Kronecker's product, as described in [9]. $\sum T$ is the transmit-correlation matrix corresponding to the case when each R_x antenna is the same,

$$\sum\mathbf{T} = \mathrm{E}\{\mathbf{h}_i\mathbf{h}_i^H\} \quad \forall i, \quad \mathbf{h}_i = [h_{i,1}, \ldots, h_{i,N_T}]^T, \tag{3}$$

and for the case when each T_x antenna is the same, the receive-correlation matrix is given by

$$\sum \mathbf{R} = \mathrm{E}\{\mathbf{h}_j \mathbf{h}_j^H\} \quad \forall j, \quad \mathbf{h}_j = [h_{1,j}, \ldots, h_{N_R,j}]^T. \tag{4}$$

The degree of sameness determine the correlation coefficient with 1 as a maximum correlation and 0 as no correlation.

3 Model Description

The antenna selection algorithms aim to improve the features and benefits that can be provided by a MIMO antenna array physically implemented. To make use of them, it is necessary to increase the number of antennas at the receiver in order to increase the diversity. Among all received signals, a selection is required based on the parameters that increase performance and capacity of MIMO systems. This process must be done without adding additional RF chains, therefore the implementation of the system that we are referring to is shown in Figure 1.

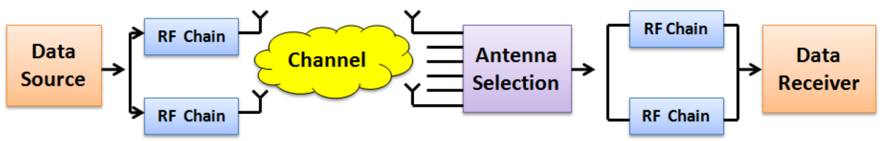

Fig. 1. Block diagram of the antenna selection model for MIMO systems.

3.1 Optimal Selection

The Optimal Selection of getting a sub-set of antennas is done by calculating $\binom{N}{L}$, which is considering all the possible combinations according to the number of antennas that exists physically and according to the number of RF chains available. Clearly, we can see that the greater number of antennas, the better results. However, notice that this operation is computationally expensive. The optimal choice is made according to the flow chart shown in Figure 2.

First we modeled the channel $\mathbf{H}$ and note that the random variables can be Rayleigh, Rician or Correlated. The channel capacity is calculated by: equation (5), $\mathbf{I}$ stands for identity matrix and ρ is the signal to noise ratio [10].

$$C = \log_2 \left[\det \left(\mathbf{I}_{N_R} + \frac{\rho}{N_T} \mathbf{HH}^H \mathbf{HH} \right) \right] \text{bit/s/Hz}. \tag{5}$$

In order to calculate the capacity is assigned a value from the matrix $\mathbf{H}$ and is placed temporarily in the $\mathbf{HH}$ variable which will be used exclusively for this operation and will have a size of 2×2. Since the simulation assumes that there are two RF chains at both the transmitter and receiver, the second value is placed in **HH** after the first and will change accordingly to the results obtained in the building process from the total combinations available. All vectors will be used and will be part of the Optimum Selection from all those vectors that produced the maximum capacity. Using this selection we can get the maximum capacity and performance that can be achieved by the system. However, because this algorithm is too complex is not advisable to use it, especially if you are in channels that affect MIMO systems, e.g. the Rician fading Channel and Correlated Channel.

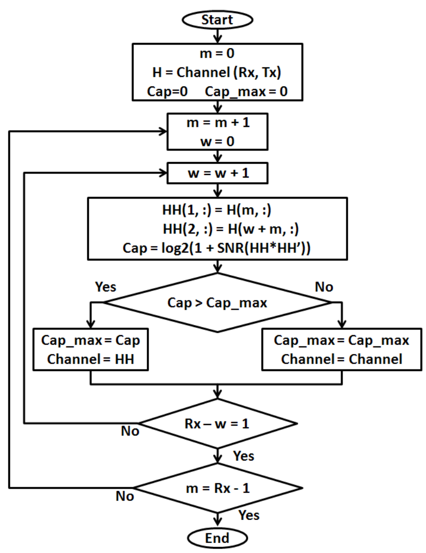

Fig. 2. Optimal Antenna Selection Model for MIMO systems.

