Energy Efficiency and Capacity Analysis for Spatial Modulation in MIMO Systems

V. Meena, RamarakulaMadhu

[1]M.Tech(computers and communications), [2]AssistantProfessor JNTU, Kakinada
Department of Electronics and Communication Engineering
JNTU, Kakinada, India

Abstract: In cellular systems the multiple-input and multiple-output (MIMO) is a method for enhancing the capacity using multiple antennas at transmitter and receiver. MIMO has become an essential element of wireless systems including 4G-LTE. MIMO is aimed to achieve good quality of service (QOS) in high mobility environments with large arrays of many antennas in order to serve several independent terminals in terms of more signal paths and link reliability. Energy efficiency(EE), spectral efficiency(SE) and capacity are the important parameters for a MIMO system. In this paper, a framework is proposed the optimization of EE and capacity using spatial modulation(SM) based schemes with different transmission modes. In this first the simplified closed-form approximation of the SER/BER is derived which is applicable for different modes. Both optimization problems are subject to certain error rate, transmission rate, and power constraints. By linking the error rate requirement to transmit power through closed-form approximation, the proposed approximations can be easily solvable by simple exhaustive search with a low complexity. The simulation results are obtained for EE, SE and capacity in terms of SNR for different transmission modes. It is observed that there is a gradual increase in MIMO capacity with respect to the gradual increment in SNR with different levels of transmission modes.

Index Terms: MIMO, LTE, Signal Beam-forming, Spatial Modulation, Energy efficiency, Transmission Modes

I.INTRODUCTION

MIMO can be extensively used in 3G/4G wireless systems. It comprises of multiple transmitter antennas and multiple receiver antennas and it also comprise of large number of fading channels[1]. MIMO helps to improve wireless access such that, connecting hotspots, providing wireless or cable and providing high speed mobile data. It is also useful for telecom devices like 4G and LTE and in different types of technology like OFDM. In MIMO the data rate can be increased by transmitting the information in parallel, the information goes in parllely is called the spatial multiplexing[2].

Now the wireless communications need high quality of services such as high data rate besides it demanding to sever more applications and subscribers at a time, this turned as a great challenge especially in cellular communication. MIMO is the advent answer to this challenge. MIMO makes a clean break with current practice through the use of a very large number of service antennas (e.g., hundreds or thousands) that are operated fully coherently and adaptively[3]. For MIMO base stations are equipped with large antenna arrays at transmitter and receiver sides and aimed to serve more independent terminals simultaneously under the single frequency-time resource. In MIMO beam forming is exploited by using radio propagation of reciprocity of uplink-downlink[4].

Quality of services that are provided by MIMO depends on the estimation of Channel State Information (CSI)[5] which is obtained from the transmitted uplink pilots by the terminals which makes the MIMO as scalable with respect to the size of base station antennas. In MIMO as antenna arrays size and correspondingly the number of data streams increases the complexity also increases rapidly. In this every node should be able to aware the data transmitted from one antenna to that transmitted from another, otherwise network performance will be severely affected. When compared to legacy LTE networks[2], MIMO supports higher spectral efficiency and these largest gains obtained from the concept of spatial modulation of several users of cells..

Spectrum efficiency(SE) refers to the information rate that can be transmitted over a given bandwidth in a specific communication system. Efficient energy is sometimes called as energy efficiency(EE),is the goal to reduce the amount of energy required to provide products. Therefore MIMO suffers from the spectral leakage if the traffic load does not meet the required threshold level. Channel capacity is that the maximum amount of data that may be transferred between the network locations over a link or a network path[6].In this paper, a framework is proposed to optimize the EE, SE and capacity of MIMO by employing the concept of transmission mode according to the large scale fading loss and spatial correlations [7]. This frame work is aimed to optimize SE and EE by considering spatial modulation based schemes such as constellations of space signal, active antennas at base stations and different transmission rates with different transmit diversity gains.

