

A DFT-Based Channel Estimation Scheme for IEEE 802.16e OFDMA Systems

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Abstract— Recent years, Orthogonal Frequency Division Multiplexing (OFDM) has been widely applied to various digital communication systems. WiMAX (Worldwide Interoperability for Microwave Access) holds a combination of fixed and mobile broadband wireless access techniques. IEEE 802.16e is the specification designed for WiMAX system in application of mobile environments. In order to achieve robust performance, one of the most important steps is the channel estimation procedure based on limited number of pilot signals. Owing to the channel's time variant characteristic caused by user's mobility and irregular arrangement of pilot signals in 802.16e system, the exact channel estimation is more difficult to achieve for this system. In this paper, under the consideration of the effects of mobility and AWGN, we propose a DFT-Based OFDM channel estimation scheme for the WiMAX systems. Simulation results show that the proposed adaptive channel estimation scheme can keep good system performance.

Keywords — Worldwide Interoperability for Microwave Access (WiMAX) ; channel estimation; DFT; virtual channel frequency response

I. INTRODUCTION

In recent years, orthogonal frequency division multiplexing (OFDM) has been considered as the most promising technology for next generation mobile communications. Due to its high spectral efficiency and robustness to multipath fading channel, OFDM has been applied widely in digital communication systems such as IEEE 802.11a, DAB, DVB and WiMAX. IEEE 802.16e [1-2] is the specification designate for WiMAX system in mobile environment.

Channel estimation plays an important role for OFDM systems to achieve robust performance by utilizing limited number of pilot signals. The estimated channel frequency response (CFR) at pilot subcarriers can be obtained by the Least Squares (LS) or the Minimum Mean Square Error (MMSE) criteria [4-5]. However, the computational complexity of MMSE is too high and requires the knowledge of channel information and operating SNR, these make MMSE difficult in practical use.

Based on the information at pilot subcarriers, the CFRs at data subcarriers can be obtained by the interpolation-based or the discrete Fourier transform (DFT)-based methods. The interpolation-based method is the simplest way to estimate CFRs by linear, second and higher order polynomials or Cubic, Spline functions, yet the performance is easily influenced by noise [3].

The DFT-Based method improves the performance by suppressing time domain noise. The main approach of DFT-Based method is described as follows: the estimated CFR at subcarriers in the frequency domain is first transformed to the time domain via IDFT to get the estimated channel impulse response (CIR), and pass the estimated CIR through the time domain processor to suppress noise, then transform the estimated CIR back to the frequency domain to get the estimated CFR at data subcarriers.

In many OFDM systems, virtual subcarriers are provided as guard bands to avoid the interference between adjacent systems. In this system there is no pilot located in the virtual subcarriers. Thus, lack of pilot during the execution of the DFT-based channel estimation will lead to estimation error at the edge of virtual subcarriers and introduce the edge effect. A low complexity method to reduce the influence of edge effect can be done by adding the virtual CFR (VCFR). In [10] the method of using the linear interpolation to generate VCFR is proposed and proves to have better performance than the VCFR method proposed in [9] by edge value repetition.

The most significant taps (MST) is a basic processor of the time domain and has the drawback of CIR energy discarded. [12] proposed an significant channel tap detector (SCTD) method to improve the performance of MST, yet the method is constrained by the block-type pilot arrangement and the maximum multipath delay must be known in advance, which can not be achieved in practical environment.

The rest of the paper is organized as follows: In section 2, the system model of IEEE 802.16e is introduced, including its frame and cluster structure. In section 3, conventional methods for DFT-Based OFDM channel estimation are discussed. Section 4 presents the proposed method. The simulation results are shown in section 5 and a conclusion is drawn in section 6.

