Performance Analysis of MIMO-OFDM Wireless Systems Employing Quadrature Amplitude Modulation

Sabah Razavi, Lecturer of Islamic Azad University of Khorramabad
sabah.razavi@gmail.com
Ali Akbar Naemi, Lecturer of Islamic Azad University of Khorramabad
Sara Razavi, M.Sc. Student of UPM University, Malaysia
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Name of the Presenter: Sabah Razavi

Abstract

Orthogonal frequency division multiplexing (OFDM) is a popular method for high data rate wireless transmission. OFDM may be combined with antenna arrays at the transmitter and receiver to increase the diversity gain and/or to enhance the system capacity on time-variant and frequency-selective channels, resulting in a multiple-input multiple-output (MIMO) configuration. As a promising technology for future broadband communication, MIMO–OFDM has gained more and more interests in recent years. In this paper, the performance of MIMO-OFDM system employing Quadrature Amplitude Modulation (QAM) is analysed. Simulation results show that this is a promising technique for next generation wireless systems.

Key words: MIMO, OFDM, QAM, Wireless Systems.

1. Introduction

The growing demand of multimedia services and the growth of Internet related contents lead to increasing interest to high speed communications. The requirement for wide bandwidth and flexibility imposes the use of efficient transmission methods that would fit to the characteristics of wideband channels especially in wireless environment where the channel is very challenging. In wireless environment the signal is propagating from the transmitter to the receiver along number of different paths, collectively referred as multipath. While propagating the signal power drops of due to three effects: path loss, macroscopic fading and microscopic fading. Fading of the signal can be mitigated by different diversity techniques. To obtain diversity, the signal is transmitted through multiple (ideally) independent fading paths e.g. in time, frequency or space and combined constructively at the receiver. Multiple input- multiple-output (MIMO) exploits spatial diversity by having several transmit and receive antennas. However the paper “MIMO principles” assumed frequency flat fading MIMO channels.

OFDM is modulation method known for its capability to mitigate multipath. In OFDM the high speed data stream is divided into *Nc* narrowband data streams, *Nc* corresponding to the subcarriers or sub channels i.e. one OFDM symbol consists of *N* symbols modulated for example by QAM or PSK[4,5]. As a result the symbol duration is *N* times longer than in a single carrier system with the same symbol rate. The symbol duration is made even longer by adding a cyclic prefix to each symbol. As long as the cyclic prefix is longer than the channel delay spread OFDM offers inter-symbol interference (ISI) free transmission. Another key advantage of OFDM is that it dramatically reduces equalization complexity by enabling equalization in the frequency domain. OFDM, implemented with IFFT at the transmitter and FFT at the receiver, converts the wideband signal, affected by frequency selective fading, into *N* narrowband flat fading signals thus the equalization can be performed in the frequency domain by a scalar division carrier-wise with the subcarrier related channel coefficients. The channel should be known or learned at the receiver. OFDM has been adopted in the IEEE802.11a LAN and IEEE802.16a LAN/MAN standards. OFDM is also being considered in IEEE802.20a, a standard in the making for maintaining high-bandwidth connections to users moving at speeds up to 60 mph. The IEEE802.11a LAN standard operates at raw data rates up to 54 Mb/s (channel conditions permitting) with a 20-MHz channel spacing, thus yielding a bandwidth efficiency of 2.7 b/s/Hz. The actual throughput is highly dependent on the medium access control (MAC) protocol. Likewise, IEEE802.16a operates in many modes depending on channel conditions with a data rate ranging from 4.20 to 22.91 Mb/s in a typical bandwidth of 6 MHz, translating into a bandwidth efficiency of 0.7 to 3.82 bits/s/Hz.
Recent developments in MIMO [6] techniques promise a significant boost in performance for OFDM systems. Broadband MIMO-OFDM systems with bandwidth efficiencies on the order of 10 b/s/Hz are feasible for LAN/MAN environments. MIMO-OFDM is under intensive investigation by researchers. This paper is intended to illustrate the potential benefits of combining MIMO with OFDM system for 4G wireless networks.