II.BEAMFORMING AND TRANSMISSION MODES

MIMO technology is used to achieve high data rates, and by exploiting the transmission modes [7] with beamforming it is possible to optimize the spectrum and energy to provide better QOS [8] to transmission users in the edges of antenna cell, provides high availability of communication links and data transmission rates. Higher data rates are achieved by using spatial modulation whereas data is divided into several individual blocks modulated and then transmitted parallel through unique air interface resources. In order to achieve the high data rates Channel State Information (CSI) [9] will be calculated via a special feedback channel, which enables a dynamic adoption of channel circumstances. Data transmission robustness will be increased by exploiting the concept of transmit diversity [4], which means that the multiple copies of same data (using redundant codes) will be transmitted using more individual antennas or arrays.

***Beam forming*:**

Beam forming [10] is a radiation pattern technique of an antenna in order to optimize the transmission/receive signal availability. Multiple antennas are used to control the direction and beam width [11]of the wave front by weighing the phase and magnitude of individual signals which are transmitted by individual antennas and this array gain also referred as beam forming gain [12]. At the receiver gain of the beam formed wave fronts will decides the optimal direction of the arrived signal (DOA). And it is also allows us to block the signals which are interfacing by exploiting null beam pattern in their arrival direction. Figure 1 represents the antenna array system of multiple individual directional antenna, and these individual antennas are far away from each other with unique distance d. As shown in fig 1 the transvers distance of a wave front [13] between two adjacent antennas is d*sin(θ) and the delay between the antennas is calculated τ as

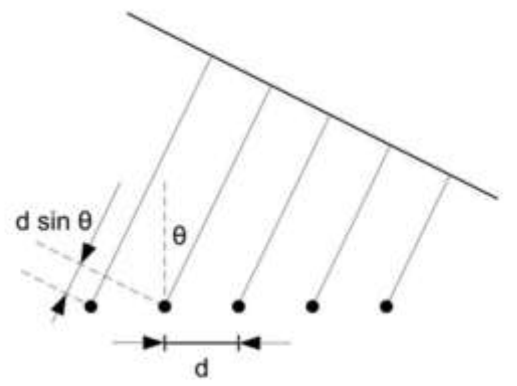

Fig1: Antenna Array

$$\tau = \frac{d \sin\theta}{c} \quad \textbf{(1)}$$

Where '*c*' is the light speed.

The signal s_i at each antenna is

$$s_1(t) = S(t-\tau) \approx s(t)e^{-j\theta} = S(t-M-1)\tau \approx s(t)e^{-j(M-1)\theta}$$

$$s_0(t) = s(t)$$

Where the beamforming signal vector s(t) is defined as

$$S(t) = \begin{bmatrix} 1 \\ e^{-j\theta} \\ e^{-j2\theta} \\ \vdots \\ e^{-j(M-1)\theta} \end{bmatrix} .s(t) = a(\theta).s(t) \quad (2)$$

The concept of beamforming is achieved [10] by calculating and assigning the weight of the signal at all antennas of the array,

$$y(t) = w^H.a(\theta).s(t) \quad \textbf{(3)}$$

All the individual signals which are transmitted by the individual antennas of array are weighted and grouped in the required direction and overall beam formed signal weight is referred [9] as *w*. At the base stations in order to calculate the weight vector of arrives beam formed signal MUSIC or ESPRIT [10] algorithms are employed.

Based on the concept of beamforming various transmission modes are exploited in MIMO as concluded in below table[10].

Table 1: MIMO transmission Modes

Transmission modes	**Description**	**Comment**
1	Transmission Antenna – Single	Single Antenna - Port 0
2	Transmit diversity	2 or 4 antennas - Ports 0,1 (…3)
3	ıtial Multiplexing – Open loop with CDD	2 or 4 antennas - Ports 0,1 (…3)
4	Spatial Multiplexing – Closed Loop	2 or 4 antennas - Ports 0,1 (…3)
5	MIMO – Multi user	2 or 4 antennas - Ports 0,1 (…3)
6	Spatial Multiplexing – Closed Loop with single transmission layer0	1 layer (rank 1),2 or 4 antennas - Ports 0,1 (…3)
7	Beamforming	single antenna port, port 5 (virtual antenna port, actual antenna configuration depends on implementation)
8	Dual-layer beamforming	dual-layer transmission, antenna ports 7 and 8

