

ICI Cancellation Using 2D Channel Estimation for OFDM Mobile Receivers

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Abstract While OFDM achieves a high spectral efficiency by using multiple orthogonal sub-carriers, it is sensitive to frequency offset. Especially, for OFDM mobile receivers, Doppler effect causes frequency offset. Consequently, ICI (inter-carrier interference) occurs and results in a serious degradation of received signal. In order to combat ICI, we proposed an iterative ICI canceller in [1]. However, in the proposal [1], channel is estimated by interpolating separately in time and frequency domain. So when high delay spread and Doppler spread happen simultaneously, channel estimation accuracy degrades severely. Thus, ICI canceller performance also degrades. To solve this problem, we implement a 2D-DFT channel estimation that can work under severe channel conditions. As a result, ICI canceller retains a good performance under severe channel conditions.

Keyword OFDM, ICI

1. Introduction

OFDM utilizes a large number of orthogonal subcarrier to achieve high-spectral efficiency. The long duration symbol and guard interval protect useful part of OFDM symbols from inter-symbol-interference (ISI). Guard interval (GI) is implemented by cyclic prefix (CP). This scheme keeps OFDM symbols smoothly in time domain, and reduces out of band power of OFDM. Moreover, cyclic prefix keeps convolution of channel and OFDM symbol is circular convolution. However, in mobile environment, GI could not prevent Doppler effect. Doppler effect causes frequency offset that destroys the orthogonality among subcarriers. After performing FFT at receivers, energy from each subcarrier interferes to other subcarriers. This called Inter-Carrier Interference (ICI).

Many researches are conducted to deal with ICI caused by Doppler. In [2] and [3], an efficient approach is to linearly approximate time-varying channel within one OFDM symbol. A large ICI matrix equation is obtained. Since most ICI power concentrates near the diagonal of ICI matrix, [4] approximates the ICI matrix by a tri-diagonal matrix. Then, instead finding invert of a $N \times N$ matrix, [4] finds inverses of N matrix of order (3×3) . However, this method still requires a heavy computation. Additionally, as pilot symbols suffer ICI, the diagonal of the ICI matrix is corrupted by ICI. Therefore those above methods need finding inverse matrix, and their performance are limited.

In order to deal with those issues, we proposed an iterative ICI canceller as in [1]. By using Jacobi iteration method, we solve the ICI matrix equation without calculating inverse matrix. Moreover, at 2nd iteration, channel is re-estimated after removing ICI from pilots. As a result, the performance is improved significantly.

However, in [1], [2], [3], and [4], channel estimation is based on 1D estimation that interpolates channel separately in time and frequency domain. For example, after the channel is interpolated in frequency domain, it is interpolated in time domain. Since high delay spread and high Doppler happen simultaneously, the 1D estimation accuracy degrades. To deal with such severe channels, in this paper, we implement a combination of 2D-DFT channel estimation and ICI canceller.

The rest of paper is organized as follows: Section 2 reviews ICI canceller. Section 3 shows an implementation of the 2D channel estimation and ICI canceller. Simulation results are shown in section 4. Finally, section 5 shows conclusion.

2. Review of ICI Canceller

First, in this section, we present the derivation of ICI equation, and how to solve this equation. As in [2], the received signal in frequency domain can be written as

$$\begin{bmatrix} Y(0) \\ Y(1) \\ \vdots \\ Y(N-2) \\ Y(N-1) \end{bmatrix} = \overbrace{\begin{bmatrix} H_{0,0} & \Phi_{-1}\bar{V}_1 & \cdots & \Phi_{-N+2}\bar{V}_{N-2} & \Phi_{-N+1}\bar{V}_{N-1} \\ \Phi_1\bar{V}_0 & H_{1,1} & \cdots & \Phi_{-N+3}\bar{V}_{N-2} & \Phi_{-N+2}\bar{V}_{N-1} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \Phi_{N-2}\bar{V}_0 & \Phi_{N-3}\bar{V}_1 & \cdots & H_{N-2,N-2} & \Phi_{-1}\bar{V}_{N-1} \\ \Phi_{N-1}\bar{V}_0 & \Phi_{N-2}\bar{V}_1 & \cdots & \Phi_1\bar{V}_{N-2} & H_{N-1,N-1} \end{bmatrix}}^{\text{ICI Matrix } [H]} \times \begin{bmatrix} X(0) \\ X(1) \\ \vdots \\ X(N-2) \\ X(N-1) \end{bmatrix} + \begin{bmatrix} W(0) \\ W(1) \\ \vdots \\ W(N-2) \\ W(N-1) \end{bmatrix} \quad (1)$$

$$Y(k) = X(k).H_{k,k} + \underbrace{\sum_{l=0, l \neq k}^{N-1} X(l).H_{k,l}}_{ICI} + W(k) \quad (2)$$

$$H_{k,l} = \frac{1}{N} \sum_{n=0}^{N-1} \sum_{m=0}^{N-1} h(m,n).e^{-j\frac{2\pi lm}{N}}.e^{-j\frac{2\pi n}{N}(k-l)} \quad (3)$$

