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Analysis the Performance of OFDM-MIMO Channel with Different Equalizers

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Abstract: The excellent efficiency, capacity, and dependability of today's wireless networks are concurrent to be achieved, and employing several communication methods antennas is an effective solution that has been extensively used. A communication system where both terminals are equipped with multi-antennas are referred to as MIMO systems, and when combined with OFDM technology are referred to as MIMO-OFDM. MIMO-OFDM has the ability to serve a large number of users with an enormous data transmission speed communication as well as utilizing the bandwidth efficiently. The aim of this simulation task explores three different equalization schemes in the MIMO flat fading channel, frequency-selective OFDM channel, and combined OFDM-MIMO wireless links on the bit error rate (BER) metric. Throughout the simulations, we modulate in 4-QAM (MIMO, OFDM-MIMO) and 16-QAM (OFDM) and observe BER performances for signal-to-noise ratio (SNR) up to 30. We find that given the specifications for OFDM as defined in IEEE 802.11a, precoding, and zero-forcing schemes in MIMO yield similar BER performances, while the MMSE scheme performs slightly worse at higher SNR's. Based on the equalization scheme, we assume perfect channel state information at the transmitter (CSIT) (for precoding) and the receiver (CSIR) (for zero-forcing and MMSE).

Keywords: CSIR, CSIT, Equalization, MIMO, OFDM, OFDM-MIMO.

I. INTRODUCTION

Wireless communication systems are ubiquitous almost everywhere. They are essential for study, business, and entertainment purposes. With more applications in emerging techniques as virtual reality and blockchain, the growing demands of capacity and reliability are challenging existing networks again [1]. Multiple-Input Multiple-Output is a spatial diversity technique that involves having several antennas at both receiver and transmitter to acquire the same performance benefits that spatial diversity offers. The popularity of MIMO has been witnessed for decades mainly because this scheme can utilize fading to achieve signal diversity. Fading indicates the transmitted signal travels through diverse paths before reaching the receiver, resulting in the received copies with different delays, attenuation, and phase shifts. Conventional systems based on a single transmitter and receiver aim to mitigate the influence by fading, but the randomness of time-varying channels cannot be eliminated; thus the performance is not satisfying. This leads to the introduction of multiple antennas. The idea of MIMO is exactly the opposite: to utilize the randomness of fading. If several antennas are far-spaced, communication channels can be regarded as parallel. Therefore signals on them experience independent fading, which brings in diversity. At the receiver end, we can use detection algorithms to remove the fading effect and recover the transmitted signal. The advantages of MIMO are obvious: capacity, reliability, and efficiency. By using multiple antennas, we can transmit more bits in a fixed time. If the transmitters split the data stream and distribute the sub-streams on antennas, the channel capacity can be increased multiple times without using extra bandwidth [2] [3].

The principle of an OFDM-based transmission is to divide an initial stream with a high transmission data rate or low symbol time into several parallel sub-streams of lower transmission rate and thus, longer symbol time. These streams are transmitted over different subcarriers regularly spaced in the frequency domain [4]. Due to its properties, namely high spectral efficiency, robustness to multipath propagation, low complexity, etc., this technology has been adopted in several commercial standards.

It was used for the first time in a cellular standard (for the downlink), namely in the current 4G systems also referred to as Long-Term Evolution (LTE). To accommodate the increasing demand for wireless services that require a high data rate, cellular systems tend to be designed with multi-antenna terminals. A system where both terminals (base station and user terminals) are equipped with multi-antennas are referred to as MIMO systems, and when combined with OFDM are referred to as MIMO-OFDM. Such a system can achieve both space diversity and/or multiplexing. The use of spatial diversity will be a key to effective use of the diversity inherent in wireless channels and the consequent increase in system reliability [5].

In digital communication systems, achieving the target data rate and bit error rate through a transmission channel is crucial for data transfer. In this regard, an equalizer is usually employed at the receiver side in order to reduce the number of incorrect instances of the transmitted signal. In general, we consider the sequence of bit transmission in the order described in Fig. 1. The modulated signal is encoded by the channel, an additive white Gaussian noise (AWGN) [6] is added, and an equalizer is applied before demodulating the received signal for signal recovery. This equalization block at the receiver serves to minimize the effect of inter-symbol interference (ISI) and inter-channel interference (ICI) [7].

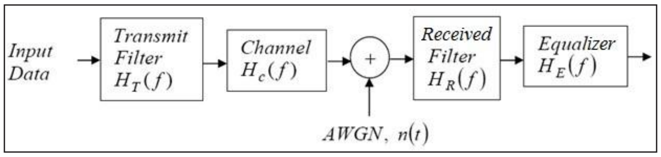

Fig. 1: Channel Equalizer Block [9]

In this paper, we study the effects of three equalization schemes – Precoding, Zero-forcing, and MMSE in MIMO links, Zero-forcing and MMSE in OFDM models, and all combinations in OFDM-MIMO channel models. These linear equalizers minimize the error between the received and transmitted symbols without enhancing the noise [8]. We do not take into account the impairments in transmission in these simulations, such as timing offset, frequency and phase offsets, and clock drift, and thus we can work in the complex band instead of the baseband.

