Analysis of Channel Capacity Maximization and Optimum Power Control of MIMO Networks

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Abstract
MIMO networks are the most power consuming components because they use multiple RF chains and multiple antennas. Due to the existence of multiple RF chains which in turn contain power amplifiers, LNA’s and different circuit elements, the circuit power consumption increases exponentially which becomes a severe problem in short-range communication scenarios like 802.11-based WLAN etc. The main objective of this paper is to present a comprehensive analysis of one of the most promising techniques for power control called as Antenna management. The proposed antenna management scheme satisfies all the requirements of MIMO systems like BER, data rate, SNR. Channel capacity maximization of MIMO networks using Antenna selection techniques is also presented. Antenna selection techniques select the antennas which gives the best Signal to Noise ratio. Results show that 95% of MIMO channel capacity can be achieved without changing the data rate.

Keywords
Power Management, MIMO, Antenna Management, Energy Per Bit

I. Introduction
In antenna communications the concept of MIMO systems (Multiple-Input Multiple-Output) are greatest extension and development. Improving spectral capacity is today’s greatest requirement while dealing with wireless communications [1]. This requirement is greatly answered by using the concept of MIMO (Multiple-Input Multiple-Output). The multiple-input multiple-output systems enables to increase the spectral efficiency for a given transmit power. Over single-antenna-to-single-antenna (SISO) communication MIMO systems provide a number of advantages. Especially the sensitivity to fading is reduced by the spatial Diversity by providing multiple spatial paths. And for high spectral-efficiency communication the power requirements are significantly reduced by avoiding the compressive region of the information-theoretic capacity bound. The spectral efficiency is defined as the total number of information bits /second/Hz transmitted from one array to the other.

MIMO technology achieves the multipath behavior by using multiple antennas at transmitter side and as well as receiver side and by providing Spatial Diversity to dramatically increase the channel capacity. By using the spatial diversity MIMO are able to allow multiple antennas to send and receive multiple spatial streams at the same time.

The two main basic formats of MIMO are:

A. Spatial Diversity
Spatial diversity used in this narrower sense often refers to transmit and receive diversity. These two methodologies are used to provide improvements in the signal to noise ratio and they are characterized by improving the reliability of the system with respect to the various forms of fading.

B. Spatial Multiplexing
For providing higher data rate capacity by utilizing different paths to carry additional traffic i.e. increasing the data throughput capability the concept of spatial multiplexing is used. However, by using the multiple antennas at transmitter side and at receiver side simultaneously and due to the existence of multiple RF chains, the circuit power consumption increases exponentially which becomes as severe problem in short-range communication scenarios like 802.11-based WLAN etc.

Therefore to address the power management problem in MIMO networks a systematic methodology called as antenna management methodology, which determines the number of antennas and transmit power for each antenna dynamically has been proposed. This proposed antenna management scheme satisfies all the requirements of MIMO systems like BER, data rate, SNR etc. To guarantee the required data rate each data bit is transmitted with minimum energy per bit. Minimum energy per bit is defined as required minimum energy per each individual bit to travel from transmitter to receiver.

The remaining paper is organized as, section II clearly explains about the system model of MIMO system and briefly explains about wireless channel model and MIMO channel model. In section III the originating idea behind this project i.e. the system capacity and MIMO power is discussed and the solutions for all the queries raised in this section clearly answered in following section i.e.in section IV.

The simulation results of this project explained in section V.

II. System Model of MIMO
In this section, the complete architecture of MIMO system which contains a complete description about the MIMO link, MIMO capacity, MIMO Link architecture etc. has been explained. Fig. 1 represents block diagram of the MIMO system with RF channels.

![Fig. 1: A MIMO Link With a Transmitter and a Receiver, Each With RF Chains and Antennas](image)

Firstly, a basic model for the wireless – SISO (Single Input Single Output) channel is presented and then the capacity of MIMO channels and benefits of using MIMO architecture has been discussed.

A. The Wireless Channel
Traditionally the wireless channel is designed as

\[ y = x + n \]

x is input symbol for the channel and it is complex number, referred to as symbol, with two bits of information.