Where $X(k)$ and $Y(k)$ is transmitted and received signal respectively. l , and k are subcarrier indexes. $h(m,n)$ is channel impulse response of path m at instant time n . N is number of subcarrier. W denotes random noise. $V_l(n)$ denotes Fourier Transform of channel impulse response $h(m,n)$ at n instant time. In [2] and [3], by approximating $V_l(n)$ or channel impulse response $h(m,n)$ by a linear function within an OFDM, the ICI equation is obtained as (4). For more detail about the linear approximation of time varying channel, please refer to [2] and [3].

$$V_l(n) = \sum_{m=0}^{N-1} h(m,n)e^{-j\frac{2\pi lm}{N}} \quad (4)$$

$$\Phi_\Delta = \frac{1}{e^{j\frac{2\pi}{N}\Delta} - 1} \quad (5)$$

$$\bar{V}_l' = \frac{H_{l,l}^{(\text{next symbol})} - H_{l,l}^{(\text{pre symbol})}}{2N_s} \quad (6)$$

In order to recover the transmitted signal $X(k)$, we have to estimate the ICI matrix $[H]$ and solve a big ICI matrix equation. To see more detail of solving the big ICI matrix equation (1), please refer to [1].

3. An Implementation of 2D Channel Estimation and ICI Canceller

As we know, the 1D interpolation that consists of 1D carrier interpolation and 1D time interpolation can estimate channel provided that number of pilots fulfill

Nyquist law. Otherwise, it fails to estimate channel. For example, if the transfer function changes faster than a half of sampling speed of pilots in frequency domain, 1D carrier interpolation is not available to estimate the transfer function. Similarly, in time domain, if channel changes faster than sampling speed of pilots, 1D time interpolations will fail to estimate channel. Therefore, in order to estimate severe channels in which high delay and high Doppler happen simultaneously, we implement a 2D channel estimation.

The process of 2D channel estimation is shown in Fig. 3. To estimate channel transfer function for each OFDM symbol, 20 OFDM symbols including the interested symbol and 19 its neighbors are processed. It is noted that there are three zeros points between two pilots in the frequency domain, so after FFT, there are four copied versions of the Delay-Doppler profile that provides image of channel in both time and frequency. In order to estimate then channel, one copied version is chosen, and others have to be removed. Then, from the channel transfer function is recovered back from the copied version we chose.

Basically, in 2D interpolation, channel is measured by scattered pilots from 20 OFDM symbols instead of from 1 OFDM symbol as in the case of 1D carrier interpolation. As a result, 2D interpolation has more samples in both time and frequency for interpolating channel than the case of 1D carrier interpolation or 1D time interpolation. For example, assuming that channel is almost not changing in time domain, scattered pilots from 20 OFDM symbols measure channel at all sub-carrier. Thereby, in this case, 2D interpolation can estimate exactly the transfer function. In contrast, with 1D carrier interpolation, the distance between two pilots is 12 in frequency domain. Consequently, it is not available to estimate channel transfer function that changes faster than 1/24.

In the next section, we will compare 1D separated iteration with 2D interpolation by simulation.

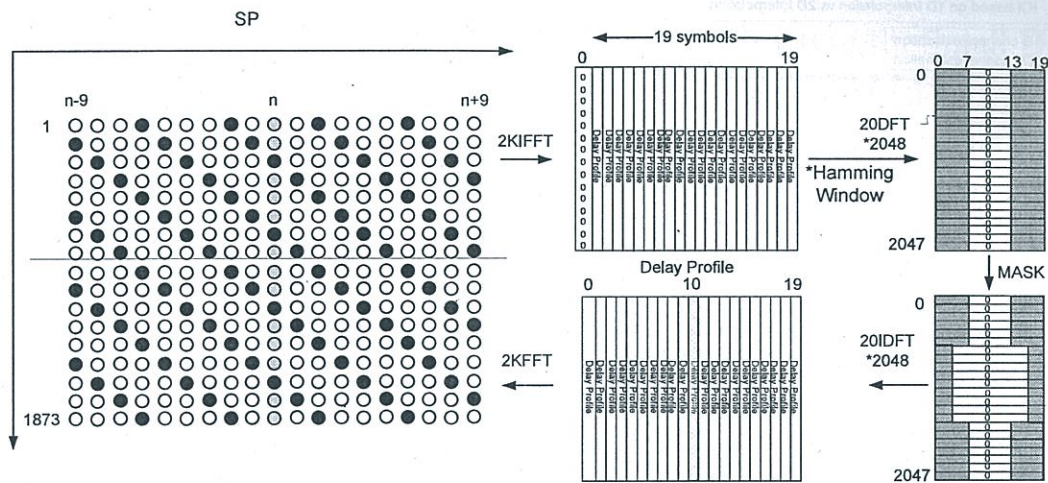


Figure.1 Implementation of 2D-DFT channel estimation

4. Simulation Result

In this section, we compare ICI canceller using 1D channel estimate and ICI canceller using 2D channel estimation. The parameters of OFDM system are set as ISDB-T mode 3, and these parameters are shown in table I. Different channel conditions are shown in table II and III.