9	8 layer transmission	Up to 8 layers, antenna ports 7 – 14
10	8 layer transmission	Up to 8 layers, antenna ports 7 – 14

Models for Mode Selection:

In order to select the appropriate mode here considered Spatial Modulation[12] based device to device MIMO system of N_t transmit antennas, N_r receiving antennas. All these transmitting and receiving antennas are communicating through the dynamic radio frequency channels[13] with known large scale fading losses We considered known transmission mode set φ with size M and based on channel correlations and large scale fading losses we need to select the appropriate mode m. At the receiver side special modulation is used based on the selection of transmission mode and at the receiver side ML (Maximum Likelihood) detector is employed for signal detection. Figure 2 represents the system model and we have considered identically distributed independent channels with uniform variance and no mean.

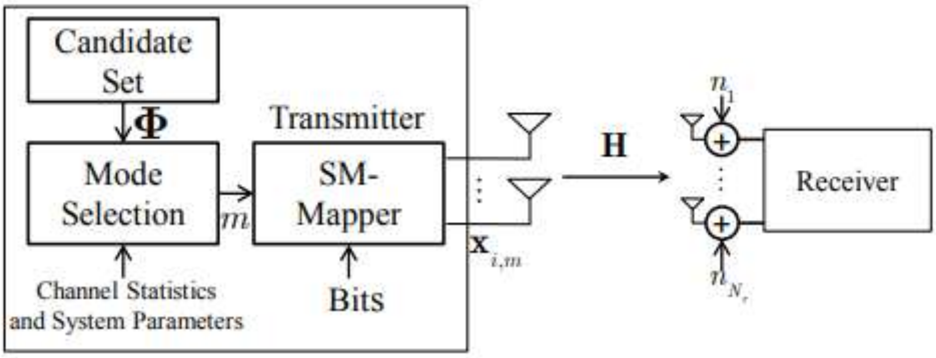

Fig. 2: System model for the SM-based MIMO with mode selection

Received signal *y* of the MIMO system [22] is

$$y = \sqrt{\frac{G_a p_{tr,m}}{d_{loss}}} R_r^{1/2} H_w R_t^{1/2} x_{i,m} + n \quad \textbf{(4)}$$

Where $x_{i,m}$ is the spatial modulated transmit symbol sequence of MIMO systems, H is uncorrelated identically distributed independent channel matrix, R_t *and* R_r are transmit and receive antennas. $P_{tr,m}$is the transmit power [16] of mode m and large scale fading loss is defined as d_{loss} and overall composite power gain of the MIMO is G_a.

As we have employed mode selection concept all the antennas are not activated while transmitting the data. Therefore spatially modulated input signal is expressed as[17]

$$x_{i,m} = \frac{1}{\sqrt{N_{a,m}}} \left(\sum_{k=1}^{N_{a,m}} e\left(l_{i,m}^{(k)}\right) S_{k,i,m} \right) \quad \textbf{(5)}$$

Multiplexing scheme of k with N_m signal constellation size is $S_{k,i,m}$, e_i is i^{th} standard unit vector $l_{i,m}^{(k)}$ is the antenna idex.

III. PROPOSED METHOD

In this paper a MIMO system is employed with predefined modes φ with known large scale fading losses. The analysis of the SER or BER with respective to the SNR in order to select the appropriate mode selection approach and SE, EE and capacity are optimized based on mode selection. Channel State Information (CSI) of MIMO is employed by closed loop feedback channel from receiver to transmitter. The SNR of a maximum likelihood type detector at receiver side as

$$\rho_m = \frac{G_a P_{tr,m}}{\sigma_n^2 d_{loss}} \quad \textbf{(6)}$$

The transmission modes based on the conditions of SER $p_{ser}^{(m)}$and BER $p_{ber}^{(m)}$ of channel as

$$\rho_{ser}^{(m)} \le \sum_{i=1}^{N_{c,m}} \sum_{j=1, i\neq j}^{N_{c,m}} \frac{Q\sqrt{D}}{N_{c,m}}$$

$$\rho_{ber}^{(m)} \le \sum_{i=1}^{N_{c,m}} \sum_{j=1, i\neq j}^{N_{c,m}} \frac{N_{i,j} Q\sqrt{D}}{N_{c,m} \log_2 N_{c,m}} \quad \textbf{(7)}$$

