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DFT-based Decision Directed Channel Estimation for OFDM Systems in Very Large Delay Spread Channels

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***Abstract*-In this paper, enhanced DFT-based channel estimation for OFDM system is proposed. Conventional DFT-based channel estimations improve the performance by suppressing time-domain noise. However, the disadvantage is that it cannot distinguish each path from the aliasing components of CIR when the periodic replicas of the estimated CIR are overlapped each other in very large delay spread channels. If any wrong CIR is chosen to obtain the CFR, a significant estimation error floor will appear despite of no ISI. In order to overcome the disadvantage, we consider a modified DFT-based channel estimation using decision-directed scheme. By using computer simulation, we show that proposed algorithm outperforms the conventional DFT-based estimation in terms of BER and MSE performance and displays sufficiently good performance similar to ideal case which is known CFR perfectly when the delay spread of multi-path channel is relatively large.**

Keywords: OFDM, DFT-based channel estimation, Channel Impulse Response (CIR), Decision-directed method, large delay spread

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is most promising as a future high data rate wireless communication system due to its advantages such as robustness in frequency-selective fading channels, high bandwidth efficiency, efficient implementation, and so on. Hence, OFDM has been widely used, and it is also the key technology for the Fourth Generation (4G) mobile communication. Some of well known examples include digital audio broadcasting (DAB), digital video broadcasting-terrestrial (DVB-T), IEEE 802. 11a wireless local area network (WLAN), and 802.16e wireless broadband (WiBro) [1]-[4].

Transmitting a radio signal over a wireless communication channel, the received signal is distorted by frequency selective fading and Doppler frequency shift because of multipath delay and mobile movement, respectively. Therefore, in the new generation communication systems based on OFDM, for coherently modulated OFDM system it necessarily requires reliable estimation of a channel frequency response (CFR) for data subcarriers [5]. The channel estimation technique can be classified into two categories. One is the channel estimation algorithm in the frequency domain. The simplest algorithm is the least square (LS) algorithm, which divides the received signal by the transmitted signal in the frequency domain. After estimating the channel in pilot position by the LS algorithm, usually, interpolation method is applied to estimate a CFR between pilots. To archive better performance in this category, Wiener filtering and minimum mean square error (MMSE) algorithms have been proposed [6]-[8]. However, the drawbacks of these algorithms have a high complexity because it requires knowledge of the channel frequency correlation and matrix inversion.

Another approach is to estimate channel in time domain. These methods estimate the channel impulse response (CIR) by an inverse discrete Fourier transform (IDFT) or a cyclic correlation. Since a CIR is not longer than the guard interval (GI) in OFDM system, we can choose the significant CIR less than the GI length and insert zero in only outside of the significant CIR part. Consequently, they provide the noise reduction effect in proportion to the number of zero-padding samples [9]-[12]. To achieve the low-complexity and reliable performance, we focus on the DFT-based channel estimation which can be implemented efficiently by the fast Fourier transform (FFT). And we consider the comb-type of pilot arrangement which can be applied to OFDM systems in fast fading channels.

Estimated CIR has periodic replicas because DFT-based channel estimation uses only pilot subcarriers which are reserved with a specific period. If maximum excess delay of channel is not longer than the GI length and the repetition interval, the DFT-based method will guarantee good performance. In very large delay spread channel environment, however, the periodic replicas of the CIR are overlapped each other and can cause aliasing error. In this case, if several main paths in the estimated CIR are chosen to obtain the CFR, a significant estimation error floor will appear at high signal to noise ratio (SNR) even though we assume that ISI does not occur. In order to solve this problem in very large delay spread channels, we propose the improved DFT-based estimation method based on the decision-directed algorithm which can estimate the CIR without aliasing.

The remainder of this paper is organized as follows. In section 2, the OFDM system model for baseband signal processing is introduced. Then, we illustrate the conventional DFT-based algorithm and propose a modified DFT-based channel estimation method in section 3. The simulation results and some analysis are given in section 4. The concluding remarks can be found in the last section.

