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Theoretical Technique to Reduce the Power Consumption of the Antennas in MIMO Transmission System

Eng. Suad Omar Jamil Al-daikh

Balqa Applied University, Faculty of glitter University, Department of Basic Sciences, Ma'an, Jordan

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ABSTRACT

As the use of Multi Input Multi Output techniques increases, especially in modern wireless network technologies, because of the huge amount of spectral efficiency gain that this technique can provide. However, as this technique relies basically on the number of antennas in the transmit and receive sides, the increase of this number enhances the efficiency, but on the other hand, increases the cost and power absorption. This work will concentrate on the parameters that are mostly affect this number, in order to have accurate determination of the required number of antennas that give the best required efficiency with lower probability of error.

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INTRODUCTION

A well-known transmission over selective frequency technique is multicarrier modulation, with its implementation as Orthogonal Frequency Division Multiplexing (OFDM) (Bingham, J.A.C., 1990). Recently, new applications explosively grown as consequences of modern technology, which made the antenna arrays no longer satisfy the requirements of the new applications, in order to guarantee quality of service, parallel OFDM transmission, denoted as Multiple Input Multiple Output OFDM (MIMO OFDM), is the most probable solution for the new generation of wireless communication applications, such as, the MIMO OFDM-Based air interface, which was proposed by Yang, *et al* (2005), aiming to find a road to future broadband wireless access.

For the sake of new modern communication applications, developers, researchers and manufacturers, paid more attention on energy-efficient designs of communication systems. On the other hand, various researches have been conducted and projects have been established, such as Energy Aware Radio and Network Technologies (EARTH), ISS, and GLOBECOM, aiming to enhance the communications systems, and optimize their absorbed energy.

Badic *et al*, in their work (Badic, B., 2009), showed how reducing the size of cells for cellular network increases the number of information-bit per unit energy for a predefined user's destiny, they showed also how the total power in service area will be reduce as a consequence. Maio *et al* in their study (Miao, G., 2009), discussed cross layer optimization in frequency, spatial and time domains. On the other hand, chen *et al* (2011), studied the four fundamental tradeoffs, including spectral energy efficiency, deployment energy efficiency, bandwidth power and delay power.

Latest researches show that increasing number of antenna at transmission base-station delivers better link quality, where it improves coverage and increase spectral efficiency.Basically, the more we placed antenna at transmitter and receiver the more we improve the channel propagation (Rusek, F., 2012). Investigation also showed that massive MIMO technology perform better than conventional MIMO as it provides higher reliability (Xin Su, Jie Zeng and Yu-Jun Kuang, 2013).

MIMO technology enhances the RF channel by using multiple antennas to send multiple RF streams/chains. When these streams combined at the receiver it can provide stronger and cleaner signal (Yasir Mehmood, Umair Younas, 2009).

The selection of antenna is an important factor for transmission quality, but is it cost wise reasonable to increase the number of antennas? and does its performance wise reasonable too? The more antennas used at transmission base-station the more costly it became to deploy massive MIMO technology, as it increase the cost of hardware, it also increases the power consumption, and make it harder to implement and deploy in real life scenario; so in order to implement massive MIMO technology and benefit from its prosperities we need new antenna

Corresponding Author: Eng. Suad Omar Jamil Al-daikh, Balqa Applied University, Faculty of glitter University, Department of Basic Sciences, Ma'an, Jordan

design that can be efficient like massive MIMO and lower in cost.

How antenna design effect Massive MIMO technology? Massive MIMO technology is an extension of array antenna communication with multiple receivers that provide high gain and spatial diversity (Daniel, W., 2005). Placing Massive antenna at terminal is limited by space constraint and the physical shape of the terminal. The limited space forces the antenna to be close to each other which cause problems like signal correlation and degrade the performance of the massive MIMO (*BuonKiongLau and Zhinong Ying, 2011*).

