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Channel Capacity Estimation in MIMO-OFDM System for different Fading Channels Using Water Filling Algorithm

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Abstract—**With the rapid enhancement in wireless communication systems, spectrum utilizations is a measure problem. The capacity of a communication system can be enhanced using Multiple Input-Multiple Output (MIMO) system and orthogonal frequency division multiplexing (OFDM) system. This paper is focused on further enhancing the channel capacity of a MIMO-OFDM system using iterative Water-filling algorithm. The simulation has been carried out on MATLAB 2010a using different antenna arrangements over Rayleigh, Rician and Nakagami fading channels. Moreover, the bit error rate (BER) performance of MIMO-OFDM system has been compared over different modulation schemes.**

Keywords- **BER, MIMO, Nakagami, OFDM, Rayleigh, Rician.**

I. INTRODUCTION

The next generation wireless communication systems are expected to provide the high data rates for high-quality multimedia services in mobile environment regardless of locations [1]. To achieve these requirements, several wireless technologies for transmission have been introduced such as MIMO (Multiple-Input Multiple-Output), OFDM (Orthogonal Frequency Division Multiplex), MC-CDMA (Multiple Carrier Code Division Multiplexing Access), and so on.

Some decades ago, we were purely dependent on analog system. Both the sources and transmission schemes were on analog format, but the innovation of technology made it possible to transmit data in digital form. Besides those, the computer was getting faster to the fastest, the data payload ability and transmission rate increased from kilobit to megabit and megabit to gigabit. From wire to wireless conception emerged and after researching and investing so much money, engineers became successful to discover wireless transmitter to transmit data. Applications similar to Internet access, voice, SMS, instant messaging, file transferring, paging, video conferencing, entertainment and gaming etc. became a part of life.

In the never-ending search for increased capacity in a wireless communication channel it has been shown that by using MIMO (Multiple Input Multiple Output) system architecture it is possible to increase that capacity substantially. Usually fading is considered as a problem in wireless communication but MIMO channels uses the fading to increase the capacity. MIMO systems transmits different signals from each transmit element so that the receiving antenna array receives a superposition of all the transmitted signals. All signals are transmitted from all elements once and the receiver solves a linear equation system to demodulate the message. The idea is that since the receiver detects the same signal several times at different positions in space at least one position should not be in a fading dip [2].

If the transmitter has CSI (Channel State Information) then the transmitter can use the “Waterfilling technique” to optimize the power allocation between the antenna elements so that an optimal capacity is achieved. When the CSI is supplied to the transmitter a decrease in spectral efficiency is unavoidable so therefore it is interesting to know in what cases it is important to have CSI and when the benefits are negligible.

MIMO-OFDM frameworks give various favourable circumstances over SISO communication. Affectability to fading is lessened by the spatial diversity offered by various spatial paths. Under diverse conservation conditions, the power necessities connected with high spectral efficiency communication can be essentially lessened. Here the spectral efficiency is defined as the total number of information bit per second per Hertz transmitted from one array to the other. As compared to SIMO system, MIMO-OFDM system need lesser transmit power to achieve the same capacity. The capacity of a MIMO-OFDM system can further be increased if we know the channel parameters both at transmitter and at the receiver and

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assign extra power at the transmitter by allocating the power according to the water filling algorithm to all the channels. As we need to minimize the energy consumed by the circuit and wants to maximize the capacity and that is possible only if we use multiple MIMO-OFDM system.

The main objective of this research work is the channel capacity estimation of MIMO-OFDM system for different fading channels; Nakagami, Rayleigh and Rician. To achieve high channel capacity, iterative Waterfilling algorithm is used for MIMO-OFDM system having different antenna arrangements. The performance analysis is recorded based on the simulation results of Bit-Error-Rate (BER) and Signal-to-Noise Ratio (SNR) using different modulation techniques; BPSK, 4-PSK, 8-PSK, 16-QAM and 64-QAM. The simulation of above mentioned system is done by MATLAB.

