POWER OPTIMIZATION FOR MULTIPLE MIMO ANTENNAS

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ABSTRACT:

Fifth generation (5G) cellular network is essentially a revolutionary paradigm shift in wireless networking to support the throughput, latency, and scalability requirements of future use cases such as extreme bandwidth augmented reality applications and connectivity management for billions of M2M (Machine to Machine) devices. High-speed wireless network interfaces are among the most power-hungry components on mobile systems that rely on battery for energy supply and passive means for heat dissipation. This is particularly true for MIMO network interfaces which use multiple RF chains simultaneously. The design of MIMO antenna systems is a challenging task. However, in previous works on multiple-input multiple-output (MIMO) antenna selection, it is usually assumed that the transmit power and the number of active antennas is fixed. In this paper, we jointly optimize the transmit power, the number of active antennas, and the antenna subsets at the transmitter and receiver to maximize the power efficiency. The results show that the proposed solution can significantly improve the power efficiency with a minimum impact on the complexity and cost of the overall system.

Keywords: Power efficiency, MIMO System, multiple antenna selection.

[1] INTRODUCTION

The antenna has become more of a challenge these days because many new wireless devices have put greater demands on it and have made wireless design more complex. Antennas are essentially resonant devices designed for a narrow range of frequencies. Today, they must serve a wider range of frequencies in form factors that present serious physical challenges as follows.

Wider frequency ranges: Cell phones must cover the low bands from 698 to 960 MHz as well as the higher bands from 1701 to 2170 MHz this is hard to do with a single antenna. Impedance matching is a chore over such a wide range, so efficiency usually suffers.

Multiple antennas per device: The average smart phone has up to seven radios. Besides the multiband cellular transceivers, smart phones include a Wi-Fi radio, Bluetooth, GPS, and possibly FM radio. TV is coming, too. All of these antennas have to fit inside a clean physical handset or a slim tablet package, and they can’t interfere with one another or be detuned by the user’s hand or face.

New modulation demands more bandwidth: Long-Term Evolution (LTE) and other modern wireless devices have all adopted orthogonal frequency-division multiplexing (OFDM) as the main modulation/access method. This broadband scheme requires lots of bandwidth from as
little as 5 MHz up to 40 MHz and beyond. The usual trade off is less efficiency for greater bandwidth.

**MIMO on everything:** The use of multiple-input multiple-output (MIMO) is a real breakthrough that is not only boosting data rates for a given bandwidth but also is making wireless links longer and more reliable despite multipath fading and other problems. MIMO means more antennas per device, so that design of MIMO antenna systems is a challenging task especially when it is made for small factor mobile terminals [1].

Hence a great deal of antenna development is focused on wireless devices. As carriers upgrade their networks to the latest technologies like HSPA+ and LTE, new antennas are a must, mainly because of the MIMO requirement to get higher data rates and improved link reliability. Power wave Technologies recently introduced an active array antenna for MIMO in wireless devices [2] [3].

In previous works on antenna selection, it is usually assumed that the total transmit power is fixed and the number of active RF chains is also given and fixed; the problem is to select the antenna subset which can achieve the highest capacity. In this work, we consider antenna selection in terms of energy efficiency. Energy efficiency, defined as the number of transmitted information bits per unit energy, is becoming increasingly important for wireless systems (e.g., see [1]). More active RF chains can usually achieve higher data rates, but they also consume more power. Here, we aim to maximize the energy efficiency through a joint optimization over the transmit power, the number of active RF chains, and the antenna subset [4]. We show that antenna selection can achieve significant improvement on power consumption in diversity systems when one data stream is employed. Antenna selection also has potential for multi-stream systems; this will be evaluated more closely in future work [5].

The rest of the paper is structured as follows: The system model and the problem description are given in Section II. In Section III, antenna selection algorithms are developed. Finally, simulation results and conclusions are presented in Sections IV and V, respectively.

**[2] SYSTEM MODEL**

Consider a point-to-point MIMO system with $N_t$ antennas at the transmitter and $N_r$ antennas at the receiver. Denote the selected transmit antenna subset as $\omega_t$ and the selected receive antenna subset as $\omega_r$; so, the number of active transmit and receive antennas are $L_t = |\omega_t|$ and $L_r = |\omega_r|$, respectively, where $|\cdot|$ denotes the cardinality of a set, $L_t \leq N_t$ and $L_r \leq N_r$. The received signal at the receiver is then
Figure 1. Block diagram of antenna selection with $L_t$ out of $N_t$ transmit antenna selected and $L_r$ out of $N_r$ receive antenna element selected.