The ultimate goals behind massive MIMO technology is increasing link robustness where massive MIMO technology enhance signal to noise ratio (SNR), and delivering higher throughput by increasing spectral efficiency, in other words; sending more bits per second per hertz. Our goal is delivering these specs with patch antenna, because patch antennas have low cost, variant shapes, low weight, and easy to manufacture.

Certain elements effect the channel quality like modulation used, transmission gain, antenna type, number of antenna, and bit error rate.

In previous studies like (Dorra Ben CheikhBattikhy, 2011) the author considered certain boundaries existed in the conventional MIMO systems, which includes the number of antennas of large scaled antenna arrays that builds a type of multi-users MIMO to improve data rate and link consistency.

In the author did not provide a method or technique to enhance the spectral efficiency but provided a valuable analysis for spectral efficiency with large number of antenna, we will consider this study to evaluate the effect of number of antenna on wireless system performance and how we can replace this large number with small number of patch antenna.

At (ShahabSanayei and Aria Nosratinia, *2004*) the author studied different element to enhance the link robustness, where the author argue that using reconfigurable antenna has huge impact on signal quality. The author claims that it increases the gain up to 30db. The author builds his theory based on diversity of the radiated field by changing polarization and space.

In (Bedri, A., 2006) the author study another approach, where he focused on using patch antenna for medium size MIMO, and how it can provides dual radiation patterns diversity for single frequency using short circuited ring patch, also he claims that it has an impact on spectral efficiency.

This paper, will differ from the previous works by discussing the mentioned topics and concentrating on the method of developing high energy efficient communication system concentrating on simple antenna design for massive MIMO technique. Tring to apply the previous studies outcomes but for simple antenna design; which is more realistic and can be achievable on new technologies, also it will consider the link robustness, because of the belief that achieving quality connectivity will be an aid to increase the spectral efficiency.

To obtain that, the methodology of this work will be by following the below points:

- Studying the requirements of MIMO technique.
- Studying different antenna parameters and evaluate them.
- Investigating the effects of the parameters.

Beside this section, the fundamentals of MIMO technique will be reviewed in the second section, The minimum distance value will be analyzed in the third section, in the fourth section, the probability of error values will be analyzed, in the fifth section, the analytical results will be shown and explained, finally the conclusions will be mentioned in the sixth section.

1. *MIMO Fundamental:s*

There are different types of antenna structures and techniques can be used for wireless communication these days. Multiple Input Multiple Output (MIMO) technique have been widely used in the design of wireless networks, recently. However, Single Input Single Output (SISO), Single Input Multiple Output (SIMO), and Multiple Input Single Output (MISO) are special cases of MIMO.

However, as MIMO technique can be effectively used for improving the capacity of wireless systems. It has tradeoff on regard of power consumption, as it increases the total power consumption for the system.

From the above simple description, some important parameters for the MIMO technique can be obtained. The number of transmit antennas,n_T number of receive antennas,n_R, the efficiency and the absorbed power.

For the number of symbols in the basic constellation, M, can be used to denote for this number. i.e. M = 4 for QPSK modulation. On the other hand, the MIMO matrix can be denoted as a combination of n_R x n_T for a channel H.

While the set of all possible transmitted vectors can be denoted as $S = \{s_p, p = 1, \dots, M^{n_T}\}$ usually, the vector s_p is said to be normalized, to have the total transmit power equal to 1. Such as:

$$\frac{1}{M^{n_T}} \sum_{p=1}^{M^{n_T}} \|s_p\|^2 = 1 \dots\dots\dots\dots\dots\dots \quad (1)$$

2. *Minimum Distance:*

The minimum distance between the elements of Scan be denoted as d_0, which is equal to the minimum norm of the vectors of S.

The technique of MIMO, which contain random matrix, produce noise which is linked to the minimum distanced_{min}. The noise vector can be denoted as R. Such as, if d_{min} is small, this results in some vectors of R are close together, as a consequence of that, a small noise is ought to create an error. This minimum distance can be determined as:

$$d_{min} = \min_{p \neq q} \|r_p - r_q\| \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

A large value of the minimum distance d_{min} ensure a low probability of error.