‘x’ can take up to four different values according to the mapping.
The probability of 'x' is equal in all cases. 'n' is defined as the channel noise component. The main reason of 'n' is due to the thermal noise induced by different parts of the receiver. n is modeled as a zero mean, complex Gaussian random variable with variance \( \sigma^2 \) per dimension, i.e., the real part of n and the imaginary part of n are zero mean, statistically independent Gaussian random variables with variance \( \sigma^2 \).

\[
E(n) = 0
\]
\[
E|n|^2 = E(n^*n) = 2\sigma^2
\]

Signal to noise ratio of the Channel is, formulated as
\[
SNR = \frac{E|\chi|^2}{E|n|^2}
\]
\[
= \frac{\rho^2}{\sigma^2}
\]

On the other hand, at the receiver side receiver observes the channel’s output y from the transmitter and decides which symbol, out of the four possible ones, was sent as discussed above. In wireless communication, fading is a most common element through entire communication process. The receiving symbol at the receiver is defined as
\[
y = hx + n
\]
‘h’ is fading constant. And h is modeled as a complex Gaussian random variable with zero mean and variance is 0.5 per dimension.

Therefore the channel SNR is
\[
SNR(h) = \frac{E|\chi|^2}{E|n|^2}
\]
\[
= \frac{\rho^2}{\sigma^2}
\]

### III. MIMO System Capacity

The MIMO system capacity is defined as total bits per second per total number of active channels [4]. Generally the capacity of the system is nothing but the maximum throughput of the system while maintaining the lowest probability of the error.

The capacity of the wire line Single Input Single Output channel is given by [6]

\[
C_{SISO} = \log_2 \left(1 + \frac{P}{2\sigma^2}\right)
\]

Where P is the transmission power
\[
P = E|\chi|^2
\]

Therefore from the above equation it is clear that for the wire line SISO channel, the capacity will be increased only if the transmission power ‘P’ is increased. But this is not the case for wireless MIMO channels. The capacity of the wireless MIMO channel is

\[
C_{MIMO} = \log_2 \det \left(1 + \frac{P}{2\sigma^2 M} Q\right)
\]

Where
\[
P = \sum_{i=1}^{n} E|x_i|^2
\]

P is the total transmission power radiating from the all active transmitting antennas at transmitter side.

Therefore, it is clear that higher transmit power ‘P’ or large number of active antennas at both the sides i.e. at transmitter side and receiver side can increase the channel capacity ‘C’.

However, these both possible ways will increase power consumption of the transceiver [8]. The efficient solution for this problem is designing a large Ricean Factor, so that the sub-channels are highly correlated and under these circumstances it may not be energy efficient to employ a large number of active antennas.

### C. MIMO Power Model

Generally a MIMO link is a combination of active transmitter antenna and an active receiver antenna. Therefore the power consumption of a MIMO link \( P_{\text{MIMO}} \) is combination of power consumption at transmitter antenna \( P_{\text{Transmit}} \) and as well as the power consumption at receiver antenna \( P_{\text{Receive}} \).

\[
P_{\text{MIMO}} = P_{\text{Transmit}} + P_{\text{Receive}}
\]

\( P_{\text{Transmit}} \) is the combind effect of all the power consumed by all power amplifiers \( P_{PA} \) and circuit elements \( P_{\text{Circuit},i} \)

\[
P_{\text{Transmit}} = P_{PA} + P_{\text{Circuit},i}
\]

Assume that identical power amplifiers are used in all RF chains so that \( P_{PA} \) depends on total transmitting power \( P_{TX} \)

\[
P_{PA} = \eta_P P_{TX}
\]

\( \eta_P \) : Drain efficiency of the power amplifier.

\( P_{\text{Circuit},i} \) can be divided into that contributed by each active transmit RF chain, \( P_{RF,\text{Chain},i} \) and that by the circuit shared by all active transmit RF chains, \( P_{\text{Shared},i} \)

Therefore

\[
P_{\text{Transmit}} = \eta_P P_{TX} + N_T P_{RF,\text{Chain},i} + P_{\text{Shared},i}
\]

\( N_T \) is the number of active antennas in the transmitter.

