Improved Channel Estimation for ISDB-T using Modified Orthogonal Matching Pursuit over fractional delay TU6 channel

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Abstract—This paper proposed an oversampling Modified Orthogonal Matching Pursuit based channel estimation for ISDB-T in fractional delay TU6 channel. The simulation shows that the proposed method has better bit-error-rate performance compared to the conventional method. In addition, the oversampling MOMP requires only less computational cost to improved the performance in fractional delay.

I. INTRODUCTION

Integrated Services Digital Broadcasting-Terrestrial (ISDB-T) is a Japanese digital television system. ISDB-T is not only limited to digital television services but also for mobile TV, and emergency notification services for earthquake, tsunami, etc. The multiservices capability of ISDB-T requires higher bandwidth which classifies the system as wideband system [1].

Nowadays, a multicarrier system called Orthogonal Frequency Division Multiplexing (OFDM) is applied for wideband system because of its capability to withstand the frequency selective fading channel. Theoretically, OFDM is proven to have robust against multipath interference and co-channel interference because the system is composed of higher number of flat fading subcarriers [2].

Nevertheless, it is still a requirement to estimate the Channel State Information (CSI) in OFDM for further improvement. The process of determining the CSI is called channel estimation. Channel estimation is a process of knowing the channel properties such as refraction, reflection, etc. of the transmitted signal, when the signal travels from transmitter to the receiver side [3]. The common method for channel estimation is to transmit a known signal called pilots that are loaded to some subcarriers of OFDM. And then at the receiver side, the response of the pilots to the channel will give an information of the channel.

There are many methods of estimating the channel available in the literature such as Ref. [4], [5], [6] . These methods have common assumption where all the OFDM symbols are perfectly synchronized. This paper considers an unsynchronized channel wherein the channel taps are fractional delays. It is assumed that when the channel taps are increased, the chances of the OFDM symbols to become unsynchronized is common. A conventional 6-tap typical urban (TU6) were used in this simulation which is the usual channel model for mobile TV [7].

In theory [8], the performance of unsynchronized symbols will drastically decrease. In order to mitigate the problem of fractional delay, the method of oversampling the signal has been proposed to increase the sample. In oversampling, the system will approach to perfect synchronization because all the samples are very close with each other.

Although oversampling the signal will solve the problem of fractional delay, but it has its own disadvantages. First, based on Nyquist sampling theorem, oversampling the signal will further increase the bandwidth that can create a possible cochannel interference. Second, the computational cost for channel estimation will increase because of the higher Fast Fourier Transform (FFT) size.

Fig. 1 shows the subcarriers in frequency domain for the two ISDB-T channels when oversampling is applied. The figure shows that an increase of bandwidth is realize when an oversampling is applied to a system. Since not all subcarriers were used for channel 1, there will be subcarriers in the middle that were suppressed to zeros. While most of the used subcarriers is in the left and right end of the channel 1. As observed in Fig. 1, the middle subcarriers of channel 1 was occupied by some subcarriers of channel 2. While the middle of channel 2 was occupied by some subcarriers of channel 1. This means that cochannel interference does not exist because all the subcarriers of the succeeding channels does not interfere with each other as what Fig. 1 shown. This assumption will solve first problem on co-channel interference.

Another problem that was mentioned is the higher computational cost for channel estimation when oversampling is
These is the simulation.

discuss the numerical results, and lastly Section V will discuss the proposed channel estimation. Section IV will discuss the computational cost in estimating the channel. The next sections will cover the system model used during the simulation, Section III will discuss the proposed channel estimation, Section IV will discuss the Modified Orthogonal Matching Pursuit algorithm. Section III-A will cover the system model used during the simulation, Section III will discuss the proposed channel estimation, Section IV will discuss the numerical results, and lastly Section V will discuss the conclusion.

II. SYSTEM MODEL

Fig. 2 shows the system block diagram that was used during the simulation.