While the statistical distribution of the minimum distance d_{min} is very important to the characteristics of a MIMO transmission system and to the rate of its error. The statistical distribution of the value ofd_{min}, is important to be derived to reach an accurate result regarding the number of antennas in the matrix.

The sum of $n_R$square moduli of complex circular Gaussian random variables with variance equal to 1, can be denoted as$\|h_m\|^2$. The Probability Density Function (PDF) for this value is as follow:

$$p_h(t) = \frac{1}{(n_r - 1)!} t^{n_R - 1e^{-1}} \;\ldots\ldots\ldots\ldots\ldots \quad (3)$$

While the cdf of d_{min} is:

$$F(a) = P(d_{min} < a) \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

$$F(a) = 1 - \prod_{m=1}^{n_T} P(d_0^2 \|h_m\|^2 > a^2 \;\ldots\ldots\ldots \quad (5)$$

$$F(a) = 1 - \left(1 - F_h\left(\left(\frac{a}{d_0}\right)^2\right)\right)^{n_T} \;\ldots\ldots \quad \ldots (6)$$

The below important equation can be reached:

$$F(a) = 1 - (1 - \Gamma_{\left(\frac{a}{d_0}\right)^2}(n_R))^{n_T} \;\ldots\ldots\ldots \quad (7)$$

Noting that d_0 is the value of the minimum distance between the possible transmit vectors.

3. *Probability of Error:*

Regarding the probability of error$P_e(d_{min})$, for the given minimum distance between the possible transmit vectorsd_{min}. This value is also as important as the minimum distance d_{min} and the number of antennas, n_T and n_R. The determination of this probability will be discussed in the next section, which will talk about the analytical results.

The below equation describes the probability of error:

$$P_e = \int_0^{\infty} p(d_{main}) P_e(d_{main}) dd_{main} \;\ldots.(8)$$

In the above equation, $p(d_{main})$ is the average probability for the channels with d_{main} as minimum distance. The probability density function (pdf) of d_{main} is noted as$p(d_{main})$. However, by solving the above equation using partial integration, the following equation will result:

$$P_e = [F(d_{min}) P_e(d_{min})]_0^{\propto} - \int_0^{\propto} F(d_{min}) p_e'(d_{min}) dd_{min} \;\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Having $p_e'(d_{min})$as the derivative of$P_e(d_{min})$, considering the cumulative distribution function of d_{min} is$F(d_{min})$. While $F(0) = 0$ and$P_e(\propto) = 0$. The below equation can be obtained:

$$P_e = -\int_0^{\propto} F(d_{min})\, p_e'(d_{min}) dd_{min} \ldots \quad (10)$$

The above integral can be computed numerically. While the value of $F(d_{min})$ is determined from equation (7).

And$F(a) = P(d_{min} < a) \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (11)$

The value of $p_e'(d_{min})$ will vary for the lower bound, upper bound and good compromise, as below:

- For the upper bound: $P_{e,inf}'(d_{min}) = -\frac{1}{2\sigma\sqrt{\pi}} \exp\left(-\left(\frac{d_{min}}{2\sigma}\right)^2\right) \ldots\ldots\ldots\ldots. \quad (12)$
- For the lower bound: $P_{e,sup}'(d_{min}) = -\frac{1}{2\sigma^2} \exp\left(-\left(\frac{d_{min}}{2\sigma^2}\right)^2\right) \ldots\ldots\ldots\ldots\ldots \quad (13)$
- For good compromise: $P_e'(d_{min}) = -\frac{1}{\sigma\sqrt{\pi}} \exp\left(-\left(\frac{d_{min}}{2\sigma}\right)^2\right) \ldots\ldots\ldots\ldots. \quad (14)$

4. *Analytical Results:*

To proof the above equations, one example, for lower bound, will be taken, supposing that a MIMO system with $n_T = 2$ transmit antennas, $n_R = 4$ receive antennas and BPSK signaling. Substituting these values in equation (10). The below illustration will result. However, for the experimental estimation can be obtained by averaging over 1000 random matrices H, and 200,000 random noise for each one of H.