II. METHODOLOGY

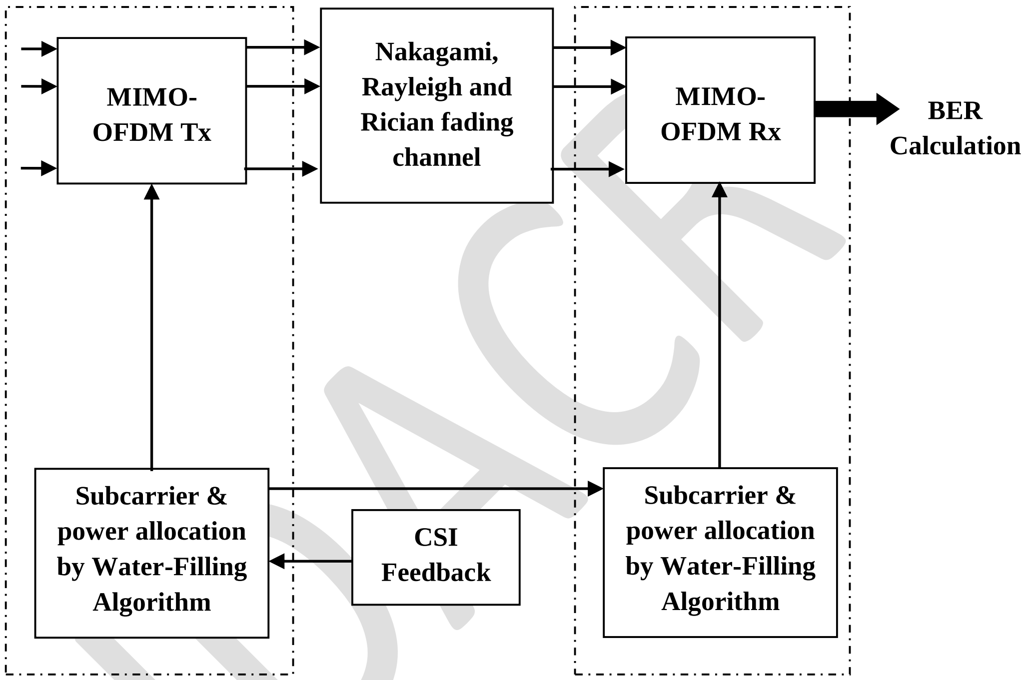

Figure 1: Block diagram for proposed work

The subcarrier and power allocation is done at the transmitter side by knowing the availability of exact channel state information (CSI) in MIMO-OFDM as shown in Figure 1. Proposed method uses Nakagami, Rayleigh and Rician fading channels.

Equation (1) shows expression for a MIMO-OFDM system with T transmit and R receive antennas, the received signal at the k-th sub-carrier of the nth block from the jth receive antenna:

$$Y_i = \sum_{i=1}^{T} H_{ij}[n,k]x_i[n,k] + \omega_j[n,k] \quad (1)$$

For j = 1,…, R and k = 0,…, K - 1, where $x_i[n,k]$ is the symbol transmitted from the ith transmit antenna at the kth subcarrier of the nth block, $H_{ij}[n,k]$ is the channel's frequency response at the kth sub-carrier of the nth block corresponding to the ith transmit and the jth receive antenna, and, $j[n;\ k]$ is additive (complex) Gaussian noise [3].

Channel Capacity Estimation using Water-Filling Algorithm

Water filling is the solution of several optimization problems related to channel capacity. The well-known water filling algorithm solves the problem of maximizing the mutual information between the input and output of a channel.

The receiver can gain knowledge about the channel by the use of a known training sequence but if the transmitter should know anything about the channel it is necessary to use a feedback channel. The feedback channel consumes bandwidth in the channel or alternatively the capacity will decrease.

When the transmitter knows the eigenvalues and eigenvectors corresponding to the H matrix and the noise power (σ^2) it can use this information to transmit in a smarter way. The Water filling technique is used to determine the powers ρ_k transmitted in each channel to achieve to greatest

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possible capacity. Consider a MIMO communication link with a shared total power budget of P_T, the capacity is then,

$$C = \sum_{k=1}^{n} Log_2\left(1+\frac{\rho_k}{\sigma^2}\lambda_k\right) \quad (2)$$

To achieve the greatest possible capacity ρ_k should be chosen in such a way that for every mode k

$$\rho_k = \left(\mu - \frac{\sigma^2}{\lambda_k}\right)^+ \quad (3)$$

Where $(x)^+ = \max(0, x)$ and μ is the "water level". Furthermore μ should be chosen such that the total power budget is not exceeded, that is,

$$\sum \rho_k = P_T \quad (4)$$

Important note: To obtain the optimal capacity the transmitter must have perfect knowledge of the H matrix (the eigenvalues and eigenvectors of H) and σ^2.