The payload is defined as a vector

\[ \text{payload} = [u_0^t, u_1^t, \ldots, u_{M-1}^t]^T \]  

(1)

and each entry of this vector is defined as

\[ u_{Mm+i}^t = \begin{cases} p_m & (i = 0) \\ d_k^t & (0 \leq i < M) \end{cases} \]  

(2)

where \( p_m \) is the \( m \)-th pilot symbol and \( d_k^t \) is the \( k \)-th data symbol at \( t \) time. This payload is \( X \) oversample by multiplying FFT matrix defined as

\[ F_X = \begin{bmatrix} \exp(-j\frac{2\pi kn}{XN}) & 0 \leq k < XN \\ 0 & 0 \leq n < XN \end{bmatrix} \]  

(3)

with the reordering matrix defined as

\[ Q_X = \begin{bmatrix} 0_{K_P, K_N} & I_{K_P} \\ 0_{XN-K,N} & 0_{XN-K,N} \\ I_{K_N} & 0_{K_N, K_P} \end{bmatrix} \]  

(4)

where \( I_K \) is the identical matrix of size \( K \) and \( 0_{K,N} \) is the zero matrix of size \( K \times N \). \( K_P \) and \( K_N \) are the number of positive and negative frequency subcarriers, respectively. Basically, the reordering matrix is used to separate the positive and negative frequency subcarriers, and suppressed those middle subcarriers that were not used.

The OFDM symbol \( s^t \) after oversampling can now be define as

\[ s^t = F_X^{-1} Q_X u^t \]  

(5)

The OFDM symbol \( s^t \) is then used to add a cyclic prefix and allow it to transmit in TU6 channel model.

At the receiver side, the received signal \( r^t \) is then given by

\[ r^t = G s^t + z^t \]  

(6)

where \( G \) and \( z^t \) represents the channel impulse response matrix and additive white Gaussian noise component, respectively.

At this point, the process are opposite with the transmitter side, wherein the inverse FFT matrix and transpose of the reordering matrix were used to obtain the received signal \( v^t \) in frequency domain. This process is define as

\[ v^t = Q_X^T F_X r^t = Q_X^T H Q_X u^t + z_F^t \]  

(7)

where \( H = \text{diag}(h) \), \( h = [h_0, h_1, \ldots, h_{XN-1}]^T \) is the diagonal matrix whose \( k \)-th diagonal element corresponds to the channel frequency response, and \( z_F^t = Q_X^T F_X z^t \) is the AWGN components in frequency domain.

III. PROPOSED CHANNEL ESTIMATION

This section will discuss the proposed channel estimation for fractional delay TU6 channel using compressed sensing. The objective is to estimate the channel impulse response using the MOMP algorithm. Section III-A will cover the Compressed Sensing based estimation, and Section III-B will discuss the Modified Orthogonal Matching Pursuit algorithm.

A. Impulse Response Estimation using Compressed Sensing

Compressed Sensing (CS) is a new method for effective reconstruction of a “sparse” signal with limited number of measurements [9]. CS is the proposed method because the signal that was estimated is the impulse response \( g \) which is a sparse signal. Fig. 3 shows the vector and matrix representation of the CS problem. As shown in Fig. 3, the CS problem is an underdetermined problem of linear algebra. The matrix \( S_{N_m, N_{e1}} \) is called measurement matrix where it contains the possible basis of the impulse response \( g \).

At first, the frequency response \( \hat{h} \) from the received signal \( v \) was obtained using

\[ \hat{h} = Ev \]  

(8)

where \( E = \text{diag}(e) \), and the entries of vector \( e \) is define as
For the non-oversampling case, respectively. Below are the details on obtaining the observed impulse response into time domain using FFT. The equation below shows the symbols define as

\[ \tilde{g} = F^{-1}Q^T \Phi X(\tilde{g}_X + z) \]  

(12)

where \( Q_s = \text{diag}(q_s) \), \( q_s = [q_0 \ q_1 \ \cdots \ q_{K-1}]^T \), and each entries of \( q_s \) is defined as

\[ q_{Mm+i} = \begin{cases} 1 & (i = 0) \\ 0 & (0 \leq i < M) \end{cases} \]  

(13)

that represents the pilot pattern.