II. OFDM Symbol Model

We consider an OFDM system that consists of N subcarriers for the parallel transmission of data and pilot symbols. Each subcarrier is denoted by $X_{m,k}$ where m represents the OFDM symbol number and k represents the subcarrier number. The binary information data are grouped and mapped into signal constellation. After the known pilot symbols are inserted in OFDM symbol, the modulated data symbols are transmitted at all positions except those of pilot symbols. In this paper, we consider QPSK modulation and comb-type of pilot arrangement, and Fig. 1 shows the pilot arrangement of OFDM system. The comb-type of pilot arrangement is evenly separated at a distance of N_{PS} subcarrier along the frequency direction.

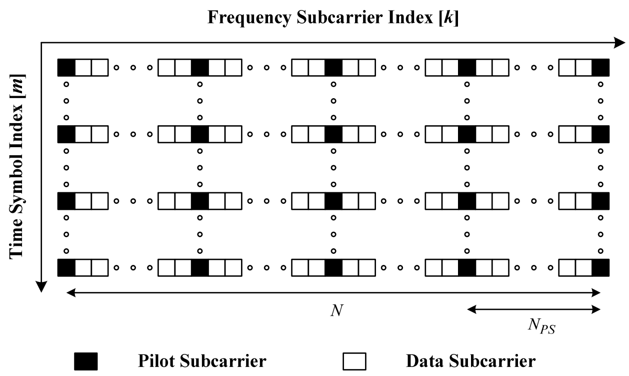


Fig. 1. Pilot arrangement of OFDM system

In order to avoid inter-symbol interference caused by multipath environments and inter-carrier interference, GI is appended to the OFDM symbol. After passing through a time-varying multi-path fading channel and removing the GI, the k-th subcarrier output in frequency domain can be represented as

$$Y_{m,k} = X_{m,k}H_{m,k} + W_{m,k} \ , 0 \le k \le N-1 \tag{1}$$

where $W_{m,k}$ is the complex-valued additive white Gaussian noise (AWGN) with zero mean and variance $\sigma_W^{\ 2}$ in frequency domain and $H_{m,k}$ is channel frequency response that is DFT of discrete time channel impulse response $h_{m,n}$ with length L and can be expressed as

$$\begin{cases} H_{m,k} = \sum_{i=0}^{L-1} h_{m,n} \exp\left(-j2\pi \dfrac{k\tau_i}{N}\right), & 0 \le k \le N-1 \\ h_{m,n} = IFFT\left[H_{m,k}\right] = \sum_{i=0}^{L-1} \alpha_i \delta\left[n-\tau_i\right], & 0 \le n \le N-1 \end{cases} \tag{2}$$

where α_i represents a different path complex gain that is complex Gaussian and τ_i is the corresponding path delays normalized by the sampling interval, which means there is no channel power loss caused by sampling time mismatch. The maximum path delay L is assumed not to exceed the length of GI N_{GI} (L<N_{GI}). To simplify analysis, we assume that synchronization is perfect at the receiver side.

III. Channel Estimation Algorithm

A. DFT-based channel estimation algorithm

A structure and an operational concept of the DFT-based channel estimation algorithm are shown in Fig. 2 and Fig.3, respectively.

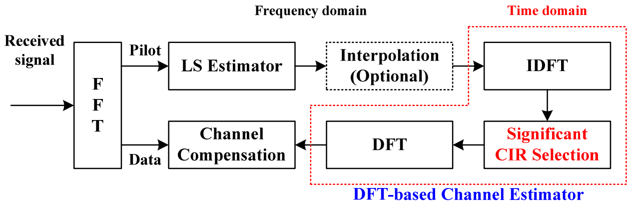


Fig. 2. DFT-based channel estimation structure

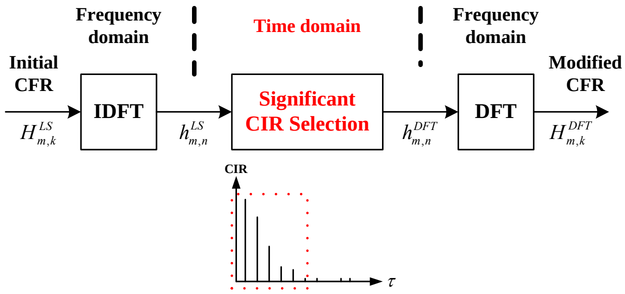


Fig. 3. Operational concept of DFT-based channel estimator

From the position of pilot subcarriers, initial LS channel estimation can be represented as