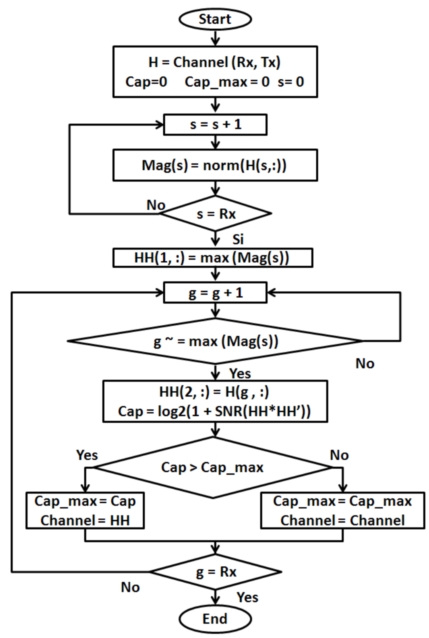

Fig. 3. Proposed Antenna Selection Model for MIMO systems.

3.2 Proposed Model

The variables generated by this algorithm have the same dimensions as the optimal selection. Random samples contained in **H** can also be Rayleigh, Rician or Correlated. Unlike other algorithms that do not handle the last two distributions. The Proposed Model algorithm begins by calculating the power of each vector of the matrix **H** by the square of the norm of the vector. Needless to say, we are after the vector (or set of vectors) that will offer the maximum power.

The capacity is also calculated using the equation (5). The vector with the maximum power is placed permanently in the first row of the matrix **HH** and has the same function as the optimal selection. This vector, will be placed consecutively in the second row of the matrix **HH** with all different vectors (sorted in terms of maximum power) and next the capacity is calculated. Finally, will be selected the second line which has obtained the highest capacity. The antenna choice of our proposed model is made according to the flow chart shown in Figure 3.

The main advantage of this algorithm is that forms the matrix of the vector channel has better power characteristics and the calculation of capacity does combinations of values of the matrix, because it assigned a specific location for the first selected signal, and only test the other options in conjunction with the first. As will be shown in the following section, this algorithm stands out because its results are very close in performance to the Optimal Selection but does the selection process with a much smaller number of operations to the Optimal Selection, as shown in the results, making this model suitable for implementation in mobile systems by the low battery consumption that will have, as well as to be implemented in fast channels.

This method is similar to the algorithms shown in Section 2, because you get a similar way the first selected signal, but also makes the calculation of capacity as it holds the optimal selection, but may seem complex at base part of their selection on ability, but having filled an area of the channel matrix with the vector of maximum power, drastically reducing the number of operations performed, showing that this model is adequate for obtaining good results with a reduced cost of complexity

4 Measuring Complexity

Through the theory of computational complexity can be aware of the resources necessary to carry out an algorithm, the more elaborate and extensive as this will require a greater number of operations which is reflected in resources in the case of a device Mobile means more battery consumption.

Using the function Floating point Operations Per Second (Flops) of Matlab [11], which measures performance based on the number and type of operations performed by the algorithm. As cited in [12], consumption of flops that have some operations is reflected in Table 1 and Table 2 . Where the degree of complexity is based on the characteristics that have the operation to do, whether scalar, vectors or matrices, real or complex.

Operation	if $\mathbf{c} \in \mathbb{R}$ $O(\cdot)$	if $\mathbf{c} \in \mathbb{C}$ $O(\cdot)$	
$\mathbf{a}+\mathbf{b}=\mathbf{c}$	$n+8$	$n+9$	$flops$
$\mathbf{a}-\mathbf{b}=\mathbf{c}$	$n+8$	$2n+9$	$flops$
$\mathbf{a}*\mathbf{b}^{\mathbf{T}}=\mathrm{c}$	$6n+10$	$2(2n+7)$	$flops$

Table 1. Elementary vector operations measured in flops

Operation	if $\mathbf{C} \in \mathbb{R}$ $O(\cdot)$	if $\mathbf{C} \in \mathbb{C}$ $O(\cdot)$	
$\mathbf{A}+\mathbf{B}=\mathbf{C}$	$n+8$	$n+9$	*flops*
$\mathbf{A}-\mathbf{B}=\mathbf{C}$	$n+8$	$2n+9$	*flops*
$\mathbf{A}*\mathbf{B}^T=\mathbf{C}$	$6n+10$	$2(2n+7)$	*flops*

Table 2. Elementary matrix operations measured in flops

5 Results

The simulations performed are developed using Monte Carlo method in Matlab. It is included for comparison purposes a MIMO system with two antennas each at the T_x and the R_x, which is called Non Selection. The MIMO system that implemented to make use of antenna selection algorithms is an array of RF chains of 2×2, where the T_x has two antennas and the R_x has eight antennas from which only two will be selected. The algorithms considered are ICBM, the Optimal Selection and the Proposed Model.