II. SYSTEM MODEL

A. Frame structure

Figure 1 depicts the time division duplex (TDD) mode operation of the IEEE 802.16e OFDMA system. Each TDD frame consists of a downlink (DL) subframe and an uplink (UL) subframe. It is also shown that the first symbol in the DL subframe is used to transmit a preamble. The spectrum of 802.16e system with virtual subcarriers is shown in Figure 2. Excluding DC and the guard bands, the remained subcarriers are divided into 60 clusters, each with 14 adjacent

subcarriers. The cluster structure and the position of pilot subcarriers in each cluster for even and odd symbols is depicted in Figure 3. For the 802.16e system, the irregular pilot arrangement with possible high mobility makes it more difficult to carry out channel estimation accurately.

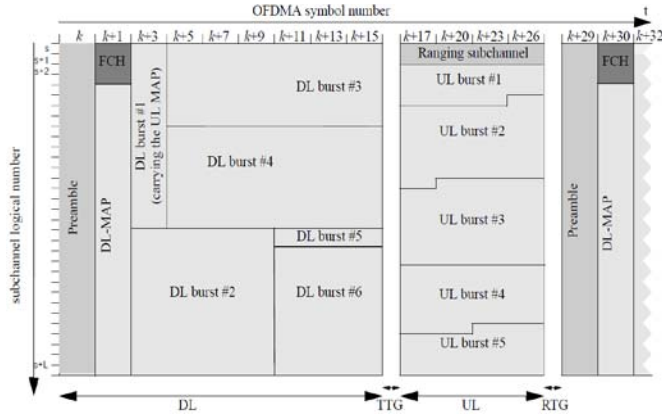


Figure 1. 802.16e OFDMA Frame Structure for TDD Mode [1]

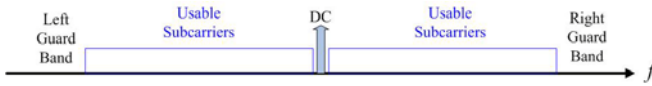


Figure 2. Spectrum of 802.16e System

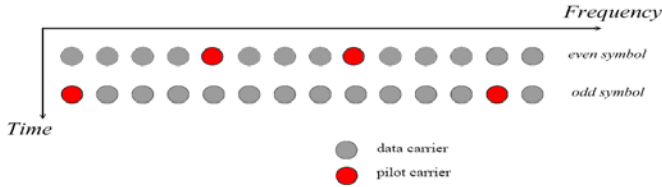


Figure 3. Cluster Structure of 802.16e DL System

B. System description

Let $X(k)$ represents the frequency domain signal at subcarrier k , then the transmitted time domain OFDM signal $x(n)$ for the N point FFT mode can be represented by:

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} X(k) e^{j2\pi \frac{kn}{N}}, \quad 0 \leq k \leq N-1 \quad (1)$$

where n represents the time domain OFDM sample index. The impulse response of multipath fading channel with the Doppler effect can be given as:

$$h(t, \tau) = \sum_{l=0}^{L-1} \alpha_l e^{-j2\pi f_c \tau_l} e^{-j2\pi f_D \tau_l} \delta(\tau - \tau_l) \quad (2)$$

The equation above models the L delay paths, each with index l , the delay τ_l , the Doppler frequency f_D , the phase variation $2\pi f_c \tau$, and the complex channel gain α_l . At time instants $t = nT_s$ and $\tau = lT_s$ where T_s is the OFDM sampling period, the channel can be represented by the concept of sample-based as discrete form $h_{n,l}$. The received

signal of time domain $y(n)$ (with CP removed) can be expressed as:

$$y(n) = \sum_{l=0}^{L-1} h_{n,l} x(n-l) + w(n), \quad n = 0 \sim N-1 \quad (3)$$

where $w(n)$ is the AWGN at time instant nT_s . After taking FFT of $y(n)$, we can obtain the received signal shown in the frequency domain as:

$$\begin{aligned} Y(k) &= \text{DFT}\{y(n)\} \\ &= \sum_{m=0}^{N-1} H(k, m) X(m) + W(k) \\ &= H(k) X(k) + \underbrace{\sum_{m=0, m \neq k}^{N-1} H(k, m) X(m)}_{\text{ICI}} + W(k), \quad k = 0 \sim N-1 \\ &= \mathbf{H}\mathbf{X} + \mathbf{W} \quad (\text{in matrix form}) \end{aligned} \quad (4)$$