Similarly, Power consumption at receiver is formulated as \( P_{\text{Receive}} \).
is power consumed by each receive RF chain and \( P_{\text{SHARED,R}} \) is shared receive circuit power consumption. Therefore from all the above discussion, the capacity of MIMO system will increase by increasing the power only. In this paper, the increased capacity of MIMO system by efficiently managing all the active antennas in MIMO transceiver and active RF chains by using Antenna Management Scheme has been discussed.

**IV. Antenna Management**

The main objective presented behind the scheme of antenna management is to provide efficient solution for the power management in MIMO systems.

Antenna management scheme consists of “Pre-built mapping techniques” and “Efficient Antenna Selection technique”. Pre-built mapping technique is used to calculate the optimal transmitting power \( P_{\text{TX,OPT}} \) and efficient antenna selection techniques are used to calculate the optimal antenna configuration \( \omega_{\text{OPT}} \).

**A. Pre-Built Mapping**

Pre-Built Mapping is a systematic procedure to calculate the optimal transmit power. In this procedure, with different combinations of \( N_T \) and \( N_R \) corresponding channel matrix, the different transmitting powers delivered from the transmitter can be calculated. While performing this procedure, approximate transmitted power level \( \rho_{\text{TX,APPROX}} \) also calculated. By repeating this process, for hundreds of different RF communication links exists between active receiving antennas and transmitting antennas \( \rho_{\text{TX,APPROX}} \) are calculated. Then by considering the systematic mean of all approximated values, the optimum transmitted power \( P_{\text{TX,OPT}} \) can be found out.

**B. Efficient Antenna Selection**

In this procedure a systematic procedure has to be followed as: At the given combination of active transmitting antennas and receiving antennas the minimum bit energy rate is calculated. And it is apparent that given fixed \( N_T \) and \( N_R \) minimizing \( E_b \) is equivalent to maximizing \( R \) since \( P \) is constant. Therefore we perform this procedure of finding \( \omega_{\text{OPT}} \) into several multiple steps where each step can be solved by existing antenna selection algorithms, e.g. [7].

**V. Simulation Results and Analysis**

The objective of this project mainly concentrates to increase the capacity of the MIMO system under giver power constraint by efficiently managing the power using proposed “Antenna Management” technique.

In this context we analyze the results in a sequential manner as discussed below.

Fig. 3 represents the comparison among 4 different combinations of single MIMO systems i.e. the capacity of MIMO system is compared when antenna selection increases linearly by 1 (like 1, 2, 3 and 4). Obviously as discussed in above sections the carrying capacity of MIMO system increases whenever the number of active antennas increases as shown in figure 3. Similar results are shown simulatively in fig. 4 as shown below

**Fig. 4: Performance comparison of MIMO system**

Fig. 4 clearly represents the performance comparison of MIMO channel capacity with Shannon capacity

Fig. 4 shows that the capacity of MIMO increases as antennas increases while the power requirement also increases linearly as number of antennas increases.

Therefore using proposed method i.e. Antenna Management technique we can efficiently manage the all active antenna under all power constrains.

Fig. 5 represents the different noise levels present in different MIMO communication links. The allocation of power levels depends on the current levels of the noise channels which are un-able to pre calculate in real world applications.

**Fig. 5: Noise Levels in MIMO Channels**

For our convenience the different levels of noise in different communication channels are pre fixed as shown in fig. 5. Here
the allocated nose level occupies some extent of MIMO link and remaining part of the communication link is occupied by antenna power as shown in fig. 6. Fig. 6 shows the power level occupation in MIMO communication link.

After considering all the above situations and effectively applying the proposed scheme, the complete results for proposed methods are shown in below fig. 7. Fig. 7 shows the results for MIMO system for different combinations of antennas under proposed scheme considerations.

VI. Conclusion
The proposed antenna management scheme has found to be the best power management technique. Compared to previous paper, the 95% of MIMO channel capacity has been obtained with out changing the data rate.

References