2. MIMO-OFDM System Model

The general transceiver structure of MIMO-OFDM is presented in Fig. 1. The system consists of N transmit antennas and M receive antennas [2,3] In this paper the cyclic prefix is assumed to be longer than the channel delay spread. The OFDM signal for each antenna is obtained by using inverse fast Fourier transform (IFFT) and can be detected by fast Fourier transform (FFT). The received MIMO-OFDM symbol of the n:th subcarrier and the m:th OFDM symbol of the i:th receive antenna after FFT can be written as

$$R_i[n,m] = \sum_{j=1}^{N} H_{i,j}[n,m]A_j[n,m] + W_i[n,m] \quad i = 1,2,\ldots,M \tag{1}$$

where $Aj[n,m]$ is the transmitted data symbol on *n*:th carrier and m:th OFDM symbol, $Wi[n,m]$ is the additive noise contribution at *i*:th receive antenna for the corresponding symbol in frequency domain and $Hi,j[n,m]$ is the channel coefficient in the frequency domain between the *j*:th transmit antenna and the *i*:th receive antenna. The channel coefficients in frequency domain are obtained as linear combinations of the dispersive channel taps [1].

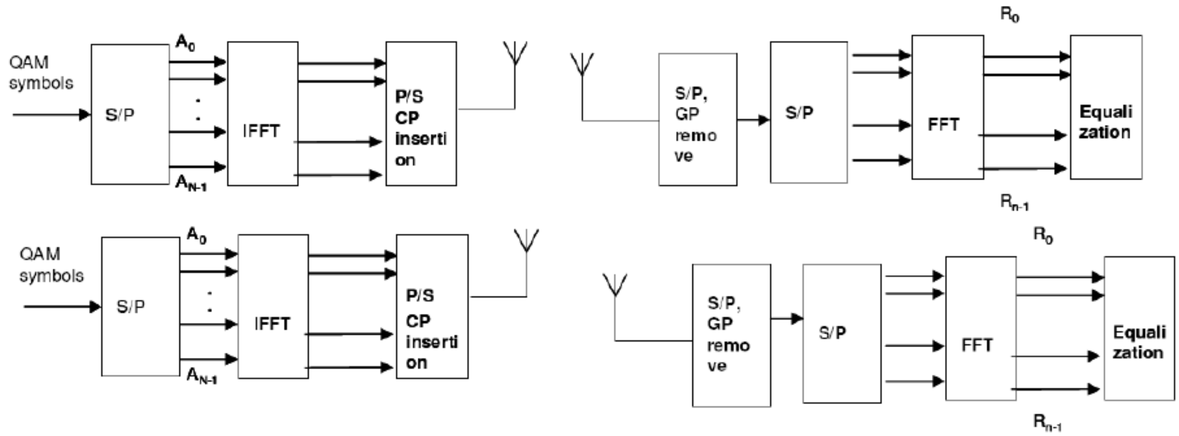

Fig 1: MIMO-OFDM Transceiver

$$H[n,m] = \sum_{i=0}^{I-1} h_i[m] e^{-j2\pi\tau_i n/T},\ n = 0,1,\dots,n-1 \tag{2}$$

Where I is the number of channel taps in time domain and $h[m]$ is modeled as an independent zero-mean random Gaussian process. The impulse response of the Rayleigh fading channel can be expressed as

$$h(t,\tau) = \sum_{i=0}^{I-1} h_i(t)\delta(\tau - \tau_i(t)) \tag{3}$$

Where hi is the tap gain and τi is the delay associated to the i:th tap. This delay can be considered to be time invariant. The channel impulse response is assumed to be static over one OFDM channel symbol duration $T_{channel} = T+T'$, where T is the OFDM symbol duration and T' is the cyclic prefix duration. This corresponds to a slowly varying channel where the coherence time is longer than the channel symbol duration. This assumption prevents from experiencing inter-carrier interference (ICI). The channel matrix H is an N x M matrix corresponding to the n:th subcarrier and m:th OFDM symbol.

$$\bar{H}[n,m] = \begin{bmatrix} H_{1,1}[n,m] & H_{1,2}[n,m] & \cdots & H_{1,N}[n,m] \\ H_{2,1}[n,m] & H_{2,2}[n,m] & & H_{2,N}[n,m] \\ \vdots & & \ddots & \vdots \\ H_{M,1}[n,m] & H_{M,2}[n,m] & \cdots & H_{M,N}[n,m] \end{bmatrix} \tag{4}$$