Where Q is a Q- function, Number of errors are N(i,j), D is the weight of the beamforming and it is defined as

$$D = \frac{\rho_m}{2} \left\| R_r^{1/2} H_w R_t^{1/2} x_{i,m} - x_{j,m} \right\|^2 \quad \textbf{(8)}$$

Transmission mode selection is based on Spectral efficiency. Total power consumption of the transmitter with mode *m* is

$$p_{T,m} = p_{c,m} + \eta^{-1} P_{T,r,m} \quad \textbf{(9)}$$

Circuit power consumption is $P_{c,m}$, efficiency of the power amplifier is represented with η and PAPR is denoted with κ_m. The total power consumption of the MIMO including active channels with the mode is defined as

$$p_{T,m} = Bb_m p_c + N_{a,m} BP_b + P_f + N_{a,m} P_{c1} + N_{a,m} P_{c2} + \ldots + N_{a,m} k_m \left(\frac{P_{tr,m}}{N_{a,m}} \right) \quad \textbf{(10)}$$

Where B is the total available channel BW,$b_m$is transmission rate, P_b is the power consumption of the base band processing, P_f fixed circuit power consumption,P_{c1} and P_{c2} are circuit power consumption parameters.

Therefore after deploying the mode selection process and considering the average transmit power P_{ave} and SER of mode m is $p_{e,m}$ the optimization problem is defined as[25]

$$\max_{m \in \phi} b_m \quad s.t \;\; P_{tr,m} = P_{ave}, P_{e,m} \le P_{req} \quad \textbf{(11)}$$

The spectral efficiency is employed when $P_{tr,m} = P_{ave},$ and closed form approximation is derived as

$$\max_{m \in \phi} b_m \quad s.t. \;\; \frac{\psi_{c,m}}{N_{c,m}} \frac{\frac{(2p-1)!}{p!(p-1)!}}{\prod_{k=1}^{p} \xi_k} \left(\frac{G_a P_{ave}}{\sigma_n^2 d_{loss}} \right)^{-p} \le P_{req} \quad \textbf{(12)}$$

Where $\psi_{c,m}$ is the eigenvalue of the channel and is defined as

$$s(t)\psi_{c,m} = \sum_{i=1}^{N_{c,m}} \sum_{j=1, i \ne j}^{N_{c,m}} \left(\psi_{ij,m}\right)^{-p} \quad \textbf{(13)}$$

P is the total power consumption, G_a overall composite power gain of the MIMO is G_a, ξ_k is none zero eigen values.

Therefore by solving the equation (12) the all available individual unique modes can be solved in the set of ϕ.

$$\frac{(2N_r - 1)!}{(N_r)!(N_r - 1)!} \left(\frac{1}{\rho_m \varphi_{ij,m}} \right)^{N_r} \; and \; \frac{(2P-1)! \big/ P!(P-1)!}{\prod_{k=1}^{p} \xi_k} \left(\frac{1}{\rho_m \varphi_{ij,m}} \right)^{p} \quad \textbf{(14)}$$

The average capacity of the MIMO for different transmitter receiver scenarios is considered to be frequency flat and the channel is assumed to have a bandwidth of 1 Hz. The channel transfer matrix is denoted by *H* with dimension $M_r \times M_t$. The input-output relation for the MIMO channel is given as

$$y = \frac{E_s}{M_t} HS + n \quad (15)$$

A deterministic channel, the capacity of MIMO

$$C = \max_{f(s)} I(s; y) \quad (16)$$

S and I(S;Y) is the mutual information

$$I(s; y) = H(y) - H(y/s) \quad (17)$$

As it have no control over the noise maximizing $I(s;y)$ reduces to maximizes to H(y) that satisfies

$$R_{yy} = \frac{E_s}{M_t} H R_{ss} H^H + N_0 I_{M_r} \quad (18)$$

The differential entropy of y and n are

$$H(y) = \log_2(\det(\prod e R_{yy})) \quad (19)$$

$$H(n) = \log_2(\det(\prod e N_0 I_{M_r})) \quad (20)$$

Thus, the capacity of the MIMO channel is

$$C = \max_{TR}(R_{ss}) = M_t \log_2(\det(I_{M_r} + \frac{E_s}{M_t N_0} H R_{ss} H^H)) \quad (21)$$