The article is structured as follows: The introduction to this study is included in Section I, Section II includes a description of system model, Section III contain the brief description of different equalizer schemes, Section IV describes results and discussion of this simulation work and finally, in Section V, the conclusion of this research work has been drawn.

II. System Model

A. MIMO Channel

We model 2x2 MIMO channels with three different flat-fading channels. For $M_{transmit} = 2$ and $M_{receive} = 2$, the channel state matrix is represented in dimensions 2x2xsymbol size in equation 1.

$$H_{MIMO} = \begin{bmatrix} H_{11} & \cdots & H_{1M_T} \\ \vdots & \ddots & \vdots \\ H_{M_R1} & \cdots & H_{M_RM_T} \end{bmatrix} \tag{1}$$

The single-user MIMO channel that we model takes two data streams given two transmit antennas, and encodes (transmits) data through the channel matrix H and multiplexes at the receiver. To the model described in Fig. 2, we add an equalizer as seen in Fig. 1, in three different schemes described in Section III [10].

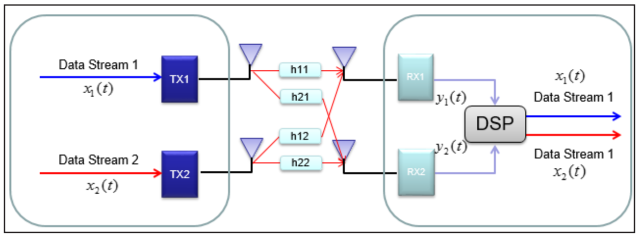

Fig. 2: Single-User Multiple-Input Multiple-Output

B. OFDM Encoding

In OFDM symbol coding, we adopt the specifications as described in the IEEE 802.11a standards. In each OFDM burst, there are a total of 80 symbols including 64 subcarriers containing 48 data samples to transmit, 12 zeros to reduce inter-channel interference (ICI), and 4 pilot symbols for channel estimation (e.g. frequency and phase offset estimation). The subcarriers are evenly spaced over 20 MHz bandwidth into 312.5 kHz. We also need to prepend 16 sample-long cyclic prefixes, which we take from the data samples in order for linear convolution to become circular convolution and to further mitigate channel distortion. Since the number of subcarriers is 64, we use 64-point IDFT (IFFT) and DFT (FFT) throughout the OFDM symbol generation stage. We transmit the OFDM symbols through a frequency-selective channel with the following parameters [11] [12]:

- Symbol time per sub-channel (sampling period of channel) = 4
- Max Doppler frequency shift (Hz) = 0
- Path delays = [0, 1e-5, 3.5e-5, 12e-5]
- Average path power gains in each path = [0, -1, -1, -3]

C. OFDM-MIMO

We put together the MIMO link and OFDM symbol transmission models into an OFDM-MIMO model, such that OFDM bursts are generated and then transmitted over the MIMO flat-fading channel. The assumptions for CSIT and CSIR are valid for this model. We note that in this combined link, the frequency selective MIMO channels essentially become a group of independent flat-fading MIMO channels [13] [14].

III. Equalizer Scheme

We employ three different equalizer approaches in each model – Precoding, Zero-forcing, and Minimum Mean-Squared error. All of these schemes are placed at the receiver in order to invert the effect of the channel on the transmitted symbols. Note that we assume perfect CSIT for Precoding and perfect CSIR for Zero-forcing and MMSE. The added AWGN level at the channel, for which its half-power is accounted, should not be too large to largely distort the transmitted signal.

A. Transmit Precoding and Receiver Shaping

Precoding requires taking the Singular Value Decomposition (SVD) of the channel matrix. By precoding and multiplying the matrix with V before the channel is applied, the channel can be undone by then multiplying the received signal by the conjugate transpose of U before multiplying the resulting matrix by the inverse of S. For channel matrix H, we perform parallel decomposition by SVD, such that

$$H = U \sum V^H$$

where we apply linear transformation as follows:

$$x = V\tilde{x}$$

where $\tilde{x}$ = input vector.

After transmitting over a channel H with additive white Gaussian noise n,

$$\begin{aligned} \tilde{y} &= U^H(Hx + n) \\ &= U^H U \sum V^H V \tilde{x} + U^H n \\ &= \sum \tilde{x} + \tilde{n} \end{aligned}$$

Where $\tilde{n} = U^H n$

B. Zero-Forcing

Zero-forcing is the simplest method of the three equalization types. The reasoning for it is simple; if multiplication with the channel is distorting the data, then multiplying the received signal with the inverse of the channel matrix should undo this effect. The error occurs because the noise that is added in also gets amplified when undoing the effects of the channel. A Zero-forcing equalizer approximates the inverse of the channel with a linear filter, by applying to the received symbols [11].

$$W_{ZF} = (H^H H)^{-1} H^H \tag{2}$$

C. Minimum Mean Squared Error (MMSE)

MMSE requires taking the Hermitian transpose of the channel matrix, it can be used in tandem with the known variance of the noise in order to undo the effect of both the channel and the noise. MMSE equalizer designs the filter to minimize the expected value of the squared error signal (filter output minus the transmitted signal). In a similar fashion to Zero-forcing, we apply, which takes into account the noise component of the channel [11] [15].

$$W_{MMSE} = (H^H + \sigma_n^2 I)^{-1} H^H$$

IV. Simulation Results and Discussion

All the simulations are implemented on MATLAB 9.6 (2019a) and the system configuration is Core i3-2.40 GHz processor with windows 10 based 64 bit operating system.

