PERFORMANCE OF MIMO-OFDM SYSTEMS IN THE PRESENCE OF JAMMING BASED ON LINEAR MINIMUM MEAN SQUARE ERROR (LMMSE) EQUALIZATION

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Abstract—This paper presents an in-depth analysis of the linear minimum mean squared error (LMMSE) equalizers applied to wireless multi-input multi-output (MIMO) systems. The LMMSE equalizer plays vital role in anti jamming OFDM technology. In this paper, we explore the use of MIMO technology for jamming resilient OFDM communication, particularly its capability to communicate against the effective reactive jammer. We first check out the jamming strategies and their impacts on the OFDM-MIMO receivers. We then present a multi-input multi-output (MIMO)-based anti-jamming scheme that exploits interference cancellation and transmit pre-coding capabilities of MIMO technology to show a jammed non-connectivity scenario into an operational network.

Index Terms—OFDM, LMMSE equalizer, MIMO, pre-coding, anti-jamming

I. INTRODUCTION

Wireless communication systems necessitate tremendously elevated data rates and high transmission reliability for multimedia applications such as high quality audio and video [3]. Existing wireless technologies cannot efficiently support high data rates, because of these technologies are very sensitive to fading. In present day’s communication, OFDM is a widespread[14] and a standout amongst the most encouraging balance strategies. It is useful in numerous ranges, for example, high other worldly proficiency, power, low computational unpredictability, recurrence specific blurring, and simplicity of usage utilizing IFFT/FFT and equalization plans [15]. As of late, there had been many interests to utilize OFDM in mix with a MIMO handset framework, named MIMO OFDM technique; which is utilized to expand the assortment procure and framework capacity [12]. MIMO as the name suggests; used multiple inputs at the transmitter and a couple of outputs at the receiver end which is wonderful instead than a single transceiver (SISO-Single input Single output) programs[4]. MIMO wireless systems are motivated by two vital goals: high-data-rate and high performance.

This blend of MIMO OFDM is an exceptionally encouraging element since OFDM ready to manage of more radio wires since it disentangles adjustment in MIMO frameworks [13]. Usually in OFDM, blurring is viewed as a disadvantage in remote system however MIMO channels utilize the blurring to expand the ability of the entire report group. MIMO is a recurrence particular method [11]. OFDM can be utilized to change over the kind of recurrence particular channel into a suite of parallel recurrence level sub channels. MIMO-OFDM innovation has been explored as the framework for the cutting edge remote/sight and sound systems.

The rest of this paper is organized as follows. Section II first reviews existing method. Our proposed method is described in Section III. Channel models are described in section IV. Then experimental results are reported in Section V to demonstrate the
superior performance of our framework. Finally, conclusions are presented in Section VI.

II. EXISTING METHOD

In the existing method, Otilia Popescu and Dimitrie C. Popescu examined the performance of precoded OFDM systems in the presence of intentional jamming [1]. Specifically, an OFDM system with sub-band precoding is considered, and the analytical expression for its corresponding SJNR is derived and compared to the SJNR of a conventional OFDM system. A simulation study of the precoded OFDM system is also presented. This is performed in a practical setup based on the parameters of the mobile WiMAX standard and compares the BER of the precoded OFDM system with that of the conventional system in multiple scenarios that include AWGN and multipath channels along with jamming signals with different bandwidths. Furthermore, the precoded OFDM system offers protection against multiple narrowband jammers that may be targeting specific sub-bands of the system.

The block diagram of the considered OFDM system with sub-band precoding is sketched in Fig. 2.1.

However, the improvements are expected to be limited by the jamming signal power, and when the total jamming power is high, precoding may not yield improvements over the conventional system. There is a direct relationship between the probability of error at the receiver and the SJNR of the recovered symbols, which depends on the actual digital modulation scheme used, while in conventional OFDM systems it is expected that symbols transmitted over distinct subcarriers will be received with different SJNR and implicitly will incur different probabilities of error, in the precoded OFDM system all the symbols transmitted together using all subcarriers of a given sub-band will be received with the same SJNR and will have the same probability of error.

2.1 DISADVANTAGES OF EXISTING SYSTEM

1. Elimination of ISI causes Inter Channel Interference (ICI).
2. The BER performance is not improved. It leads to decrement in SNR.
3. Tight Synchronization between users is required in receiver. It leads to time latency.
4. Co-channel interference is occurred.
5. Dealing with this is more complex in OFDM than in CDMA. Static channel allocation with advanced coordination among adjacent base stations.
6. Pilot signals are used for synchronizations.
7. Dynamic channel allocation with advanced coordination among adjacent base stations.

