Abstract—This project proposed a low-complexity turbo receiver using ICI-aware dual-list MIMO detection method to recover the transmitted bits with impairments often seen in the mobile MIMO-OFDM systems, e.g., Inter carrier interference (ICI) and Inter Antenna interference (IAI). By considering multiple ICI-inducing vectors, the proposed TRIDL algorithm solves the inherent error propagation problem in the conventional interference mitigation solutions. The IDL MIMO detector based on the Maximum A Posteriori (MAP) technique. This technique utilizes two lists: X-List and Z-List. The MIMO detector produces a list of solution vectors at the current subcarrier called the X-List. The IDL Detector contains a list of ICI inducing vectors called the Z-List, and it updates the list as the iterations proceeds. Three complexity-reduction schemes are Delta-ICI evaluation, Hierarchical ICI-inducing vector enumeration method, Early-skip technique, these schemes are used to avoid redundant computation, thus making the TRIDL implementation feasible. Further we are comparing with the modulation (BPSK, QAM-16, QAM-64, and PSK) to analyze the system and also increasing the number of Iterations to get a better performance.

Index Terms --- Multiple-output multiple-input (MIMO), OFDM, inter-carrier interference (ICI), MAP detection, turbo receiver, performance analysis.

I. INTRODUCTION

The first turbo code, based on convolutional encoding, was introduced in 1993 by Berrou et al. Since then, several schemes have been proposed and the term “turbo codes” has been generalized to cover block codes and also convolutional codes. A turbo code is formed from the combination of parallel concatenation of two codes separated by an interleaver. It is a general way of processing data in receivers so that no information is destroyed. This technique corresponds to an continuous repetitive exchange of soft information between different blocks in a communications receiver in order to improve overall system performance. It is a new way of thinking in the construction of algorithms. This method was introduced in a system of controlling error for data transmission, called turbo codes. This family of Forward Error Codes (FEC) consists of two key design innovations: concatenated encoding and iterative decoding. MULTIPLE-input multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM) is a powerful technology for enhanced performance in wireless communication systems. The combination of MIMO and OFDM opens new avenues for current- and future-generation wireless communication systems to achieve higher performance and better service quality. Unfortunately, non-stationary channels in mobile communications destroy the orthogonality among OFDM subcarriers, escalating the interferences from neighboring subcarriers, the inter-carrier interference (ICI). Many recent mobile MIMO-OFDM studies viewed ICI as an additional interference source and tackled this detection problem as an extension of MIMO detection in stationary channels.

The Orthogonal Frequency Division Multiplexing (OFDM) transmission scheme is the optimum version of the multicarrier transmission scheme. In the past, as well as in the present, the OFDM is referred in the literature Multi-carrier, Multi-tone and Fourier Transform. OFDM is a promising candidate for achieving high data rate transmission in mobile environment. Introduction of OFDM into cellular world has been driven by two main benefits: Flexibility and Easy equalization. In the mobile radio environment, the relative movement between transmitter and receiver causes Doppler frequency shifts, in addition, the carriers can never be perfectly synchronized. These random frequency errors in OFDM system distort orthogonality between subcarriers and thus inter carrier interference (ICI) occurs.

The sequential interference mitigation (SIM) structure, assume that the input signals to the MIMO detector are ICI-free. From another point of view, the SIM structure merely considers one interference assumption which is provided by interference cancellation. On the contrary, the joint interference mitigation (JIM) structure considers ICI and IAI as a whole and tackles these problems simultaneously. This paper proposes an ICI-aware Dual-List (IDL) MIMO detector, based on the maximum a posteriori (MAP). The IDL MIMO detector requires significant computational complexity in metric evaluation. Therefore, we further propose three complexity-reduction schemes. First, a novel metricupdate scheme, called delta-ICI evaluation, exploits the difference between the z vectors to reduce computation complexity. Secondly, we introduce a hierarchical ICI-inducing vector enumeration method to eliminate redundant computations. Finally, an early-skip technique avoids unnecessary metric calculation whenever possible. The proposed IDL MIMO detection is embedded in an iterative (turbo) receiver structure to form a Turbo Receiver with ICI-aware Dual-List (TRIDL) MIMO detection. This TRIDL receiver includes two essential parts: the IDL MIMO detection and soft-in-soft-out forward.
error correction (FEC) decoding. The proposed TRIDL receiver provides an efficient signal reception method for mobile MIMO OFDM systems and it possesses the following features:

Consideration of multiple ICI-inducing vectors to avoid the error propagation problem;
A list-update concept that makes searching more effective; Delta-ICI evaluation and hierarchical enumeration to avoid redundant computation;
An early-skip technique that reduces IDL complexity in metric updating; BER performance comparable to the ICI-free scenario.