where

$$H(k, m) = \frac{1}{N} \sum_{l=0}^{L-1} \sum_{n=0}^{N-1} h_{n,l} e^{-j2\pi \frac{n(k-m)}{N}} e^{-j2\pi \frac{lm}{N}} \quad (5)$$

and

$$W(k) = \sum_{n=0}^{N-1} w(n) e^{-j2\pi \frac{kn}{N}} \quad (6)$$

If $k \neq m$, $H(k, m)$ represents the effect of subcarrier m influencing upon subcarrier k , also called the ICI terms of a channel matrix. As user's speed grows, the ICI terms become more and more significant; this makes it a tough task to the channel estimation.

III. CONVENTIONAL METHOD

A. Mitigate Edge Effect

In this paper the focus of the channel estimation method is the DFT-based type, while the interpolation one is mainly used for comparison. In order to reduce the edge effect in DFT-Based methods, in [9] and [10] proposed the VCFR method with low complexity is proposed. The method to generate VCFR in [9] is simply by using edge value repetition, which is expressed in the following formula:

$$\hat{H}_{\text{VCFR}}(l) = \begin{cases} \hat{H}_{\text{LS}}(k_{\text{AC}}^R) & l = 0, 1, \dots, \frac{N_{\text{VC}}}{2} - 1 \\ \hat{H}_{\text{LS}}(k_{\text{AC}}^L) & l = \frac{N_{\text{VC}}}{2}, \dots, N_{\text{VC}} - 1 \end{cases} \quad (7)$$

- k_{AC}^L : The index at the edge of left active band.
- k_{AC}^R : The index at the edge of right active band.
- N_{VC} : The number of virtual subcarriers.

The method of generating VCFR in [10] is to use the two-point linear interpolation:

$$\hat{H}_{VCFR}(l) = \hat{H}_{LS}(k_{AC}^L) + \frac{l}{N_{VC}}(\hat{H}_{LS}(k_{AC}^R) - \hat{H}_{LS}(k_{AC}^L)), \quad l = 0, \dots, N_{VC} - 1 \quad (8)$$

The method to generate VCFR by the linear function is better than that of the edge value repetition when in high E_b/N_0 , therefore the linear VCFR is chosen to be the proposed method in simulation of this paper.

B. Time Domain Processing

In order to reduce the time domain noise, the SCTD method is proposed in [12]. In this method, the noise power is estimated first, then the estimation result is used to detect the channel taps, as shown below:

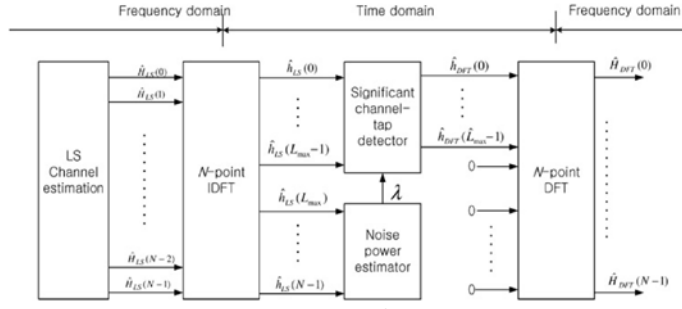


Figure 4. The block diagram of SCTD method [12]

The mathematical expression of SCTD is:

$$\bar{h}_{SCTD}(n) = \begin{cases} \hat{h}(n), & \text{if } |\bar{h}(n)|^2 > \sigma_{est}^2 \\ 0, & \text{otherwise} \end{cases} \quad (9)$$

$$\sigma_{est}^2 = \frac{1}{N - L_{max}} \sum_{n=L_{max}}^{N-1} |\bar{h}(n)|^2$$

- n : Time domain sample index.
- $\hat{h}$: The estimated CIR.
- $\bar{h}_{SCTD}$: The estimated CIR after SCTD.
- σ_{est}^2 : The threshold to detect the channel taps.