III. PROPOSED METHOD

In LML (Linear Maximum Likelihood) channel estimation for multicarrier systems, one needs to know the channel correlation functions [11]. This represents an issue for systems with a little number of pilots working in time-changing channels. We propose to rough the channel control delay profile (PDP) with a shape that can totally be portrayed in two parameters, to be specific, the mean deferral and the root-mean-square (RMS) defer spread [6]. Moreover, we build up a straightforward procedure to evaluate these postpone parameters. The inexact PDP is then used to produce the LML channel coefficients for information subcarrier channel estimation. Scientific expressions are inferred that can be utilized to anticipate the precision of the different evaluations, and they are checked by recreation. The proposed procedure is relevant to both indicate point
correspondence and multi get to correspondence where diverse clients may encounter distinctive channel conditions. Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier modulation scheme, which has been adopted for numerous wireless principles such as IEEE 802.11a and HiperLAN2. A familiar problem of OFDM is its sensitivity to frequency compensate between the transmitted and received carrier frequencies.

**Fig. 1. Block diagram of proposed system**

### 3.1 QUADRATURE AMPLITUDE MODULATION

QAM, or Quadrature Amplitude Modulation, is the modulation scheme used in cable plants. Basically, QAM is how the modem encodes digital information to be sent over the RF interface of the modem. This modulation method is a aggregate of both Amplitude and phase modulation strategies. QAM is better than QPSK in terms of information carrying capacity. QAM takes benefit from the idea that two signal frequencies; one shifted by means of 90 degree with respect to the other may be transmitted on the same carrier. For QAM (Quadrature amplitude modulation), each carrier is ASK/PSK modulated. Therefore information symbols have different amplitudes and phases.

As mentioned for each symbol both phase and amplitudes are varied to represent different bits. There are two levels of amplitudes for each phase that is d1 level and d2 level. There are many variants to this technique. Most popular are 16-QAM, 64-QAM and 256-QAM. 64QAM and 256QAM are two very common modulation schemes used in the downstream channels for cable modem or digital cable plants. 16 QAM and QPSK are two modulation schemes commonly used for the upstream channels in a cable plant [2].

The quantity earlier than QAM (for instance 16QAM) refers directly to the number of decision factors in the constellation. This means, 256QAM has 192 more decision points than 64QAM. The quantity before QAM is likewise usually a power of two. (EG.2^6=64QAM). The more decision points, the more throughput per channel.

### 3.2. RESILIENT JAMMING

To meet resilient jamming challenge, we endorse a defense mechanism for resilient OFDM communication based totally on MIMO interference cancellation technique, which tracks jamming signal's path in real-time earlier than canceling it out. We devise an iterative channel tracking device to calculate the sender and jammer's channels alternatively and iteratively in a nicely timed fashion. More drastically, we initiate an advanced defense mechanism holding signal enhance rotation approach, which strategically rotates sender's signal to enhance the projected signal power, resulting in an improved anti-jamming overall performance. Two essential demanding situations in designing these mechanisms are: how to track the channels directly, and how to feedback the rotation vectors reliably. In reaction, we set up more than one pilots to facilitate channel tracking, carrying tactical interference cancellation to remarks messages [18].

The aim of this paper is to preserve operational OFDM structures in the face of reactive jamming attack. The contributions of this paper are -fold: first, we take advantage of the MIMO interference revocation and transmit precoding techniques to counter reactive jamming attacks for securing OFDM wireless communications.
IV. TYPES OF CHANNEL MODEL

The outline of received signal can be obtained from that of the transmitted signal if we’ve a model of the medium between the two. This model of the medium is known as channel model. The estimation of the channel is carried out using the following three channel models namely, Additive White Gaussian Noise, Rayleigh and Rician. It is accomplished by using implementing LMMSE channel estimation algorithms.

4.1 AWGN CHANNEL

This channel is a Primary or generally used channel model for analyzing Modulation schemes. On this model, the Additive White Gaussian Noise Channel provides a white Gaussian noise to the signal that passes through it. This means that the channel’s Amplitude frequency response is flat (thus with unlimited or infinite bandwidth) and phase frequency retort is linear for all frequencies so that modulated signals go through it without any amplitude loss and phase distortion. Fading does not exist for this channel. The transmitted signal gets distorted only by using AWGN system [16]. AWGN channel is a well known channel used for analysis reason only. The mathematical formulation in receiving signal is:

\[ r(t) = s(t) + n(t) \]  

That passes via the AWGN channel where \( s(t) \) is transmitted signal and \( n(t) \) is additive white Gaussian noise.