\[ y = \sqrt{p_t} u^H H[\omega_t, \omega_r] q + u^H n \]  

(1)

where $x$ is a single-stream transmit signal, $p_t$ is the transmit power, $q$ is the normalized precoding vector of length $L_t$ at the transmitter, $u$ is the normalized decoding vector of length $L_r$ at the receiver, $H[\omega_t, \omega_r]$ is the $L_r \times L_t$ channel matrix between the $\omega_t$ transmit antenna subset and the $\omega_r$ receive antenna subset, and $n$ is an additive white Gaussian noise vector at the receiver. The channel coefficients are modeled as i.i.d. complex Gaussian random variables with zero mean and unit variance. The SNR at the receiver can be written as

\[ SNR = \frac{p_t ||u^H H[\omega_t, \omega_r] q||^2}{\sigma_n^2} \]  

(2)

Where $\sigma_n^2$ is the additive noise power. In order to maximize the SNR, maximal ratio transmission (MRT) and maximal ratio combining (MRC) are applied at the transmitter and receiver, respectively. Thus, we have $||u^H H[\omega_t, \omega_r] q_{MRC}||^2 = \lambda_{\text{max}}[\omega_t, \omega_r] = ||H[\omega_t, \omega_r]||^2_2$ where $\lambda_{\text{max}}[\omega_t, \omega_r]$ is the largest eigenvalue of the channel matrix $H[\omega_t, \omega_r]$, which is also equal to the square of the 2-norm of $H[\omega_t, \omega_r]$. Therefore, the SNR in (2) can be rewritten as

\[ SNR = \frac{p_t ||u^H H[\omega_t, \omega_r]||^2}{\sigma_n^2} \]  

(3)

And the achievable rate (in bits/sec/Hz) is

\[ r = \log_2(1 + \frac{p_t ||H[\omega_t, \omega_r]||^2}{\sigma_n^2}) \]  

(4)

The energy efficiency can be expressed as

\[ \eta_{EE} = \frac{\text{(Br)}}{\rho p_t + p_c} \text{ bits/joule} \]  

(5)

Where $B$ is the bandwidth, $\rho$ is the reciprocal of the power amplifier efficiency, and $p_c$ is the circuit power excluding the power consumed by the power amplifier [8]. Thus, the numerator in (5) is the rate (in bits/sec) achieved, and the denominator is the total power consumption.

We model the circuit power $p_c$ as a function of the number of active RF chains [10]

\[ p_c = L_r p_{et} + L_r p_{er} + p_{co} \]  

(6)

Where $p_{et}$ and $p_{er}$ are the power consumed by each transmit and receive RF chain, respectively, and $p_{co}$ is the power consumed in all the other parts of the circuitry, such as in the DSP. Here,
we assume that $p_{co}$ is fixed. Thus, the overall power consumption of MIMO system can be obtained as

$$P = \frac{1}{\eta_{pa}} \cdot p_t + p_c$$  

(7)

Where $\eta_{pa}$ is the drain efficiency of the power amplifier, therefore, the normalized (with respect to bandwidth) energy efficiency is

$$EE = \frac{\log_2 \left( 1 + \frac{p_t \| h \|_F^2 |\mathbf{a}_r^* \mathbf{a}_t|^2}{\sigma_k^2} \right)}{p_t \| h \|^2 (\mathbf{a}_r \mathbf{a}_t^*)^2}$$  

(Bits/Hz/Joule)  

(8)

We will maximize the normalized energy efficiency (8) by optimizing the receive antenna subset and the transmit power, subject to a spectral efficiency (SNR) constraint, that is,

$$\left( p_t^{opt}, \mathbf{a}_r^{opt}, \mathbf{a}_t^{opt} \right) = \arg \max EE$$  

(9)

$\therefore$ $SNR \geq \gamma$  Where $\gamma$ is the required SNR at the receiver.

[3] ANTENNA SELECTION ALGORITHMS

In this section, we propose a low complexity algorithm to achieve the near-optimal antenna selection performance. Figure 2 aims is to find the optimal number and subsets of active receive or transmit antennas that achieve the maximum capacity under the constraint of a total power consumption $P$.