The \( F \) and \( Q \) is simply the FFT matrix and reordering matrix for the non-oversampling case, respectively. Below are the details about \( F \) and \( Q \).

\[ F = \left[ \exp \left( -j \frac{2\pi kn}{N} \right) \right]_{0 \leq k < N \ 0 \leq n < N} \]  

(14)

\[ Q = \begin{bmatrix} 0_{K_p,K_N} & I_{K_p} \\ 0_{N-K_N,K_N} & 0_{N-K_N,K_p} \\ I_{K_N} & 0_{K_N,K_p} \end{bmatrix} \]  

(15)

Finally, the Eq. (12) can be simplified into

\[ \tilde{g}_N = S_{g_X} + z_l \]  

(16)

where

\[ S = F^{-1}QQ^T F \]  

(17)

is the measurement matrix with size \( N \) by \( XN \) and

\[ z_l = S_z \]  

(18)

is the converted noise component.

The Eq. (16) can be further reduced to

\[ \tilde{g}_{Ngi} = S_{Ngi,XNgi}g_{XNgi} + z_{gi} \]  

(19)

where \( S_{Ngi,XNgi} \), \( \tilde{g}_{Ngi} \), \( g_{XNgi} \) represents the submatrix of \( S \), subvector of \( \tilde{g}_N \), and subvector of \( g_{XN} \), respectively.

Eq. (16) was scaled down into a smaller size matrix and vectors in Eq. (19) since the non-zero portion of the observed impulse response \( \tilde{g}_N \) is within the size of a guard interval. This is possible because the maximum delay is within the guard interval.

**B. Modified Orthogonal Matching Pursuit**

Modified Orthogonal Matching Pursuit (MOMP) is a solution for compressed sensing problem. MOMP requires low computational cost as long as the estimated signal does not change much over time [10]. This assumption is valid for the impulse response estimation that was considered in this paper where in the channel is only a frequency selective channel.

MOMP is a greedy algorithm that will determine which columns of the measurement matrix \( S_{Ngi,XNgi} \) that has the best basis of the observed impulse response \( \tilde{g}_{Ngi} \) in solving Eq. (19).

Below are the detailed steps of the conventional Orthogonal Matching Pursuit (OMP) algorithm for solving the impulse response \( g_{amp} \) [11], [12].

Let the columns of the measurement matrix \( S \) denote as

\[ S = \begin{bmatrix} s_0 & s_1 & \cdots & s_{N_{gi}-1} \end{bmatrix} \begin{bmatrix} s_{kn} \end{bmatrix}_{0 \leq k < XN \ 0 \leq n < XN} \]  

(20)

1) Let the residual vector be \( r_i = \tilde{g}_i \), the index set \( \Lambda_i = \phi \), and the iteration counter \( i = 1 \) as an initialization. Let \( X_i = \phi \) be the empty matrix of the chosen atom.

2) Solve for index \( \lambda_i \) by computing the maximum inner product between the residual and columns of measurement matrix.

\[ \lambda_i = \arg \max_{k} |r_i|^2 \]  

(21)

where \( x^H \) is the Hermitian transpose of \( x \).

3) \( \lambda_i \) is added to the index set as

\[ \Lambda_i = \Lambda_{i-1} \cup \{ \lambda_i \} \]  

(22)

while the \( \lambda_i \)-th column vector \( s_{\lambda_i} \) is augmented as

\[ X_i = [X_{i-1}, s_{\lambda_i}] \]  

(23)

4) Solve the estimated signal using least square.

\[ w_i = \arg \max_{w} ||\tilde{g}_i - X_i w||^2 \]  

(24)

where \( w_i \) is the \( i \)-dimensional vector.
5) Update the residual as
\[ r_i = \hat{g} - X_i w_i \] (25)

6) Increment the iteration counter \( i \) and repeat step 2 to 5 until \( i \leq m \) where \( m \) is the sparsity level.

7) The OMP estimate is then given by
\[ \hat{g}^{omp} = [i_{k_0} \ i_{k_1} \ \cdots \ i_{k_{m-1}}] w_m \] (26)

where
\[ i_k = \left[ \bar{k}_0 \bar{k}_1 \cdots \bar{k}_{N_{xi}-1} \right]^T \] (27)
is the \( N_{xi} \)-dimensional vector, of which the \( k \)-th element is one and other elements are set to be zero.