There is not be a general proof of the Water filling technique, but the idea is shown for a 2×2 MIMO system. The Method of Lagrange Multipliers is used, Maximize $f(\rho_1, \rho_2)$ where,

$$f(\rho_1,\rho_2) = \log_2\left(1+\frac{\rho_1}{\sigma^2}\lambda_1\right)$$
$$= \log_2\left(1+\frac{\rho_1}{\sigma^2}\lambda_1+\frac{\rho_2}{\sigma^2}\lambda_2+\frac{\rho_1.\rho_2}{\sigma^2.\sigma^2}\lambda_1\lambda_2\right) \quad (5)$$

Under the power constraint,

$$g(\rho_1.\rho_2) = \rho_1+\rho_2.P_T = 0 \quad (6)$$

Which is an equivalent problem with Maximize

$$f(\rho_1,\rho_2) = 1+\frac{\rho_1}{\sigma^2}\lambda_1+\frac{\rho_2}{\sigma^2}\lambda_2+\frac{\rho_1.\rho_2}{\sigma^2.\sigma^2}\lambda_1\lambda_2 \quad (7)$$

Under the constraint,

$$g(\rho_1.\rho_2) = \rho_1+\rho_2.P_T = 0 \quad (8)$$

Since $\log_2(\dots\dots)$ the function is monotonic.
Let,

$$L(\rho_1,\rho_2,\nu) = 1+\frac{\rho_1}{\sigma^2}\lambda_1+\frac{\rho_2}{\sigma^2}\lambda_2+\frac{\rho_1.\rho_2}{\sigma^2.\sigma^2}\lambda_1\lambda_2 + (\rho_1+\rho_2-P_T) \quad (9)$$

For critical points we want

$$0 = \frac{\partial L}{\partial \rho_1} = \frac{\lambda_1}{\sigma^2}+\frac{\rho_2}{\sigma^2.\sigma^2}\lambda_1\lambda_2+\nu \quad (10)$$

$$0 = \frac{\partial L}{\partial \rho_2} = \frac{\lambda_2}{\sigma^2}+\frac{\rho_1}{\sigma^2.\sigma^2}\lambda_1\lambda_2+\nu \quad (11)$$

$$0 = \frac{\partial L}{\partial \nu} = \rho_1+\rho_2-P_T \quad (12)$$

$$\text{Equation (A)} => \rho_2 = -\nu\frac{\sigma^2.\sigma^2}{\lambda_1\lambda_2}-\frac{\sigma^2}{\lambda_2} \quad (13)$$

$$\text{Equation (B)} => \rho_1 = -\nu\frac{\sigma^2.\sigma^2}{\lambda_1\lambda_2}-\frac{\sigma^2}{\lambda_1} \quad (14)$$

But since ν is a variable which can be chosen arbitrary, a substitution can be made without any loss of generality,

$$\mu = -\nu\frac{\sigma^2.\sigma^2}{\lambda_1\lambda_2} \quad (15)$$

And since $\rho_1, \rho_2 \geq 0$ must we have constraints on the choice of μ. In the end we get that by choosing μ in a proper way that satisfies and an optimal capacity is achieved.

$$P_T = \left(\mu-\frac{\sigma^2}{\lambda_1}\right)^+ + \left(\mu-\frac{\sigma^2}{\lambda_2}\right)^+ \quad (16)$$

Accordingly to [4] the water-filling technique gives three different kinds power allocation depending on the SNR.

Low SNR

At low SNR the Water filling technique finds the largest eigenvalues to H and sends the entire power through one single mode (channel). At this level of SNR the increase of capacity is almost linear and increases with 1bit/s/Hz for every 3dB increase of P_T power.

Intermediate SNR

At intermediate SNR the water-filling technique uses L number of modes where 1<L<min (n_T, n_R). At this level of SNR the capacity is almost linear and increases with L bit/s/Hz for every 3dB increase of P_T.

High SNR

At high SNR the water-filling technique uses all $min(n_T, n_R)$ modes for transmission. At this level of SNR the capacity is almost linear and increases with $min(n_T, n_R)$ bit/s/Hz for every 3dB increase of P_T.

III. Simulation and Results

Simulation is carried out using MATLAB 2010a.