II. SYSTEM MODEL

Consider a mobile spatial-multiplexing MIMO-OFDM system with \( M_T \) transmit antennas and \( M_R \) receive antennas, where the transmitter sends \( M_T \) independent OFDM symbols simultaneously. Further assume that the time-varying wireless multipath channel from the \( p \)th transmit antenna to the \( q \)th receive antenna has a channel impulse response given by

\[
h_{q,p}(t; T) = \sum_{r=1}^{L} \delta(T - T_r(t)).
\]  

(1)

The path gain \( h_{q,p}(r; t) \) is the result of superposition of all scattered waves with delay \( T_r(t) \) and its amplitude is described by the Rayleigh distribution. Without loss of generality, consider only the received signals at the \( l \)th subcarrier and express all signals in the vector form. Then the equations is given as

\[
y_{l} = \sum_{k=0}^{N-1} H_{l;k} X_{k} + w_{l},
\]

\[
= H_{l;0} X_{l} + \sum_{k=0, k \neq l}^{N-1} H_{l;k} X_{k} + w_{l}
\]

Desired signal

\[
+ \frac{\text{IAI}}{} \quad \quad \quad \quad \frac{\text{ICI}}{}
\]

(2)

Where \( y_{l} = [y_{l}^T \quad y_{l}^2 \quad \ldots \quad y_{l}^{M_R}]^T \) and \( X_{l} = [x_{l}^1 \quad x_{l}^2 \quad \ldots \quad x_{l}^{M_T}]^T \) are the received signal vector at the \( l \)th subcarrier and the transmitted signal vector at the \( k \)th subcarrier, respectively, and \( w_{l} \) is an \( M_R \times 1 \) noise vector. Note that \( H_{l;k} \) is a matrix consisting of channel gains from the \( k \)th subcarrier to the \( l \)th subcarrier. Thus, the received signal at a particular subcarrier takes the form of

\[
y = GX + GZ + W = G'V + W,
\]  

(3)

Where \( G = H_{l;0} \rightarrow X_{l} \rightarrow \sum H_{l;k} \rightarrow \sum \) \( C_{M_R \times M_T}^{(N-1)} \), \( Z = [(X_{l})^T \quad (X_{l})^2 \quad \ldots \quad (X_{l})^{N-1}]^T \), \( G' \rightarrow H_{l;0} \rightarrow \sum \rightarrow \sum \rightarrow \sum \rightarrow \sum \rightarrow C_{M_R \times M_T}^{(N-1)} \), \( V = [(X_{l})^T \quad (X_{l})^2 \quad \ldots \quad (X_{l})^{N-1}]^T \), \( W \) = \( W_{l} \). we refer to \( G' \) as ICI gains.

III. TURBO RECEIVER WITH ICI-AWARE DUAL-LIST DETECTION

Turbo Receiver with ICI-aware Dual-List (TRIDL) MIMO detection to deal with the IAI and ICI in mobile MIMO OFDM systems. In the wireless MIMO-OFDM communications scenario, analogy can be drawn by looking at the MIMO solutions as horses and the ICI-inducing vectors as jockeys. As with horses and jockeys, merely choosing the best ICI, as in the SIM structure, does not guarantee the best performance.

![TRIDL Block Diagram](fig1.png)

Fig (1) TRIDL Block Diagram

The proposed TRIDL method, based on the MAP criterion, pairs a few better MIMO solutions with a few likely ICI-inducing vectors to find the best combination and thus avoids the error propagation problem. Figure 1 depicts the block diagram of the proposed TRIDL method. Basically input data is given to symbol mapping then we should do the IFFT operation and it is transmitted to the Channel. Again FFT operation is performed then we are converting the input data in to trellis structure. In the decoding MAP technique is used and it utilizes two lists: X-List and Z-List. The MIMO detector produces a list of solution vectors at the current subcarrier called the X-List. The IDL Detector contains a list.
of ICI inducing vectors called the Z-List, and it updates the list as the iterations proceed.