$$H^{LS}_{m,k} = \frac{Y_{m,k}}{X_{m,k}} = H_{m,k} + \frac{W_{m,k}}{X_{m,k}} \ , \quad k \in S_p : \text{set of pilot subcarriers} \tag{3}$$

The corresponding CIR can be obtained by N-point IDFT of the initial CFR as follows:

$$h^{LS}_{m,n} = IDFT\left[H^{LS}_{m,k}\right] = h_{m,n} + w'_{m,n} \tag{4}$$

where $w'_{m,n} = IDFT[W_{m,k} / X_{m,k}]$. The CIR is typically limited to the maximum delay L which is less than N_{GI} and L is much smaller compared with the number of subcarrier N. Thus the CIR can be described as

$$h_{m,n} = \begin{cases} IDFT\left[H_{m,k}\right], & 0 \le n \le L-1 \\ 0 & , \ otherwise \end{cases} \tag{5}$$

By using (5), Eq. (4) can be divided into two parts; CIR part including noise and only noise part as

$$h^{LS}_{m,n}[n] = \begin{cases} h_{m,n} + w'_{m,n} & , \ 0 \le n \le L-1 \\ w'_{m,n} & , \ L \le n \le N-1 \end{cases} \tag{6}$$

Hence, taking the first L samples and ignoring noise-only samples, we can obtain a noise reduction effect. As represented in [9] and [13], the significant path detection of CIR is performed by path-to-noise power ratio (PNR) threshold

$$h_{m,n}^{DFT} = \begin{cases} h_{m,n}^{LS}, & \left|h_{m,n}^{LS}\right|^2 \geq \Gamma \\ 0, & \left|h_{m,n}^{LS}\right|^2 < \Gamma \end{cases}, \quad \begin{pmatrix} \Gamma = \rho\sqrt{2N_{av}} \cdot SNR^{-1} \\ , \rho = J_0(2\pi f_D \Delta m T_s) \end{pmatrix} \qquad (7)$$

where, f_D, Δm, T_s, and N_{av} are maximum Doppler frequency, OFDM symbol interval, sample duration and the number of OFDM symbols for PNR averaging, respectively. In the case of the optimal algorithm, only effective CIR values are selected among the first L samples as follows:

$$h_{m,n}^{DFT} = \begin{cases} h_{m,n} + w'_{m,n} & , n \in \{\tau_0, \tau_1, \cdots, \tau_{L-1}\} \\ 0 & , \ otherwise \end{cases} \qquad (8)$$

From (7) and (8), the DFT-based channel estimation is denoted as

$$H_{m,k}^{DFT} = DFT\left[h_{m,n}^{DFT}\right], 0 \leq k, n \leq N-1 \qquad (9)$$

B. Coarse CIR estimation

To estimate the multipath fading channel, pilot symbols are evenly inserted into the N subcarrier, where the interval between two adjacent pilots NPS is shorter than coherence bandwidth Bc that defines a range of high correlation among adjacent frequencies of the channel. Coherence bandwidth that has more than 50% correlation in frequency is defined as [14][15]:

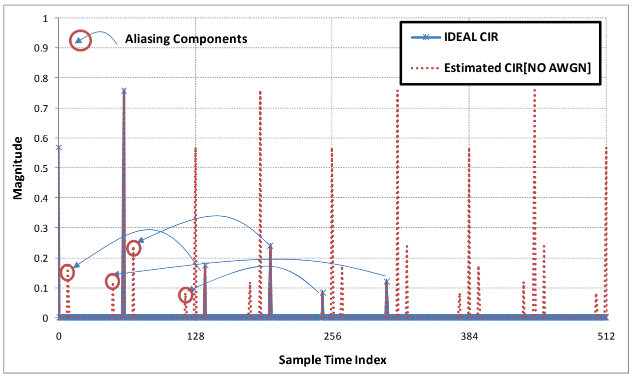
$$B_c \approx \frac{1}{5\tau_{rms}} \qquad (10)$$

where τ_{rms} is rms delay spread of the channel. According to Nyquist sampling theorem, in order to prevent aliasing in time domain, it is required that

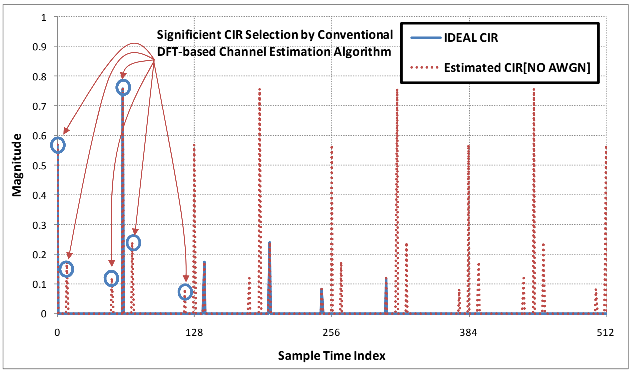
$$N_{PS} \cdot \Delta f < B_c \qquad (11)$$

where Δf is the space between subcarriers.

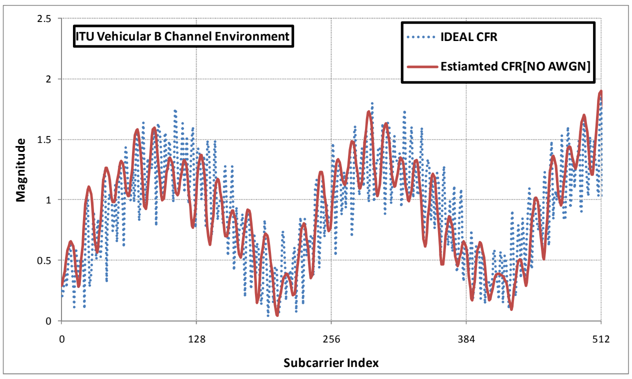
The estimated CIR has periodic replicas because DFT-based channel estimation uses only pilot subcarriers which are reserved with a specific period. When we design OFDM system, we consider various channel environments and decide N_{PS}. But it is impossible to consider all the channels. If designed OFDM system does not have suitable pilot structures to estimate CFR or CIR in the large delay spread channel, for example, when the periodic replicas of the CIR would be overlapped and can cause aliasing error, we could not apply interpolation method in the frequency domain to the system. Also we could not use conventional DFT-based channel estimation because we cannot divide path delay value from the aliasing components of CIR. And if several main paths in the first L samples are chosen to obtain the CFR as in (8), a significant estimation error floor will appear at high signal to noise ratio (SNR) even though we assume that ISI doesn't occur, which is illustrated in Fig. 4. If the OFDM system was composed of narrow N_{PS}, it enables us to have exact estimates of channel but it requires more pilot symbols and means decrease of data rate. Therefore we need to think about the channel estimation algorithm that can assure stable receiver performance without decrease of data rate in any channel environments.



(a) Aliasing components of estimated CIR



(b) Significant CIR selection error by conventional DFT-based method



(c) Estimated CFR by conventional DFT-based method

Fig. 4. An example of performance degradation due to aliasing components of the estimated CIR

C. Proposed DFT-based decision-directed channel estimation algorithm

In order to avoid the aliasing of estimated CIR in time domain in that conventional DFT-based channel estimation and to maximize the noise reduction effect at all subcarriers, we consider DFT-based decision-directed channel estimation algorithm. The proposed channel estimation method is summarized in Table 1.