3. Performance Analysis

Taking the received data symbols of all antennas into account, the expression of the received data symbol can be presented in the matrix form as follows

$$\vec{R}[n,m] = \bar{H}[n,m]\vec{A}[n,m] + \vec{W}[n,m] \tag{5}$$

Where $$\vec{A}[n,m] = [A_1[n,m]\ \ A_2[n,m]\ \dots\ A_N[n,m]]^T \tag{6}$$

And $$\vec{R}[n,m] = [R_1[n,m]\ \ R_2[n,m]\ \dots\ R_M[n,m]]^T \tag{7}$$

Are the Nx1 and Mx1 vectors of the transmitted and received data symbols. To obtain the transmitted data symbols Eq. 5 should be solved which is called MIMO-OFDM equalization.

$$\vec{A}[n,m] = \bar{H}[n,m]^{-1}(\vec{R}[n,m] + \bar{W}[n,m]) \tag{8}$$

This equalization works well in case of small noise and no ISI or ICI. In the presence of ICI and ISI the received signal can be written as in [5]

$$\begin{aligned}\vec{R}_i[n,m] &= \sum_{j=1}^{N} R_{j,i}^{U}[n,m] + \sum_{j=1}^{N} R_{j,i}^{ICI}[n,m] + \sum_{j=1}^{N} R_{j,i}^{ISI}[n,m] + W_i[n,m] \\ &= C(k) + I(k)\end{aligned} \tag{9}$$

Where the first term $C(k) = \sum_{j=1}^{N} R_{j,i}^{U}[n,m]$ represents the transmitted MIMO-OFDM signal and $I(k) = \sum_{j=1}^{N} R_{j,i}^{ICI}[n,m] + \sum_{j=1}^{N} R_{j,i}^{ISI}[n,m] + W_i[n,m]$ represents the result due to interference.
The useful power $P_U = E\lfloor |C(k)|^2 \rfloor$ and the interference power can be expressed as $P_I = E\lfloor |I(k)|^2 \rfloor$. The carrier to interference ration (CIR) is given by

$$CIR = \frac{P_U}{P_I} = \frac{E\lfloor |C(k)|^2 \rfloor}{E\lfloor |I(k)|^2 \rfloor} \tag{10}$$

The bit error rate (BER) of MIMO-OFDM system employing QAM can be derived from CIR as

$$P_b = \left(\frac{3}{8}\right)\left[1 - \left(\frac{1}{\sqrt{1+\frac{\frac{5}{CIR}}{2}}}\right)\right] \tag{11}$$

4. Simulation Results

A The BER performance of the proposed MIMO-OFDM receiver schemes was analyzed through simulations of a 2×2 system with 2 antennas at the transmitter and 2 at the receiver. The information bits of each transmit chain are encoded with a ½-rate convolutional encoding (constraint length 7, G=[171,133]), QAM modulated and subsequently mapped to 48 data subcarrier of a 64-point OFDM system based upon the IEEE 802.11a standard. Therefore one codeword spans over all frequencies and additionally over 10 consecutive OFDM symbols to yield sufficient decoder performance (474 information bits per codeword). The carrier frequency was chosen to 5.2GHz and the velocity in the environment was assumed to 50km/h resulting in a maximum Doppler frequency shift of 240Hz. The channel model employed is Rayleigh fading channel.
The channel simulation allows examination of common wireless channel characteristics such as noise, multipath, and clipping. By adding random data to the transmitted signal, simple noise is simulated. Multipath simulation involves adding attenuated and delayed copies of the transmitted signal to the original. This simulates the problem in wireless communication when the signal propagates on many paths. Although OFDM successfully prevents the ISI, it does not suppress channel fading. By using coding and interleaving across the frequency and time

domain, the transmitted data can be effectively protected. Further improvement can be achieved through other advanced techniques, such as power allocation and adaptive modulation.