The initial detection phase, e.g., a soft-output list based MIMO detector, generates an \( \mathbf{x} \) list with \( L_\mathbf{x} \) MIMO solution vectors in the first iteration. These MIMO solution vectors are generated by searching through solution space, calculating metrics and sorting, and keeping the vectors with better metrics. On the other hand, the \( \mathbf{z} \) list containing \( L_\mathbf{z} \) ICI inducing vectors is then generated by bit flipping based on the results of the initial detection in the first iteration or the FEC decoder output in subsequent iterations. The IDL detector selects likely solutions based on these two lists, and generates soft information for each bit accordingly. That is the reason why the method is named dual-list detection. The soft information used for each bit is its log-likelihood ratio (LLR), which is defined as,

\[
\lambda(b_x(m)) = \log \left( \frac{P(b_x(m)) = 1}{P(b_x(m)) = 0} \right)
\]

where \( b_x(m) \) is the \( m \)th bit value of \( \mathbf{x} \) and it is either 1 or 0. After the LLRs of all the bits at all subcarriers have been computed, they are adjusted by the IDL input a priori information, \( \Lambda(\cdot) \), and then sent to the outer soft-in-soft-out FEC decoder for further processing. The next IDL iteration begins with a set of new a priori information computed from soft-in-soft-out FEC decoder outputs, likewise adjusted by the decoder input a priori information. The following explains the detection principle and the list generation method.

A. Transmitter

Input data is given to symbol mapping to map the symbols. We use IFFT in OFDM to convert the signal from frequency domain to time domain in the idea of OFDM generation, the source accepts a stream of data and converts them to symbols using modulation procedure, for example QPSK. Then the Serial to parallel converter takes the output of 4 symbols and mixes each one with one of the subcarrier, then now we have 4 sine waves then add the 4 sine. Now we notice that Serial to Parallel conversion stage represent as a function of frequency. After addition of sine waves that stage represents as a function of time.

B. Channel

Additive white Gaussian noise (AWGN) is a basic noise model used in the channel, it introduces noise in the communications channel. This model is used in Information theory to minimize the effect of various random processes that occur in the atmosphere. It has specific characteristics they are:

- Additive- it is added to noise that might be essential to the information structure.
- White- it refers to an idea that it has consistent power across the frequency band for the information system, white colour indicates the consistent emissions at all frequencies in the visible spectrum.
- Gaussian- it has normal distribution in the time domain and has an average time domain value is always zero.

AWGN is often used as a channel model in which the only impairment to communication is a linear addition of wideband or white noise with a constant spectral density and a Gaussian distribution of amplitude. It does not have fading problem, frequency selectivity, interference, nonlinearity or dispersion. Its applications are satellite and deep space communication links.

C. Receiver

1) MAP Detection Technique:

The maximum a posteriori (MAP) detection finds the transmitted symbols \( (\mathbf{x}, \mathbf{z}) \) in (3) by maximizing the metric \( J(\mathbf{x}, \mathbf{z}) \) given by

\[
J(\mathbf{x}, \mathbf{z}) = -\frac{\|y - G_x - G_z\|}{N_0} + \Lambda(\mathbf{x}) + \Lambda(\mathbf{z}),
\]

Where \( N_0 \) is the noise variance and \( \Lambda(\cdot) \) indicates the symbol a priori information. More precisely, \( \Lambda(\cdot) \) is the sum of bit a priori information for the corresponding symbols (\( \lambda a(\cdot) \)). This process can be regarded as detecting \( \mathbf{x} \) with the help of the ICI-inducing vector \( \mathbf{z} \). The LLR for the \( m \)th bit of \( \mathbf{x} \) at the IDL output is defined as

\[
\lambda(b_x(m)) = \max \left\{ J(\mathbf{x}, \mathbf{z}) \right\}_{\mathbf{x} \in \mathcal{X}_m^{(1)}} - \max \left\{ J(\mathbf{x}, \mathbf{z}) \right\}_{\mathbf{x} \in \mathcal{X}_m^{(0)}},
\]

where \( \mathcal{X}_m^{(1)} \) and \( \mathcal{X}_m^{(0)} \) consist of all symbol vectors that have the \( m \)th bit of \( \mathbf{x} \) equal to 1 and 0, respectively.

MAP algorithm minimizes the symbol (or bit) error probability and outputs a real number (soft decision) which is a measure of the probability of decoding a particular bit correctly. The decoding process is performed block by block employing a forward and a backward recursion. Although the output sequences for the MAP decoder have surprisingly similar patterns in the time domain, the soft outputs from the MAP decoder have larger deviations when compared with the soft outputs from a Viterbi decoder.