4.2 RAYLEIGH CHANNEL

The consequences of multipath include constructive and destructive interference, and phase shifting of the signal. This causes Rayleigh fading. There’s no line of sight (NLOS) path means no direct path among transmitter and receiver in Rayleigh fading channel [16]. The obtained signal can be simplified to:

\[ R(n) = \sum [h(n,\tau)s(n-m) + w(n)] \]  

Where \( w(n) \) is AWGN noise with zero mean and unit variance, \( h(n) \) is channel impulse response i.e.

\[ h(n) = \sum \alpha(n)e^{-j\theta(n)} \]

Wherein \( \alpha(n) \) and \( \theta(n) \) are attenuation and phase shift for \( n \)th path. If the coherence bandwidth of the channel is greater than signal bandwidth, the channel is referred to as flat; otherwise it is frequency-selective fading channel. in this paper, MIMO OFDM is simulated under frequency-selective fading channel.

The Rayleigh distribution [2] is essentially the magnitude of the sum of equal independent orthogonal Gaussian random variables and the probability density function (PDF) given by using:

\[ p(z) = \frac{z}{\sigma^2} e^{-\frac{z^2}{2\sigma^2}}, \quad z \geq 0 \]  

in which \( \sigma^2 \) is the time-average power of the received signal and eq. (3) is referred to as a Rayleigh random variable.

In environments where there is a dominant Line-of-Sight (LOS) path between the transmitter and the receiver, the complicated gaussian distributed fading coefficient ought to be modeled with a non-zero mean, giving rise to the Rician fading. Or additionally say that, Rayleigh fading with a strong line of sight (LOS) content is stated to have a Rician distribution, or to be Rician fading. The Rician distribution is usually characterized with the aid of the Rice factor \( \kappa \).

\[ \kappa = \frac{m}{2\sigma^2} \]  

Eq(4) which indicates the relative strength of the direct LOS path component of the fading coefficient. When \( \kappa = 0 \) this model reduces to Rayleigh fading and as \( \kappa = \infty \) the fading becomes deterministic giving develop to an AWGN channel.

4.3 LMMSE EQUALIZER

It is a cyclic extension of an OFDM symbol to purgeline SI effect on original OFDM symbol. The length of cyclic prefix is picked \( \frac{1}{4} \) of the length of symbol [9]. The cyclic prefix includes time over head reducing the general adequacy of the framework. Additive white Gaussian Noise (AWGN) is a direct model in which the main impedance to correspondence is a straight option of wideband or background noise an enduring ethereal thickness (communicated as watts standard hertz of data...
transfer capacity) and a Gaussian circulation of amplitude [7].

The model does not account for fading, frequency, selectivity, interference, nonlinearity or dispersion. In any case, it produces basic and tractable scientific models which are helpful for picking up knowledge into the fundamental conduct of a system before these other phenomena are considered[8]. This creates the cyclic defer differing qualities.

Two of the most equalization algorithms are minimum mean square error (MMSE) equalizer and Linear MMSE equalizer [4]. The LMMSE equalizer is used to enhance the channel gain in terms of signal to noise ratio. LMMSE algorithm is prolonged with maximum likelihood (ML) technique which could be applied to decrease the Cyclic delay diversity (CCD)[15].

\[
\begin{bmatrix}
  r_1^1 \\
  r_1^2 \\
  r_2^1 \\
  r_2^2
\end{bmatrix} =
\begin{bmatrix}
  h_{11} & h_{12} \\
  h_{21} & h_{22}
\end{bmatrix}
\begin{bmatrix}
  t_1 \\
  t_2
\end{bmatrix} +
\begin{bmatrix}
  n_1^1 \\
  n_2^1 \\
  n_1^2 \\
  n_2^2
\end{bmatrix} (3.1)
\]

Assuming that the channel remains constant for the second time slot, the received signal is in the second time slot is,

\[
\begin{bmatrix}
  r_1^2 \\
  r_2^2
\end{bmatrix} =
\begin{bmatrix}
  h_{11} & h_{12} \\
  h_{21} & h_{22}
\end{bmatrix}
\begin{bmatrix}
  -t_2^* \\
  t_1^*
\end{bmatrix} +
\begin{bmatrix}
  n_1^2 \\
  n_2^2
\end{bmatrix} (3.2)
\]