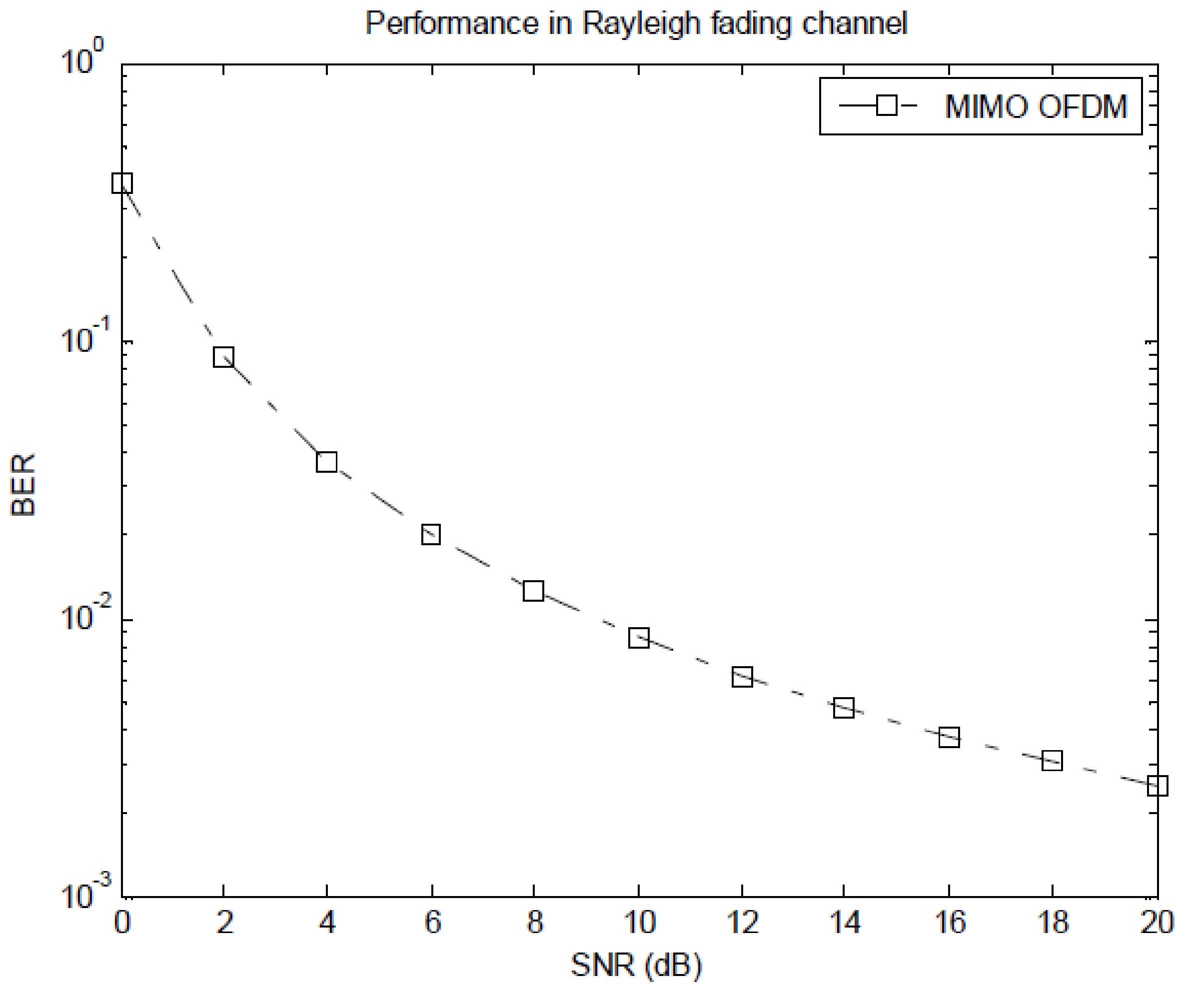

Fig 2: BER Performance of 2:2 MIMO-OFDM System

5. Conclusion

A In this paper, the performance of MIMO-OFDM system employing Quadrature Amplitude Modulation (QAM) in Rayleigh fading channel is analyzed. The use of multiple antennas at both ends of a wireless link (multiple input multiple output (MIMO) technology) has recently been demonstrated to have the potential of achieving extraordinary data rates. Orthogonal frequency division multiplexing (OFDM) significantly reduces receiver complexity in wireless broadband systems. The use of MIMO technology in combination with OFDM, i.e. MIMO-OFDM therefore seems to be an attractive solution for future broadband wireless systems.

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