The MAP algorithm is more suitable and also the best algorithm which can be used in an iterative decoding. It is used in conjunction with turbo codes, it will allow us to operate at Eb/N0 levels lower than with any other forward error correction scheme used. It gives the better performance when it is used in an iterative decoder. MAP algorithm which can be applied to convolutional codes whose regular trellis structure is equivalent to a stationary Markov source. At the receiver end, we define the log likelihood ratio, \( \lambda(d_x) \), as
\[ L(d_k) = \log \frac{P_r(d_k = 1)}{P_r(d_k = 0)} \]

Where \( P(d_k = i | \text{observation}) \), \( i = 0, 1 \) is the APP of the data bit \( d_k \). Also suppose that the information bit sequence \( \{d_k\} \) is made up of \( N \) independent bits \( d_k \), taking values 0 and 1 with equal probability and that the encoder initial state \( S_0 \) and final state \( S_N \) are both equal to zero. This can be achieved by making the last \( N - \nu \) bits drive the encoder to state zero. These \( N - \nu \) bits are called a “tail”. This will decrease the rate by a factor \( (N - \nu)/N \) which can be made very close to one for long sequences.

The advantages of the MAP algorithm can be summarized as follows:

- Minimizes the symbol (bit) error probability
- Provides soft outputs.

Has a higher dynamic range than a Viterbi algorithm which is very important in an iterative decoding scheme.

2) Metric Update based on List:

The proposed IDL detection searches (e.g., using sphere decoder) for better MIMO solution vectors in the first iteration to build an \( x \) list and correspondingly an initial bit-metric memory (\( J \) memory) based on the initial \( z \) vector. The \( J \) memory contains the current best metrics for both hypotheses, 1 and 0, of every solution bit, i.e., \( J_0^m \) and \( J_1^m \). The algorithm then examines the candidates in the \( x \) list, recalculates their metrics based on other \( z \) vectors in the \( z \) list, and updates the \( J \) memory whenever necessary, namely, \( \nu \) bits in \( x \).

If \( J(x, z) > J_{m}^{(b_{m}(z))} \), assign \( J(x, z) \) to \( J_{m}^{(b_{m}(z))} \),

\[ J(x, z) = \max_{b} \{ J_0^m(b) \} \]

Where \( J_{m}^{(b_{m}(z))} \) is the component of \( J \) memory for the hypothesis that the \( m \)th bit of \( x \) is equal to \( b_{m}(z) \). This list-update approach offers remarkable saving in complexity because it eliminates the search process for \( x \) candidates when another \( z \) vector is considered.

3) Z-List Generation:

ICI inducing vectors are selected based on an ICI gains and a priori information. If subcarriers contain small ICI gains and it introduce insignificant ICI and also little effect on updating the metric. If it contains high priori bit information magnitude indicates that the FEC decoder has high confidence about that bit decision. ICI inducing vectors can be generated in the \( Z \)-List by flipping up to \( R_t \) bits of the hard-decision solution vector in the previous iteration.

The flipped bits are chosen according to the ICI gains and the a priori information. The bits are ranked according to

\[ \sum_{j=0}^{R_t} \left( \frac{R_t}{j} \right) \]

Where \( G'(z(m)) \) are the ICI gains corresponding to the \( m \)th bit of \( z \). The indices of those bits that can be flipped are collected and form a set \( B = (b_1, \ldots, b_{R_t}) \). It is divided into two process: Interference Generation and Metric update. First we should find \( Z_{\text{base}} \) from the previous iteration followed by QAM mapping. \( R_t \) bits are selected and sorted, whereupon ICI-inducing vectors are generated by flipping bits and then QAM mapping. Second the metric of each \( (x_i; z_j) \) pair from the \( x \) list and the \( z \) list is calculated and the \( J \) memory is updated. Output extrinsic LLRs are computed when all \( (x_i; z_j) \) pairs are tested and the \( J \) memory is updated.

IV. THREE COMPLEXITY-REDUCTION SCHEMES

Three complexity-reduction schemes are Delta-ICI evaluation, Hierarchical ICI-inducing vector enumeration method, Early-skip technique, these schemes are used to avoid redundant computation.