The SCTD method can effectively reduce the time domain noise, yet it has the drawback that the pilot arrangement must be block type and the maximum multipath delay must be known. To remedy these drawbacks, a modified SCTD method is proposed in the DFT-based channel estimation method of this paper.

IV. PROPOSED DFT-BASED CHANNEL ESTIMATION SCHEME

DFT-Based method has the advantage of suppressing the time domain noise through the time domain processing, achieving good performance in low E_b/N_0 . However, the pilot arrangement in 802.16e system is not regular as in the comb-type or block-type pilot arrangement. The first step for 802.16e system to apply the DFT-Based channel estimation method is to arrange pilots with equal-spacing.

Figure 5 presents the proposed DFT-Based channel estimation method. After interpolating the symbols, there are 4 usable CFRs in a cluster and labeled as $\hat{H}_c^l(1)$, $\hat{H}_c^l(5)$, $\hat{H}_c^l(9)$, $\hat{H}_c^l(13)$ respectively, as shown in Figure 6. The distance between these CFRs is 4 subcarrier spacing. However, the distance between CFRs in adjacent clusters, take $\hat{H}_c^l(13)$ and $\hat{H}_{c+1}^l(1)$ as an example, will not be more than 4 subcarrier spacing. Furthermore, the distance between $\hat{H}_c^l(13)$ and $\hat{H}_{c+2}^l(1)$ is adjusted to be integral multiple of 4 subcarrier spacing, as shown in the Figure 7.

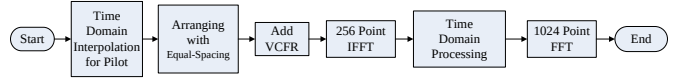


Figure 5. Proposed flowchart of DFT-Based method



Figure 6. Pilot spacing of 802.16e system

With the above characteristics, keep positions of the CFRs in odd clusters unchanged, and adjusting the even clusters such that pilots are equally-spaced. Since the allocated pilot is within the coherent bandwidth, linear interpolation is been used to obtain CFRs in even clusters, then combine the CFRs in even and odd clusters, as depicted follows:

$$\begin{cases} \hat{H}_c(3) = \frac{\hat{H}_c(1) + H_c(5)}{2} \\ \hat{H}_c(7) = \frac{\hat{H}_c(5) + H_c(9)}{2} \\ \hat{H}_c(11) = \frac{\hat{H}_c(9) + H_c(13)}{2} \end{cases} \quad c \in \text{even cluster} \quad (10)$$

$$\begin{aligned} \hat{\mathbf{H}}_{noVCFR} &= [\hat{\mathbf{H}}_1, \hat{\mathbf{H}}_2, \hat{\mathbf{H}}_3, \dots, \hat{\mathbf{H}}_{60}]^T \\ &= [\hat{H}_1(1), \hat{H}_1(5), \hat{H}_1(9), \hat{H}_1(13), \hat{H}_2(3), \hat{H}_2(7), \hat{H}_2(11), \dots, \hat{H}_{60}(11)]^T \\ &= [\hat{\mathbf{H}}_{noVCFR}(m)]^T, \quad m = 1 \sim 210 \end{aligned} \quad (11)$$

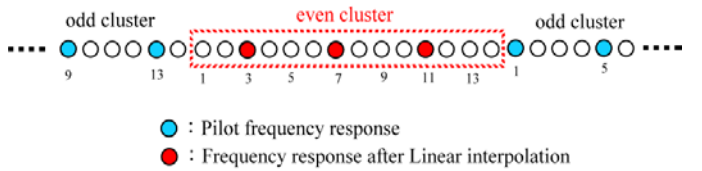


Figure 7. Arranging with equal spacing

After the equal spacing arrangement arranging with equal spacing, the CFRs will be uniformly distributed over frequency domain, and will not introduce aliasing during the processing of the DFT-Based method.