CBM algorithm was used as reference by the good results obtained in time using it, in the Figures 4, 5 and 6, do not show these results to avoid congestion at the figures and it was decided to begin comparisons with ICBM.

Figure 4 top shows that the proposed antenna selection model is very close to optimal model performance and far superior to the improvements made to CBM and especially at 2×2 MIMO system. Note that although, note in Figure 4 that the proposed model cannot fully achieve the same capacity as the Optimal Selection nevertheless it achieves a higher capacity than ICBM in a Rayleigh channel (the channel where ICBM performs better). Note the capacity obtained with ICBM and the proposed model are similar, however, if we also compare them in terms of Bit Error Rate, as shown in 4 our proposed method is better.

Figures 5 and 6 do not include the 2×2 MIMO system, or ICBM, because the proposed model have better performance than those methods, also to be subject to drastically different channels lose their properties, hence the interest focuses only on the proposed model and the optimal selection.

Figure 5 shows the performance and capacity that can have both the Optimal Selection and the Proposed Model under a Rician fading Channel. It can be seen that the Rician channel clearly affects the performance of both techniques. The Optimal Selection performs better but the proposed model stays very close. At this point, we have to emphasize the fact that the Proposed Model remains very close to the optimum signal showing robustness and ence against the absence of multi path, something that does not happen with CBM or ICBM.

The correlated channel also affects the performance of both algorithms, but the most notable change comes from the correlation coefficient of 0.5 and onwards. Figure 6 shows that although the proposed model calculates the signal strength based on mathematical correlation, this estimation is not affected by the correlated channel while keeping a close performance in comparison with the optimal. Again, the proposed model shows better characteristics against correlated channels, particularly against its counterparts CBM and ICBM (which effectiveness lie upon low correlation channels).

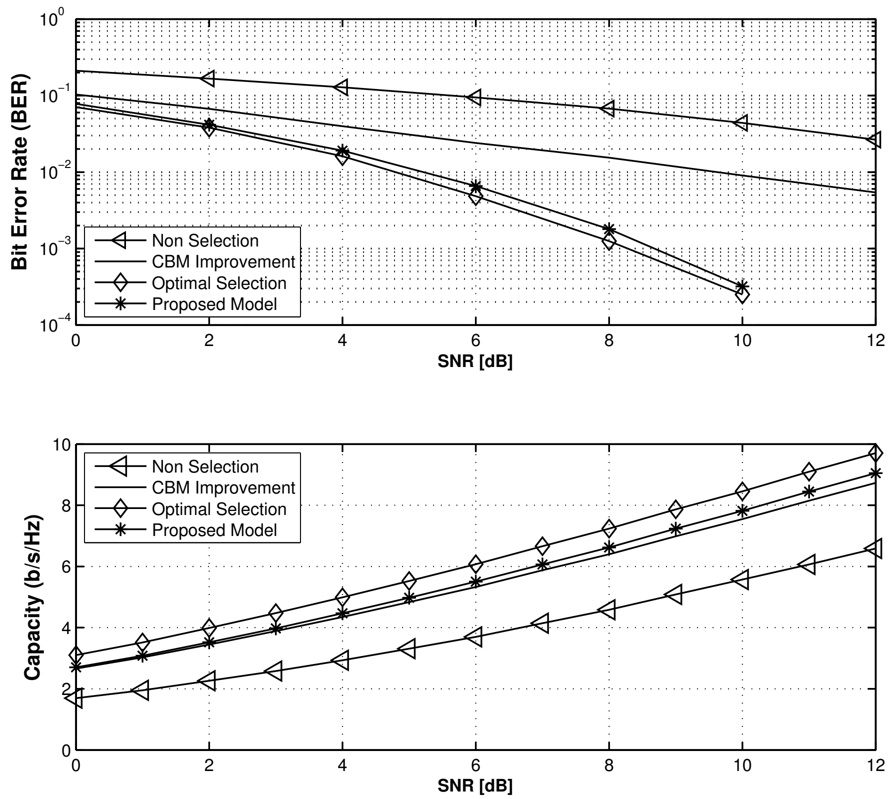

Fig. 4. Performance in Bit Error Rate (top) and Capacity (bottom) in b/s/Hz achieved by the non selection model, ICBM, optimal model and the proposed model under a Rayleigh channel conditions.