Where,

\[
\begin{bmatrix}
  r_1^1 \\
  r_1^2 \\
  r_2^1 \\
  r_2^2
\end{bmatrix}
\]

are the received information at time slot 1 on receive antenna 1, 2 respectively,

\[
\begin{bmatrix}
  r_1^2 \\
  r_2^2
\end{bmatrix}
\]

are the received information at time slot 2 on receive antenna 1, 2 respectively,

\[
h_{ij}
\]

is the channel from \( i^{th} \) receive antenna to \( j^{th} \) transmit antenna,

\[
t_1, t_2
\]

are the transmitted symbols,

\[
\begin{bmatrix}
  n_1^1 \\
  n_1^2 \\
  n_2^1 \\
  n_2^2
\end{bmatrix}
\]

are the noise at time slot 1 on receive antenna 1, 2 respectively and

\[
\begin{bmatrix}
  n_1^2 \\
  n_2^2
\end{bmatrix}
\]

are the noise at time slot 2 on receive antenna 1, 2 respectively.

Combining the equations at time slot 3.1 and 3.2,

\[
\begin{bmatrix}
  r_1^1 \\
  r_1^2 \\
  r_2^1^* \\
  r_2^2^*
\end{bmatrix} =
\begin{bmatrix}
  h_{11} & h_{12} \\
  h_{21} & h_{22}
\end{bmatrix}
\begin{bmatrix}
  t_1 \\
  t_2 \\
  -h_{11}^* \\
  -h_{21}^*
\end{bmatrix} +
\begin{bmatrix}
  n_1^1 \\
  n_1^2 \\
  n_2^1 \\
  n_2^2
\end{bmatrix} (3.3)
\]
Also,
\[
H = \begin{bmatrix}
h_{11} & h_{12} \\
h_{21} & h_{22} \\
h_{12}^* & -h_{11}^* \\
h_{22}^* & -h_{21}^*
\end{bmatrix}
\]
(3.4)

To solve for \[
\begin{bmatrix}
t_1 \\
t_2
\end{bmatrix}
\]
we know that we need to find the inverse of \(H\).

We know, for a general \(m \times n\) matrix, the pseudo inverse is defined as,
\[
H^+ = (H^H H)^{-1} H^H \quad (3.3)
\]

The term,
\[
(H^H H) =
\begin{bmatrix}
|h_{11}|^2 + |h_{21}|^2 + |h_{12}|^2 + |h_{22}|^2 & 0 \\
0 & |h_{11}|^2 + |h_{21}|^2 + |h_{12}|^2 + |h_{22}|^2
\end{bmatrix}
\]
……..(3.4)

Since this is a diagonal matrix, the inverse is just the inverse of the diagonal elements, i.e
\[
(H^H H)^{-1} =
\begin{bmatrix}
|1/|h_{11}|^2 + |h_{21}|^2 + |h_{12}|^2 + |h_{22}|^2| & 0 \\
0 & 1/|h_{11}|^2 + |h_{21}|^2 + |h_{12}|^2 + |h_{22}|^2|
\end{bmatrix}
\]
(3.5)

The estimate of the transmitted symbol is,
\[
\begin{bmatrix}
n_1 \\
n_2
\end{bmatrix} = (H^H H)^{-1} H^H
\begin{bmatrix}
r_1 \\
r_2
\end{bmatrix}
\]
(3.6)

4.4 MATLAB Implementation

**Fig:** flow chart for MATLAB implementation of LMMSE algorithm.

4.5 BITERROR RATE (BER):
In digital transmission, the number of bit errors is the number of received bits of a data stream over a communication channel that have been altered due to noise, interference, distortion or bit synchronization errors[16]. The bit error rate or bit error ratio (BER) is the number of bit errors divided by the total number of transferred bits during a studied time interval. The bit error rate or bit error ratio (BER) is defined as the rate at which errors occur in a transmission system during a studied time interval. BER is a unit less quantity [17].

\[
BER = \frac{\text{number of errors}}{\text{total number of bits sent}}
\]

4.6 SIGNAL TO NOISE RATIO
The SNR is the ratio of the acquired signal power over the noise power within the frequency range of the process. Signal to Noise Ratio( SNR) is inversely related to BER, that is high Bit Error Rate( BER) causes low SNR[16]. High BER causes an increase in packet loss, enhance in delay and reduce throughput. SNR is an indicator usually measures the clarity of
the signal in a circuit or a wired/wireless transmission channel and measure in decibel (dB). The SNR is the ratio between the desired signal and the undesirable background noise [17].

\[ SNR = \frac{P_{signal}}{P_{noise}} \]