A. Delta-ICI Evaluation

Delta-ICI scheme saves the previous result and only calculates the difference. For example, the metric \( J(x_i, z_j) \) for an arbitrary symbol vector \( x_i \) based on the ICI-inducing vector \( z_j \) is given by

\[ J(x_i, z_j) = -\frac{\|y - G_z - G'z\|^2}{N_0} + A(x_i) + A(z_j), \]

Where \( \gamma_i \in \mathbb{C}^{M_i \times 1} \) and \( A(x_i) + A(z_j) \) are saved in the memory for future use. When another ICI-inducing symbol vector \( z_{j+1} \) is involved in metric update, we apply the delta vector concept, that is, the metric \( J(x_i, z_{j+1}) \) can be written based on \( z_{j+1} = z_{j+1} + \Delta z_{j+1} \) and \( A(x_i) + A(z_{j+1}) = A(x_i) + A(z_j) + A(\Delta z) \):

\[ J(x_i, z_{j+1}) = -\frac{\|y_i - G_z - G'z\|^2}{N_0} + A(x_i) + A(z_j) + A(\Delta z), \]

Where both \( \gamma_i \) and \( A(x_i) + A(z_j) \) have been calculated previously. In addition, \( G' \Delta z \) and \( A(\Delta z) \) can be calculated in advance and used by all MIMO solutions in the \( x \) list.

B. Hierarchical ICI-inducing vector enumeration method

ICI-inducing vectors are generated by flipping bits. Hierarchical enumeration can further reduce complexity. Assume we select \( R_t \) bits based on the aforementioned principle and flip up to \( Q_t \) out of these \( R_t \) bits, resulting in a

\[ \sum_{j=0}^{R_t} \left( \frac{R_t}{j} \right) \]
distances to the base ICI-inducing vector, $z_{base}$, which is derived from the hard-decision results of a priori information. Since a vector with larger Hamming distance has relatively smaller probability to be the winner based on the MAP criterion, we proposed to give higher priorities for ICI inducing vectors with smaller Hamming distances. As a result, the proposed approach calculates metrics more efficiently using a hierarchical structure.

C. Early-skip technique

The main idea of IDL is to enhance quality of bit LLR defined in (1) by taking more ICI-inducing vectors into consideration. Although the delta-ICI scheme reduces complexity greatly, it still needs the square norm calculation. In fact, many calculation results for some candidates will be discarded since they cannot improve the soft information in the J memory. Toward this end, we propose the following early-skip method with a check to avoid computing the metrics of all pairs from the two lists.

The early skip check is then easily executed by computing the above upper bound for $J(x_i, z_{j+1})$ and comparing this upper bound with the minimum value in the current J memory. If the upper bound is smaller, then the pair $(x_i; z_{j+1})$ can be excluded from the metric-update operation. Moreover, the remaining entries in the $x$ list can also be skipped.

V. Simulation Results and Comparison

Fig (1) Bit error probability curve

Fig (2) Transmitted signal constellation

Fig (3) Received signal constellation

Figure (4) Bit comparison at receiver:
TABLE I ITERATIONS

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<tr>
<th>SNR in db</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>10</th>
<th>Average</th>
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<tbody>
<tr>
<td>BER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For 1st iteration</td>
<td>0.0375</td>
<td>0.013</td>
<td>0.002</td>
<td>3.87*10^-6</td>
<td>0.0197</td>
</tr>
<tr>
<td>BER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For 5th iteration</td>
<td>0.0275</td>
<td>0.03</td>
<td>4*10^-4</td>
<td>2.87*10^-6</td>
<td>0.01456</td>
</tr>
<tr>
<td>BER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For 10th iteration</td>
<td>0.036</td>
<td>3*10^-4</td>
<td>3*10^-7</td>
<td>3.72*10^-7</td>
<td>0.0106</td>
</tr>
</tbody>
</table>

From the Table I BER for 1st, 5th and 10th iterations for the corresponding SNR in db.

VI. CONCLUSIONS

Thus we proposed a low-complexity turbo receiver using ICI-aware dual-list MIMO detection method to recover the transmitted bits with impairments often seen in the mobile MIMO-OFDM systems, e.g., ICI and IAI. By considering multiple ICI-inducing vectors, the proposed TRIDL algorithm solves the inherent error propagation problem in the conventional interference mitigation solutions. Three complexity-reduction schemes are proposed to avoid redundant computation, thus making the TRIDL implementation feasible. Further we are compared with the modulation (BPSK, QAM-16, QAM-64, and PSK) and analysed the system and also increased the number of Iterations (10) to get a better performance. From the analysed Result will give the best modulation.

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