IV. SIMULATION RESULTS

The simulation results for proposed scheme are obtained using MATLAB by considering the following approximations as the receive correlation matrices $R_r = I_{N_r}$ and considering the pair wise error probability is approximated as

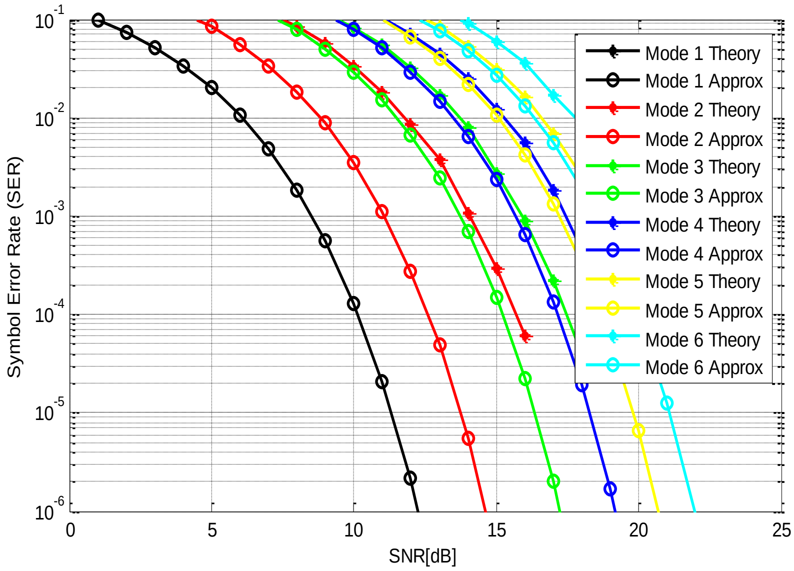

Fig 3: SNR vs SER of uncorrelated channels

From the figure 3, our simulation results proved that our proposed approximation results are very close enough to regular monte-carlo results un-correlated which mean that successfully achieved the spectral efficiency using the transmission modes.

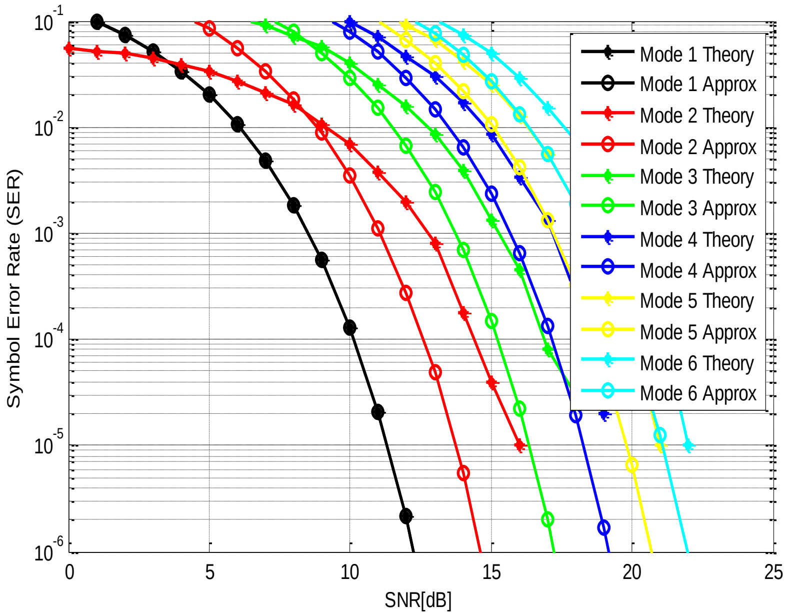

Fig 4: SNR vs SER of correlated channels

Above figure 4 represents the exploitation of proposed scheme with in the correlated channel environment, like as previous results our proposed approximation results are very close to monte-carlo simulation results.