Figure 7 makes use of the function to measure the complexity Flops. The algorithms CBM, ICBM, the Proposed Model and the Optimal Selection are simulated in a Rayleigh channel. Clearly we can see that ICBM, and the Proposed Model are less than half the computational cost of the Optimal Selection, the Proposed Model stands out as making use of the ability to obtain a reasonable performance close to that of the selection optimal, but with a much lower complexity.

6 Conclusions

In this paper, we presented a new model of antenna selection for MIMO systems which is able to get better results than other algorithms that fulfill the same function. The antenna selection algorithms are designed to slow channels, but our proposed model shows more flexibility since can work in Rayleigh channels, Rician channels and under highly correlated conditions while maintaining its properties. Despite the fact of the

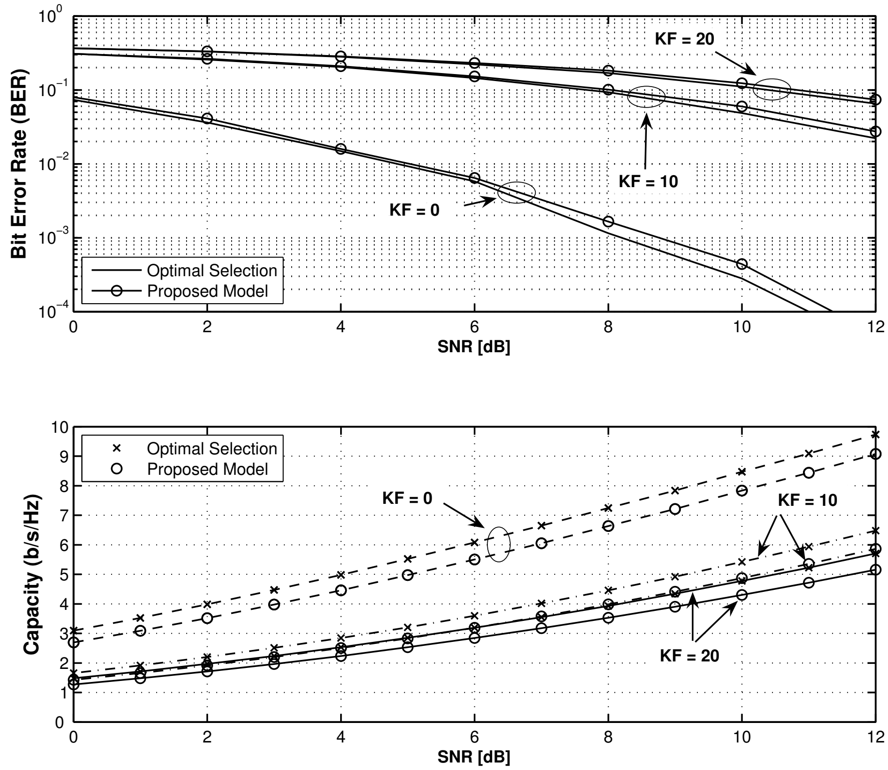

Fig. 5. Performance in Bit Error Rate (top) and Capacity (bottom) in b/s/Hz achieved by the optimal model and the proposed model under a Rician-fading channel.

influence of the channel, the proposed model shows that can be able to keep similar capacity levels as the optimal thanks to a clever choice of antennas. The analysis of the proposed model in this paper is conducted comparing the characteristics of the different antenna selection algorithms, showing the advantages of the new model as well as the favorable results very close to the best possible selection (Optimal).

The contribution made by the proposed model is to maintain the performance and capacity values similar to those obtained by the optimal model, but without making the same number of operations it. The proposed model can be implemented on mobile devices without posing a problem for battery consumption.