The first channel condition is in table III, Doppler Spread equals to 50Hz and Delay changes within a range of $[0\mu s \ 125\mu s]$. Simulation result in fig. 2 shows that since delay is greater than about $25\mu s$, the 1D channel estimation degrades performance, but the 2D channel estimation still works well. When delay spread is high, channel transfer function changes faster than sampling speed of pilots in frequency domain. So the 1D channel estimation fails to estimate channel transfer function. However, the 2D channel estimation takes advantage of scattered pilots and measures the channel transfer function by pilots at from OFDM symbols. So it still can estimate channel.

The second channel condition is shown in table III. In this case, delay of each paths is fixed and Doppler spread changes within a range of $[0Hz \ 200Hz]$. Simulation realizes that in the high Doppler spread area, while the 1D channel estimation fails to estimate channel, the 2D one works well. The reason for this is similar to the first channel condition case.

5. Conclusion

In paper, we implemented an ICI canceller using 2D-DFT channel estimation that can estimate serious

channel in which high delay and high Doppler occurs simultaneously. Simulation results have demonstrated that the 2D-DFT channel estimation is better than 1D based channel estimation under serve channel conditions. However, the 2D-DFT channel estimation requires storing 20 OFDM symbols for estimating channel transfer function at subcarriers of one OFDM symbol.

TABLE I. ISDB-T MODE 3 PAREMETERS

Parameters	Values
FFT size	8192
Number of sub-carrier	5617
Carrier interval	992.06 (Hz)
Effective Sym. Duration	1008 μs
Guard interval	126 μs
Modulation	64QAM

TABLE II. THREE PATHS CHANNEL

Delay Path	Delay (μs)	DUR (dB)	Doppler Spread (Hz)
Direct Path	0	0	50
Delay Path 1	$[0 \ 125]$	-5	50
Delay Path 2	Delay1+12.5	-10	50

TABLE III. THREE PATHS CHANNEL

Delay Path	Delay (μs)	DUR (dB)	Doppler Spread (Hz)
Direct Path	0	0	$[0 \ 200]$
Delay Path 1	6.25	-3	$[0 \ 200]$
Delay Path 2	12.5	-6	$[0 \ 200]$

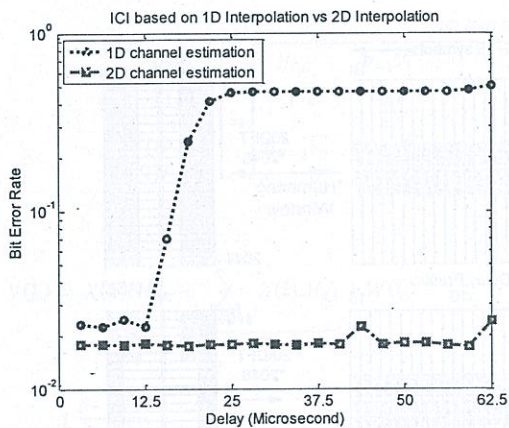


Figure.2 Comparing 2D-DFT and 1D channel estimation

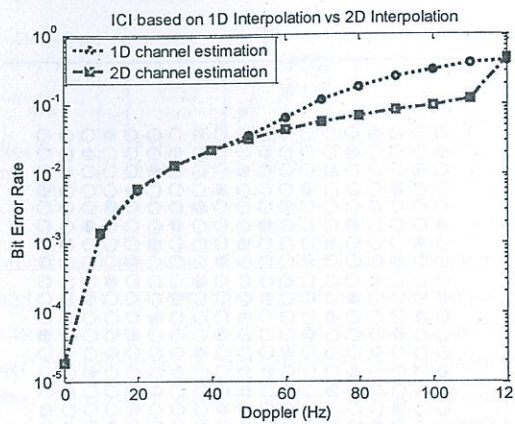


Figure.3 Comparing 2D-DFT and 1D channel estimation

References

- [1] Hai Minh TRAN, Tomohisa WADA "On Improvement of the ICI Cancellor for OFDM Mobile DTV Receiver," ICAC 2013, Korea, pp. 1134-1139f
- [2] Fischer, V. and Kurpiers, A. and Karsunke, D., "ICI reduction method for ofdm systems", Hamburg: 8th International OFDM-Workshop, pp. 1-5, 2003.
- [3] Mostofi, Y. and Cox, D.C., "ICI mitigation for pilot-aided OFDM mobile systems", Wireless Communication, IEEE Transactions on, IEEE, vol. 4, no. 2, pp. 765-774, 2005.
- [4] Jeon, W.G. and Chang, K.H. and Cho, Y.S., "An equalization technique for orthogonal frequency-division multiplexing systems in time-variant multipath channels", Communications, IEEE Transactions on, IEEE, vol. 47, no. 1, pp. 27-32, 1999
- [5] Henrik Schulze and Christian Luders, "Theory and Applications of OFDM and CDMA Wideband Wireless . Communications", John Wiley&Sons, Ltd 2005