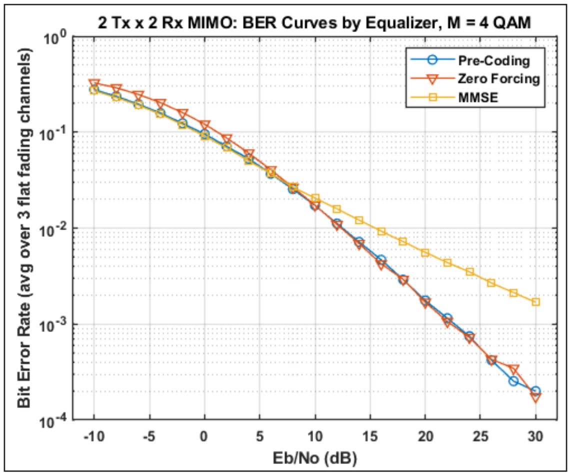

Fig. 3: MIMO with Equalizers BER Curve

In the MIMO channels with the three equalizers, we observed that at lower SNRs (SNR < 8) MMSE corrected the most, and precoding then zero-forcing in order, and at higher SNR's precoding and zero-forcing performed similarly in BER, but MMSE yielded worse performance than the other two (see Fig. 3). Although MMSE equalizers take into account the interferences from adjacent symbols and adjacent subcarriers, some ICI and ISI still remain, thereby limiting the performance at high SNRs. One way to improve the equalizer performance at high SNRs is to use interference cancellation techniques.

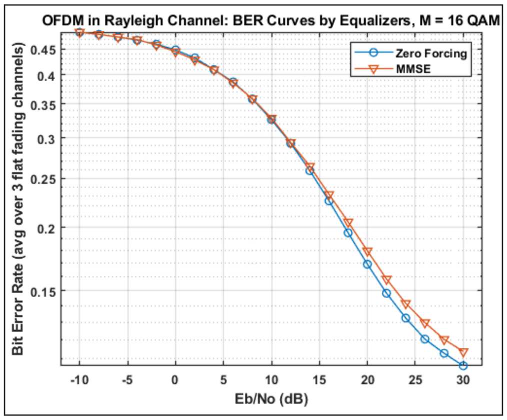

Fig. 4: OFDM with Equalizers BER Curve

For transmission of OFDM symbols through flat-fading Rayleigh channels, zero-forcing and MMSE equalizers gave similar BER performances (see Fig. 4). At lower SNRs, the MMSE approach yielded slightly better BER's, yet not significantly, yet at higher SNR's zero-forcing performed better. We note that due to the specifications of the channel, the general BER level remains in the order of 10^-1. With different values for the taps (paths) for the channel, the order would be much lower.

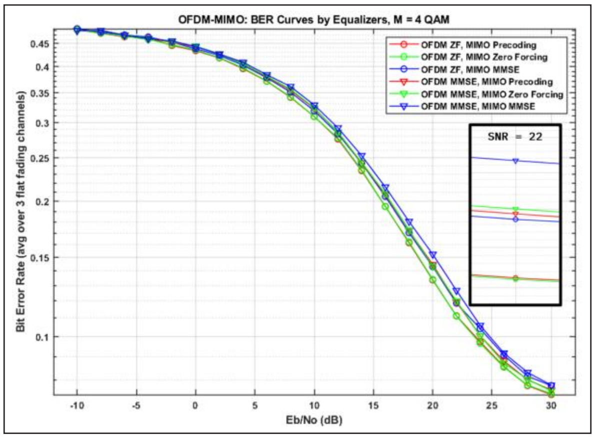

Fig. 5: OFDM-MIMO with Equalizers BER Curve

In combination with the two approaches, we noticed that OFDM with zero-forcing equalizers resulted in lower BER's in general than OFDM with MMSE equalizers (see Fig. 5). Within OFDM zero-forcing scheme, zero-forcing was the best, and precoding then MMSE in order, while within OFDM MMSE scheme, in the order of precoding, zero-forcing, and MMSE, at SNR of 22.

V. CONCLUSION

In this paper, we simulated the MIMO, OFDM, and OFDM-MIMO models with three different equalization schemes and in combination for 4-QAM in MIMO and OFDM-MIMO and 16-QAM in OFDM modulation technique. We observed that the MMSE performance varied by SNR, while precoding and zero-forcing were very similar in MIMO. For OFDM symbols, zero-forcing, and MMSE yielded similar BER performances, but slightly better overall for the latter. In OFDM-MIMO, besides the overall order of BER being lower due to the channel parameters defined in the OFDM (as per IEEE 802.11a standard), the performance in BER resulted as observed in each respective model.

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