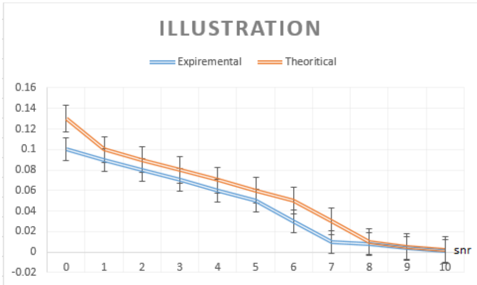

Fig. 1: Illustration: Experimental vs Theoretical of the probability of error (nT = 2, nR = 3).

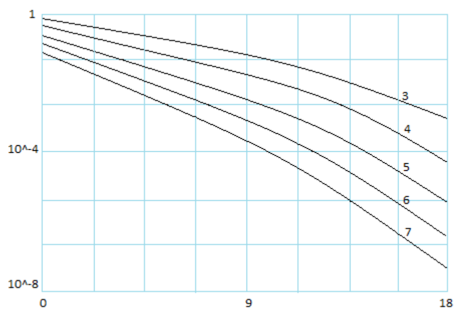

Fig. 2: Probability of error considering snr, for nT = 3 transmit antennas and nR = 3 to 7 receive antennas.

The above figure is the result of the use of equation (48), showing the probability of error, theoretically, considering *snr*, for $n_T = 3$ Transmit antennas andn_R, the number of receive antennas, vary between 3 receive antennas and 7 receive antennas.

The above results can be used to determine the number of antennas, for example when the probability of error less than 10^{-4} and the required *snr* = 14dB. From figure 2, the number of received antennas can be obtained. The value of n_R=6 received antennas.

The same result can be obtained to determine the number of transmit antennas. Figure 3 shows the illustration, that determine the number of required number of received antennas when $n_T = 6$, the error curves for the received antennas between 6 and 10.

For example, if the probability of error lower than 10^{-4} at *snr* = 14dB, then the required receive antennas n_R=9, as shown in figure 3.

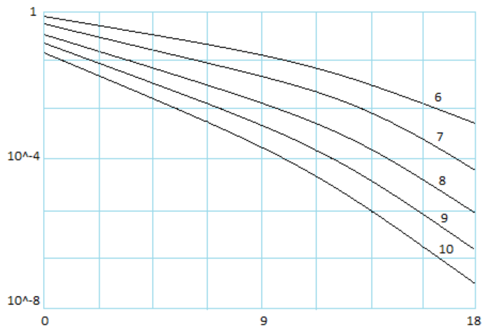

Fig. 3: Probability of error considering snr, for nT = 6 transmit antennas and nR = 6 to 10 receive antennas.

Conclusions:

After reviewing several related works about that deals with the antenna design for MIMO technique. Several methods have been used in these works to enhance the efficiency of the MIMO technique. As this work targets the power efficiency of the MIMO technique antenna design, the analyses concentrated on the antenna parameters that affects the performance and the probability of error.

While the enhanced performance and efficiency, reduces requires increasing the number of required antennas, in the transmit and receive sides, this will increase the probability of error and the power absorption.

However, from this study, a theoretical method were used to find the parameters that affects the determination of the number of the required antennas. As noticed above, the values of *snr*, in addition to the probability of error, can be used effectively to determine the required number of receive and transmit antennas.

Using this method, the number of antennas can be determine, while the parameters that affects this number of the probability of error and the *snr*.

By choosing the best *snr* with the lowest probability of error. The optimal antennas number can be determined. Considering that, the lower number of antenna, the least power absorption. However, using this method, the lower and most optimal number of antennas can be determined, resulting in lower power absorption.

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