In order to mitigate the edge effect, linear function is been used to generate the VCFR. In this paper, the FFT size is chosen as 1024 points, the size of the required VCFR is 46 points. $\hat{H}_{noVCFR}(1)$ and $\hat{H}_{noVCFR}(210)$ are used to do linear interpolation so as to generate the 46 point VCFR, given as:

$$\hat{H}_{VCFR}(v) = \hat{H}_{noVCFR}(210) + \frac{v}{47}(\hat{H}_{noVCFR}(1) - \hat{H}_{noVCFR}(210)), \quad v = 1 \sim 46 \quad (12)$$

The final 256 points CFRs are combined as:

$$\hat{\mathbf{H}}_{addVCFR} = [\hat{\mathbf{H}}_{noVCFR}^R, \hat{\mathbf{H}}_{VCFR}, \hat{\mathbf{H}}_{noVCFR}^L]^T \quad (13)$$

- $\hat{\mathbf{H}}_{noVCFR}^L$: The first 105 points of $\hat{\mathbf{H}}_{noVCFR}$.
- $\hat{\mathbf{H}}_{noVCFR}^R$: The rest 105 points of $\hat{\mathbf{H}}_{noVCFR}$.

After adding VCFR, we can transpose these CFRs through 256 point IFFT to time domain, then performing time domain processing.

The SCTD method proposed in [12] is able to effectively reduce the time domain noise. Yet, the constraint of this method is the pilot arrangement must be the block type and the maximum multipath delay must be known in advance. The modified SCTD method for IEEE 802.16e system is proposed in this paper to improve the overall performance. Passing $\hat{\mathbf{H}}_{addVCFR}$ through 256 point IFFT, we can get the estimated CIRs $\hat{h}(q)$ as:

$$\hat{h}(q) = \frac{1}{256} \sum_{p=0}^{255} \hat{H}_{addVCFR}(p) e^{j2\pi \frac{pq}{256}} \quad (14)$$

- p : The frequency domain index, 0~255.
- q : The time domain index, 0~255.

Because of the characteristics of the Fourier transform and the virtual subcarriers, there still exist some multipath energy leakage in the tail of the estimated CIRs $\hat{h}(q)$. It is assumed that this system is ISI (inter-symbol interference) free. That is, the maximum multipath delay is not longer than the CP. The modified SCTD method is presented follows:

Step1. Averaging the power in the middle $\lambda \times N_{CP} \sim 256 - (1 - \lambda)N_{CP}$ points of $\hat{h}(q)$, where λ is set by the rule of thumb, then multiplied with a weighting w to get the threshold Th_{SCTD} :

$$Th_{SCTD} = w \times \frac{1}{256 - N_{CP}} \sum_{q=\lambda N_{CP}}^{256-(1-\lambda)N_{CP}} |\hat{h}(q)|^2, \quad \lambda = \frac{3}{4} \text{ or } \frac{7}{8} \quad (15)$$

Step2. Detecting the $\lambda \times N_{CP}$ points ahead and $(1 - \lambda)N_{CP}$ points behind by the following rule:

$$\hat{h}_{pass}(p) = \begin{cases} \hat{h}(p), & \text{if } |\hat{h}(p)|^2 > Th_{SCTD} \\ 0, & \text{else} \end{cases} \quad (16)$$

- p : The scan range,
- $p \in \{0 \sim \lambda N_{CP} - 1, 256 - (1 - \lambda)N_{CP} \sim 255\}$.

Step3. Padding $N - N_{CP}$ zeros to get the N point estimated CIR:

$$\bar{h}(n) = \begin{cases} \hat{h}(p), & n = p = 0, 1, 2, \dots, \lambda N_{CP} - 1 \\ 0, & \lambda N_{CP} \leq n < N - (1 - \lambda)N_{CP} \\ \hat{h}(p), & \begin{cases} n = N - (1 - \lambda)N_{CP} \sim N - 1 \\ p = 256 - (1 - \lambda)N_{CP} \sim 255 \end{cases} \end{cases} \quad (17)$$

Then pass $\bar{h}(n)$ through N point FFT to get $\bar{H}(k)$:

$$\bar{H}(k) = \sum_{n=0}^{N-1} \bar{h}(n) e^{-j2\pi \frac{kn}{N}}, \quad k = 0 \sim N - 1 \quad (18)$$

$\bar{H}(k)$ is the result of the proposed DFT-Based channel estimation method.