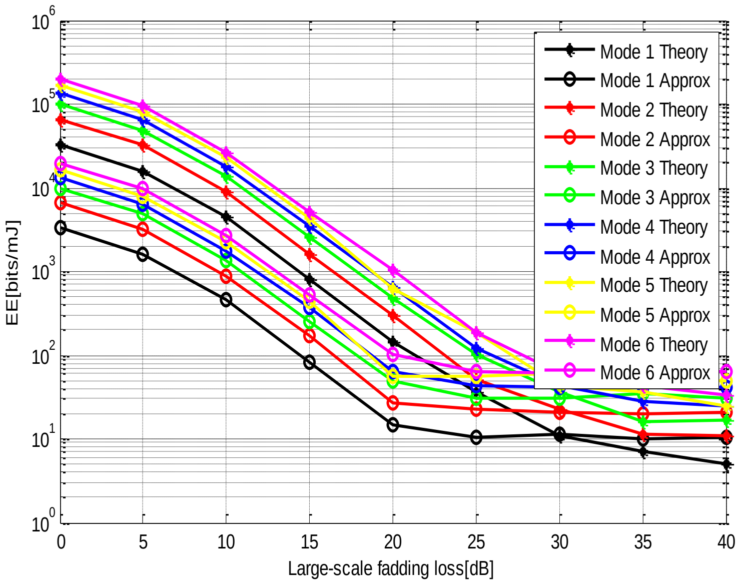

Fig 5: EE based mode selection

Figure 5 represents the energy efficiency of the MIMO system with uncorrelated channels, and from the results we have observed that the increment in RF chains whenever there are large benefits in occurred but the our proposed selection process activates the required RF chains based on arrived signal spectral spatial directionality which means avoiding the power consumption leakage. However still the power consumption increases spectral efficiency will be reduces to optimize the energy efficiency.

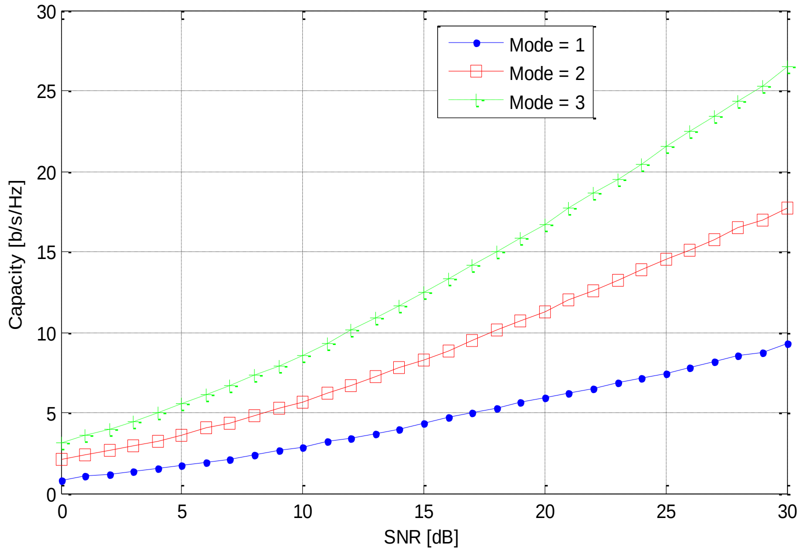

Fig 6: Average Channel capacity of the MIMO system

Above simulation results represents the average capacity of the MIMO for different transmitter and receiver scenarios. From the simulation results we have observed that there is a gradual increment in MIMO's capacity with respect to the gradual increment in SNR. The capacity of the system depends on power levels at transmitter and receiver besides the upper boundary limits of SER and BER of channels.

V. CONCLUSION

In this paper, a systematical frame work is introduced in order to reduce the spectral and energy leakages by employing predefined transmission mode selection candidate set. By employing the mode selection process the complexity of MIMO is greatly reduced by using the device to device connectivity concept of MIMO. In this work the spectrum is optimized and energy using predefined transmission modes but the work should be extended for dynamic selection of transmission mode instead of predefined transmission mode set. By the capacity analysis the channels are increased without sacrificing quality of service(QOS). The performance of proposed work will be improved by simplifying the expressions of BER, SER, expressions of power models,

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