As mentioned, the present impulse response \( g^t \) and the previous impulse response \( g^{t-1} \) does not change much, the columns of the measurement matrix \( S \) is preselected using the search boundary selector vector \( b^t = [b_0^t \ b_1^t \ \cdots \ b_{N_{xi}-1}^t] \) where each entry of this vector is define as
\[ b_k^t = \begin{cases} 1 & (|g_{k}^{t-1}| \geq \eta_g) \\ 0 & (|g_{k}^{t-1}| < \eta_g) \end{cases} \] (28)
The \( g_{k}^{t-1} = \alpha g_{k-1}^{t-1} + g_{k}^{t-1} + \alpha g_{k+1}^{t-1} \) is the recalculated impulse response with \( \alpha \) as an arbitrary weight factor. While the \( \eta_g \) is the average threshold of \( g_{k}^{t-1} \) for determining the search region with highest peak.

The search boundary selector \( b^t \) will be use to condition the Eq.( 21) as
\[ \arg \max_{k} |r_{k-1}^H s_k| \] (29)

The modification of Eq.( 21) to Eq.( 29) differs between OMP and MOMP. Eq.( 29) was simply conditioned using search boundary selector \( b^t \) for computational reduction.

IV. NUMERICAL RESULTS

This section will discuss the simulation result using C++ programming with IT++ library for communication systems [13]. The proposed method was evaluated in terms of bit-error-rate (BER) performance in TU6 channel model. In addition, the computational cost for conventional sampling MOMP [11] and the proposed oversampling MOMP was evaluated in terms of average complex operation count per frame.

Table I shows the simulation parameters wherein ISDB-T One-Seg for mobile reception was considered. While Table II shows the details about the TU6 fractional delay channel model.

Fig. 4 shows the bit-error-rate performance in an ideal synchronized environment. The figure shows that both proposed oversample (oversample=2) MOMP and non-oversample (oversample=1) is very close to an ideal channel estimation.

Fig. 5 shows the bit-error-rate performance in non-ideal synchronized environment. In Fig. 5, the BER performance of oversample (oversample=2) MOMP was compared with the conventional linear interpolation, ideal estimation and non-oversample (oversample=1) MOMP. The perfect estimation represents the optimum improvement for all channel estimation methods. The figure shows that the proposed oversample MOMP has better performance compared to the conventional linear interpolation. The proposed oversample MOMP is also close to ideal estimation. On the other hand, if we compare the BER performance between the oversample MOMP and non-oversample MOMP, the oversample MOMP has better performance since it is robust against fractional delay.

Table III shows the computation time between non-oversample case vs. oversample case using MOMP in solving Eq.( 19). The table shows that only a very small increase of computation time when oversample was applied. The reason behind the lesser increase in computational time for oversam-
Fig. 5. BER performance

![BER performance in fractional TU6](image)

TABLE III

<table>
<thead>
<tr>
<th>oversample=1</th>
<th>oversample=2</th>
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<tbody>
<tr>
<td>689</td>
<td>709</td>
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ber performance in fractional TU6

AVERAGE COMPUTATION TIME PER FRAME IN MICROSECOND

<table>
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<tr>
<th>oversample=1</th>
<th>oversample=2</th>
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pling case can be seen in Eq.( 19) wherein only the columns of the measurement matrix $S_{N_G X N_A}$ was increased, and not the row. This means that the increasing size of measurement matrix is very minimal. Although the proposed system has thrice FFT operation at the receiver side, but theoretically, FFT is negligible since it requires only $O(N \log N)$ computation for $N$ composition.

V. CONCLUSIONS

This paper proposed a Modified Orthogonal Matching Pursuit (MOMP) based channel estimation for ISDB-T for fractional delay TU6 channel model. It has been verified using the simulation, that the proposed oversampling MOMP has better bit-error-rate performance compared to the conventional method. The simulation also shows that the proposed method is robust against fractional delay. It was also proven in this paper that only a small increase of computational time was realized when the proposed oversampling MOMP was applied in TU6 channel.

REFERENCES