Table 1. Proposed channel estimation method

Step 1: Set the initial CFR.

$$H_{m,k}^{DD} = H_{m,k}^{LS} \;,\; k \in S_P$$

Step 2: Equalizing $Y_{m,k\pm i}$ with $H_{m,k\pm i\mp 1}^{DD}$

$$\widehat{X}_{m,k\pm i}^{DD} = \frac{Y_{m,k\pm i}}{H_{m,k\pm i\mp 1}^{DD}} \tag{12}$$

Step 3: Estimate the $H_{m,k\pm i}$ using the $\overline{X}_{m,k\pm i}$. $\overline{X}_{m,k\pm i}$ is hard-decision-value of $\widehat{X}_{m,k\pm i}^{DD}$.

$$H_{m,k\pm i}^{DD} = \frac{Y_{m,k\pm i}}{\overline{X}_{m,k\pm i}} \tag{13}$$

Step 4: Finish the Decision-Directed method if $i > N_{PS}/2$. Otherwise, return to step 2.

We can find that estimated CIR using the proposed method does not have periodic replicas unlike the conventional method and Fig. 5 illustrates this estimated CIR.

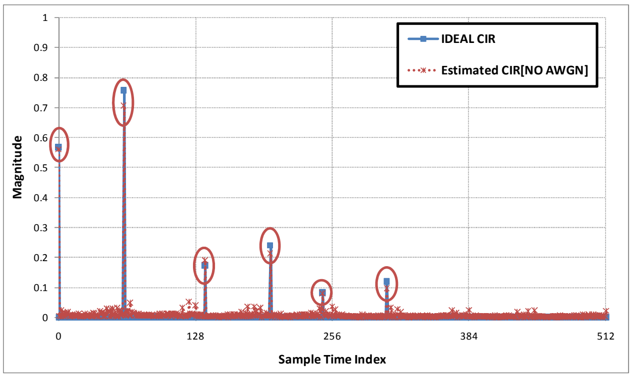


Fig. 5. An example of estimated CIR using the proposed method

The advantages of proposed method are to find path time delay more accurately, and to separate the significant CIR among the overlapped CIR. Therefore, if we use path time delay information which is estimated by decision-directed method, we achieve more stable receiver performance than conventional method without change of pilot symbols arrangement in the very large- delay- spread channels.

IV. Simulation Result

Table 2 summarizes major OFDM system parameters for performance evaluation. Channel coding scheme is not considered and the multipath fading channel with large delay spread characteristic is generated by ITU Vehicular B model. The rms delay τ_{rms} of this channel model is about $4\mu s$ and in order to avoid ISI we set the GI length enough. Also N_{PS} is selected to be 8 so that estimated CIR using the conventional method is overlapped. The performance comparison of channel estimation methods is performed by mean square error (MSE) of CFR and uncoded bit error rate (BER) where the CFR is obtained by discrete Fourier transform of the estimated CIR. For simplicity of expression, we use Proposed Method 1 and Proposed Method 2. The former means that we apply DFT-based method with only estimated CIR using the decision-directed method. The latter means that we apply path time delay information which is estimated by decision-directed method to conventional DFT-based method with the aim of separating CIR among the aliasing CIR.

Table 2. Major OFDM system parameters

Parameters	Values
Center frequency	2GHz
Bandwidth	10MHz
Sampling Frequency(F_s)	15.36MHz
FFT size (N)	1024
Sub-carrier spacing (ΔF)	15KHz
Pilot spacing(N_{PS})	8
Mobile velocity	60 km/h
Data modulation type	QPSK