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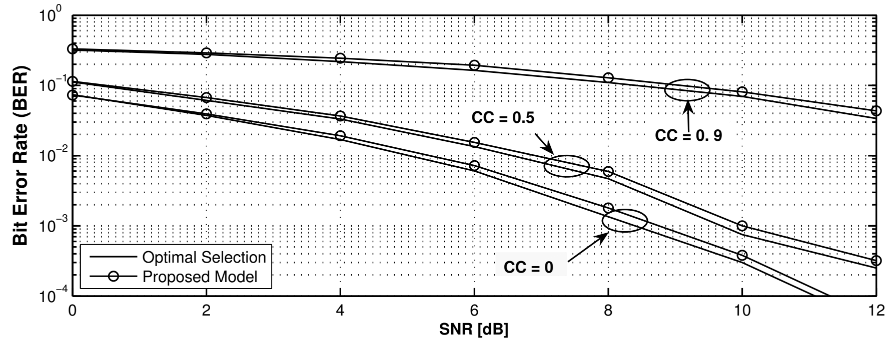

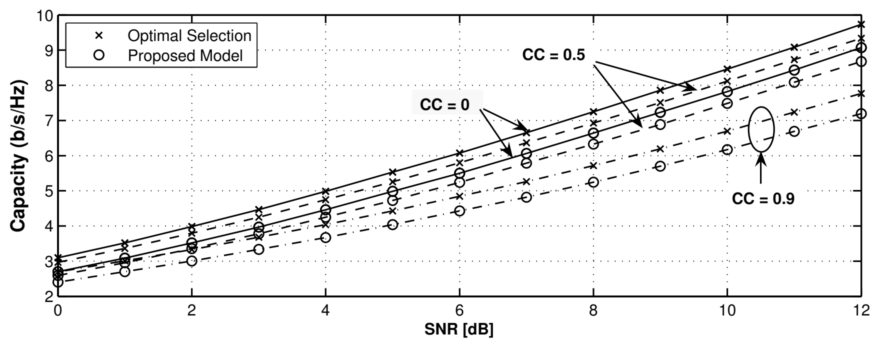

Fig. 6. Performance in Bit Error Rate (top) and Capacity (bottom) in b/s/Hz achieved by the optimal model and the proposed model under a Correlated channel.

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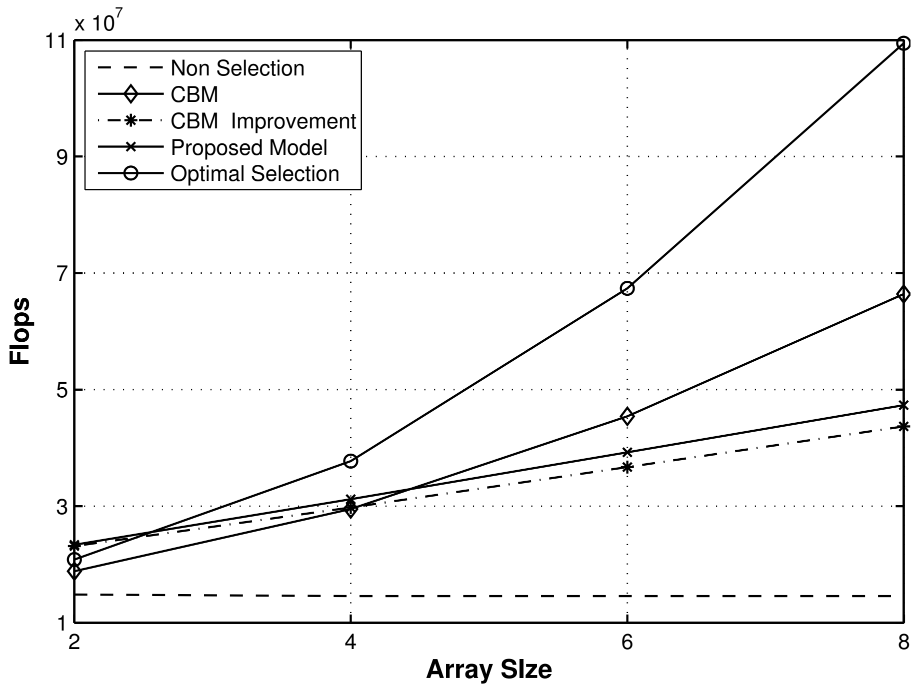

Fig. 7. Measurement of operations performed by Flops function as a function of increase diversity in the receptor achieved by a non selection model, the improved CBM, the optimal model, and the proposed model.

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