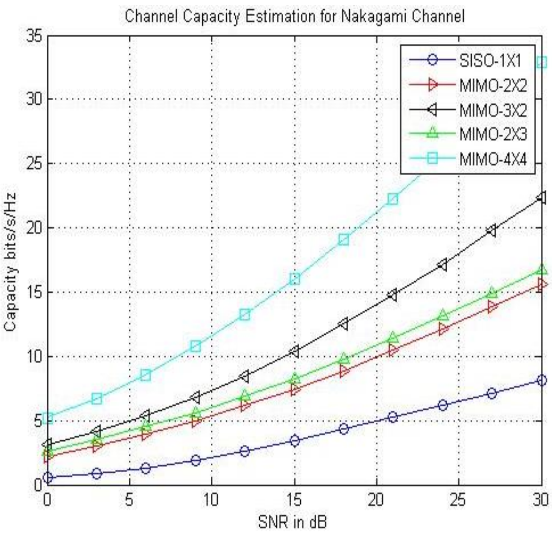

Figure 2: Channel capacity estimation for Nakagami fading channel

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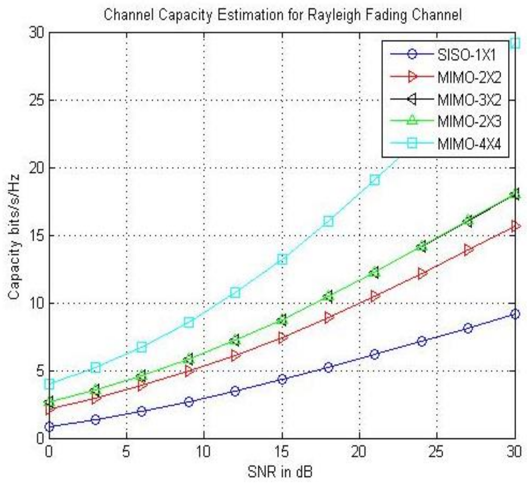

Figure 3: Channel capacity estimation for Rayleigh fading channel

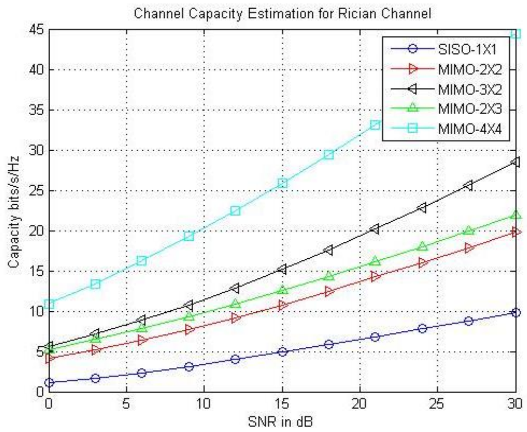

Figure 4: Channel capacity estimation for Rician fading channel

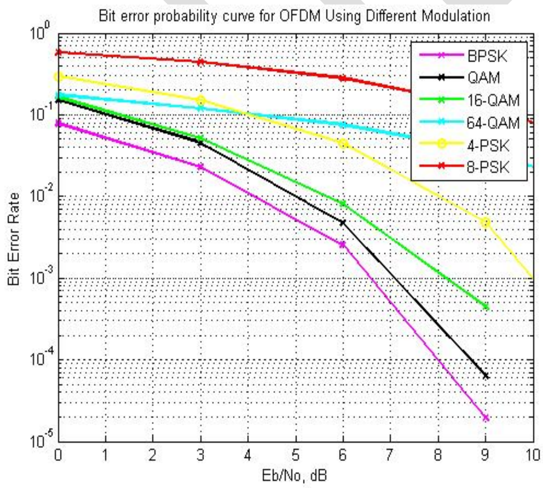

Figure 5: Bit error rate curve for OFDM using different modulation schemes

Table 1: Performance comparison of channel capacity for different fading channels

	Nakagami Fading Channel		Rayleigh Fading Channel		Rician Fading Channel	
	SISO 1×1	MIMO 4×4	SISO 1×1	MIMO 4×4	SISO 1×1	MIMO 4×4
Channel capacity (Approx.)	8	33	8	28	10	45

IV. Conclusion

This paper presents the MIMO OFDM model using MATLAB. The results of simulation from the model enable the researches to choose water filling algorithm for their requirements. MIMO has helped to ISI problem. The Results indicates that the Capacity is enhanced significantly by transmitting the data through different channels. On observing the simulations, the capacity of MIMO-OFDM system for different fading channels is expressed in Table 1.

The simulation results shows that water filling algorithm give enhanced results for Rician channel in MIMO-4×4 antenna configuration.

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