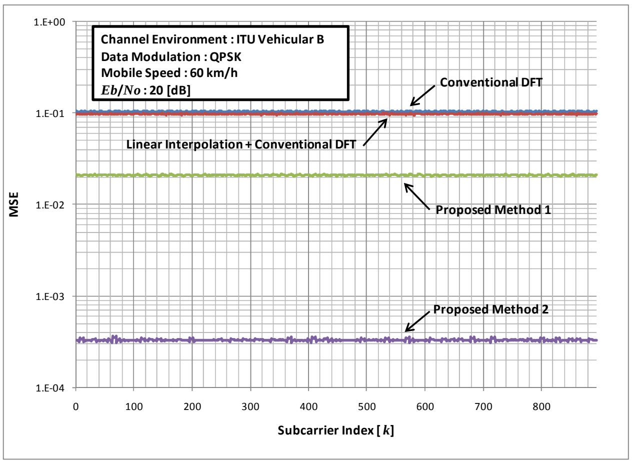


Fig. 6. MSE performance in each subcarrier index

Fig. 6. is shown that interpolation and the conventional DFT method which selected aliasing CIR components are significantly degraded in large delay spread channels. In case of the proposed method, it has better performance than the conventional methods and Proposed Method 2 indicates the best performance.

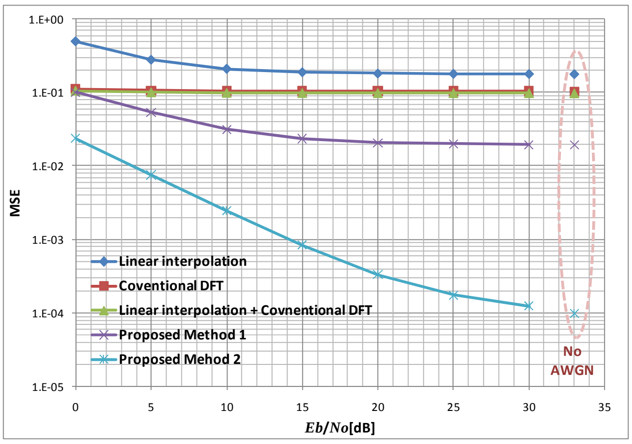


Fig. 7. MSE performance versus average Eb/No

In Fig. 7, we can know that the proposed method overcomes the disadvantage of conventional method. Notice that the Proposed Method 1 has some degradation compare with Proposed Method 2 because the power spectrum density of estimated CIR at proposed method 1 is dependent on the hard-decision performance. However, it has more accurate delay path detection than conventional method. Therefore, Proposed Method 2 indicate gradually better performance according to increasing *Eb*/*No* because it uses the more accurate information and obtains the noise reduction effect alike the conventional method.

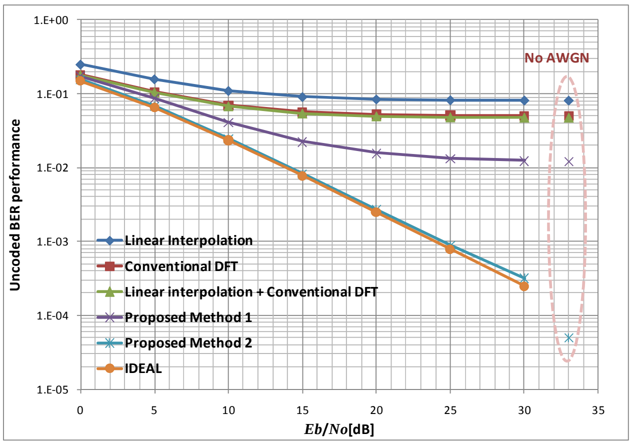


Fig. 8. Uncoded BER performance versus Eb/No

The uncoded BER performance versus *Eb*/*No* for considered estimator is shown in Fig. 8. We can see that the proposed method outperforms the conventional method and displays sufficiently good performance similar to ideal case which is known CFR perfectly.

V. Conclusions

In this paper, we have proposed improved DFT-based channel estimation in multipath fading channels with very large delay spread for OFDM systems. From the analysis and simulation, compared with the conventional scheme, the proposed DFT-based decision-directed channel estimation algorithm can improve the performance when the periodic replicas of the CIR would be overlapped and can cause aliasing error. We achieved similar performance to ideal case without changing the pilot structure and assure that stable receiver performance in the any channel environments. Simulation results presented in section IV confirmed these points.

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