### 4.7 ADVANTAGES OF PROPOSED SYSTEM

1. The IFFT and FFT operations are computationally efficient.
2. The BER performance improves significantly using these equalizers.
3. More resistant to fading.
4. Broadband signals experience frequency selective fading.
5. OFDM allows different users to transmit over different portions of the broadband spectrum (traffic channel).
6. Different users perceive different channel qualities; a deep faded channel for one user may still be favorable to others.
7. Synchronization between the users are not required in the received which will increase Signal to Noise ratio by decreasing the Bit error rate.
8. Efficient use of spectrum is possible.
9. Less complexity when compared to other modulation techniques.
10. While simulating the algorithm, the MATLAB takes less memory space.
11. High accuracy and sensitivity.
12. Speed is improved.
13. Antenna diversity scheme technique can significantly increase the data rate and improve the quality of wireless transmission, which is limited by interference, local scattering and multipath propagation.
14. The idea behind multiple antenna diversity is to supply the receiver by multiple versions of the same signal transmitted via independent channels.

### V SIMULATION AND RESULTS

#### 5.1 SIMULATION PARAMETERS

Simulation parameters chosen for the model of MIMO OFDM is shown in the below table.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise model</td>
<td>i.i.d. AWGN</td>
</tr>
<tr>
<td>FFT &amp; IFFT Point</td>
<td>64</td>
</tr>
<tr>
<td>Sub-carrier Number</td>
<td>52</td>
</tr>
<tr>
<td>Used sub carrier index</td>
<td>{-26 to -1, +1 to +26}</td>
</tr>
<tr>
<td>CP Length</td>
<td>16</td>
</tr>
<tr>
<td>OFDM symbol length</td>
<td>4\mu s</td>
</tr>
</tbody>
</table>

Table1. Simulation parameters for MIMO OFDM

#### 5.2 RESULTS

The use of MIMO technology for jamming resilient OFDM communication, especially its capability to communicate against the powerful reactive jammer by using LMMSE equalizers simulated using MATLAB simulation tool in windows 8 Operating Platform and the following results are obtained.

NT and NR represents the number of transmitters and number of receivers. Fig. 3 shows the BER comparison for SISO, MIMO-OFDM with (NT=NR=2) 16 array QAM. Among the three methods the MUD OFDM with 2 transmitters and 2 receivers using 16 QAM based on LMMSE gives the best performance because it increases the SNR with the decrease in BER.
Fig. 3. BER comparison for SISO, MIMO-OFDM with (NT=NR=2) 16 array QAM

The Fig.4 shows the BER comparison for SISO, MIMO-OFDM with (NT=NR=2) 64 array QAM, here the modulation is done by using the 64 array. The MUD OFDM with 2 transmitters and 2 receivers using 64 QAM based on LMMSE gives the best performance with increased SNR and low BER.

Fig. 4. BER comparison for SISO, MIMO-OFDM with (NT=NR=2) 64 array QAM

The Fig.5 describes the performance of SISO, MIMO-OFDM, MUD OFDM with LMMSE equalization with 256 arrayQAM. Here also the proposed method using LMMSE equalization gives the better SNR with decrease in BER.

Fig. 5. BER comparison for SISO, MIMO-OFDM with (NT=NR=2) 256 array QAM

The Fig.6. describes the capacity estimation for conventional OFDM, proposed OFDM using 64 QAM and proposed OFDM using 256 QAM with LMMSE equalization. The capacity increases with increase in sum rate for all the three methods. Among them high capacity is achieved by the proposed technique with LMMSE.

Fig. 6. Capacity estimation

Fig. 7. Power vs Sum rate for different system using Modified Waterfilling algorithm

Fig.7 reveals the power across different channels. The channels are Rician, Rayleigh and AWGN channel. This is done by using the modified water filling algorithm. The ergodic capacity increases with increase in power in watts.
VI. CONCLUSIONS
This paper presented novel OFDM systems using broadly linear MMSE-based equalization for precoding the MIMO-OFDM systems. The use of widely linear processing brings, when the transmitter uses inappropriate constellations, a performance gain compared to when ordinary strictly linear MMSE processing is used. As for OFDM systems utilizing MMSE equalization scheme, together with the gain, the utilization of broadly makes the mistake error less delicate to the input channel estimate. Error performance gain of MIMO-OFDM precoded systems using widely linear processing is also observed when there are channel estimation/CSI errors. Conceivable outcomes for future work incorporate consolidating generally direct preparing with the down to frequency-domain equalization method for SC-FDE systems employing offset modulation and pulse shaping.

VII. REFERENCES
[1] Otilia Popescu and Dimitrie C. Popescu, “on the performance of precoded OFDM in the presence of jamming,” Department of Electrical & Computer Engineering Old Dominion University, Norfolk, Virginia, USA.