**Optimum antenna selection:**

The capacity of MIMO system using all antenna elements is given by

$$C_{full} = \log_2 \left[ \det \left( I_{N_t} + \frac{SNR}{N_t} HH^* \right) \right]$$  

(10)

Where $I_{N_t}$ the identity matrix, superscript $\dagger$ denotes the Hermitian transpose. The receiver now selects those antennas that allow a maximization of the capacity, so that
The optimum selection of the antennas requires \( \binom{N}{L} \) computations of determinants, and is thus rather computationally intensive. It seems thus worthwhile to investigate suboptimum algorithms with lower computational complexity. In this section, we present a family of such algorithms that result in a small SNR penalty while drastically reducing computation time. The determinant in (11) can be written as

\[
\text{det} \left( I_L + \frac{S/N}{L_e} H H^T \right) = \prod_{l=1}^{L} (1 + \frac{S/N}{L_r} \lambda_l^2)
\]  

Where \( m \) is the rank of the channel matrix and \( \lambda_1 \) is the singular value of \( HH^T \) the rank and the singular values should be maximized for the maximum capacity. Suppose there are two rows of \( H \) which are identical. Clearly only one of these rows should be selected in (11). Since these two rows carry the same information, we can delete any of these two rows without losing any information regarding the transmitted vector. In addition if they have different powers (i.e. square of the norm of the row), we select the row with the higher power. When there are no identical rows, we choose those two rows for the possible deletion whose correlation is the highest. In this manner we can have the channel matrix \( HH^T \) whose rows are maximally uncorrelated and have maximum powers. This intuition leads to the following algorithm, will be called “Power Based Method (PBM)”

1. Channel vector \( h_l \) is defined as the \( l \)-th row of \( H \) with \( l \) being an element of the set \( X = \{1, 2, 3, \ldots, N_r\} \)
2. For all \( l \) and \( p \), \( l > p \) compute the correlation \( \rho(l, p) \) the correlation defined as \( \langle h_l, h_p \rangle \) where \( \langle a, b \rangle \) represents an inner product between vector a and b.
3. Loop
   a. Choose the \( l \) and \( p \) (with \( l, p \in X, l > p \)) that give the largest \( \rho(l, p) \), if \( ||h_l||^2 > ||h_p||^2 \), eliminate \( h_l \) otherwise eliminate \( h_p \)
   b. Delete \( l \) or \( p \) from \( X \)
   c. Go to loop until \( N_t - L_t \) and \( N_r - L_r \) rows are eliminated.

\[ C_{\text{select}} = \max \{ \log_2 [\text{det} \left( I_L + \frac{S/N}{L_e} H H^T \right)] \} \]
The PBM does not require knowledge of the SNR value and is based on the correlation of the rows of the channel matrix $\langle h_i h_j^* \rangle$, which is approximated by the correlation of the noisy estimates $\mathbb{E}\{y_i y_j^*\}$.

[4] SIMULATION RESULTS

In this section, we evaluate the capacity as obtained with our selection algorithm, as well as that obtained by exhaustive search, for practical system parameters. For the computer experiments (Monte Carlo simulations), we created random realizations of mobile radio channels. For the exhaustive search, we create a complete set of all possible matrices $\mathbb{H}$ by eliminating all possible permutations of $N_t - L_t$ and $N_r - L_r$ rows from the matrix realization $H$. For each of the $\mathbb{H}$ we compute the capacity by (11) and select the largest capacity from the set. The values for the parameters $Pct, Pcr, Pco$ and $\eta_{pa}$ are 120mW, 85mW, 30mW, and 35%, which are adopted from [9]. $d$ is the distance between the transmitter and receiver. The log-distance path loss model with an exponent of 4 is adopted as the large-scale path loss. $N_t = N_r = 8$, and $R$ is 5(bits/s/Hz).

Figure 4 illustrates the optimal transmission power $P_t$ as a function of the transmission bit rate. It can be seen that much more power is consumed for the transmission when there is no antenna selection. On the other hand, we can see that the optimal transmission power with antenna selection is small and changes very slowly for most of the bit rate. This fact shows that antenna selection not only improves the energy efficiency but also reduces the transmission power.
Figure 5 Exhibits the transmission powers with antenna selection. We observed that by increasing the number of antenna array elements ‘M’, the data rate performance improved. It is noticeable that the crossover point is higher than that for the ideal receiver, i.e., $r/w = 3.9$ bps/Hz.

![Figure 5. Transmission Power Consumption](image)

Figure 6 shows the expected delays for the arrival traffic rates. We observe that by increasing the number of antenna array elements ‘M’ the delay performance improved,

![Figure 6. Average delay Vs Arrival rate](image)
[5] CONCLUSION

We developed antenna selection algorithms for Low power multiple MIMO antenna based on the tradeoff between the data rate, power consumption, and energy efficiency. we jointly optimize the transmit power, number of active RF chains, and antenna subsets to maximize the system energy efficiency and power reduction is almost as good as that using the exhaustive search.

REFERENCES


Author[s] brief Introduction

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