In order to compare the effect of different weighting in the proposed DFT-Based method, the weighting w is set to be 2, 4, and 8, respectively as shown in the Figure 8.

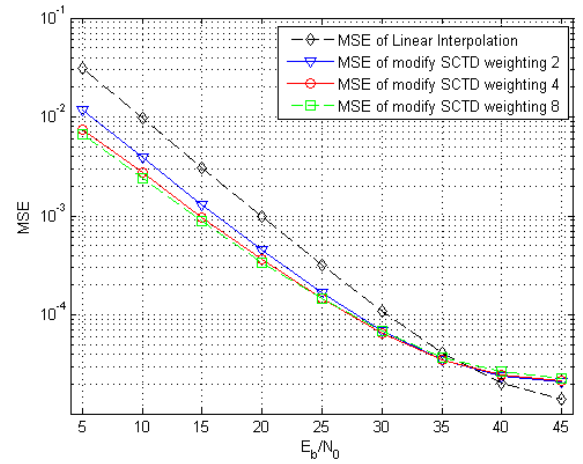


Figure 8. MSE of modified SCTD in different weighting

From the figure above, it is observed that when $E_b/N_0 < 35$ dB, the estimation result of proposed method is better than that of the linear interpolation. There is 5 dB difference when MSE is 10^{-3} . When $E_b/N_0 < 35$ dB, the DFT-Based method will eliminate useful information, thus result in the MSE floor. As the weighting w grows larger, the MSE performance is also getting better. However, the estimation result improvement becomes trivial when w is larger than 4. Thus, w is set to be 4 in our simulation.

V. SIMULATION SETTING

We simulate the 802.16e system in PUSC mode by using the ITU-R M.1225 vehicular channel A model. The following table lists the parameters in our simulation.

Table 1. Fading profile of ITU model in vehicular channel A

Tap Number	Relative tap delay (ns)	Relative tap amplitude (dB)	Doppler spectrum
1	0	0.0	Classical
2	310	-1.0	Classical
3	710	-9.0	Classical
4	1090	-10.0	Classical
5	1730	-15.0	Classical
6	2510	-20.0	Classical

Table 2. Parameters in simulation

Parameter	Value
FFT size	1024
Number of guard subcarriers, left	92
Number of guard subcarriers, right	91
Number of DC subcarriers	1
Number of pilot subcarriers	120
Number of data subcarriers	720
Carrier frequency	2.5 GHz
Bandwidth	10 MHz
Cyclic Prefix ratio	1/8
CP point N_{cp}	128
Subcarrier spacing	10.94 kHz
Useful OFDM symbol time	91.4 μ s
Data mapping	QPSK

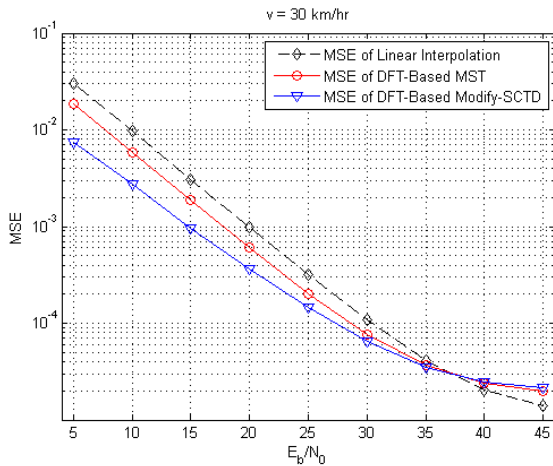
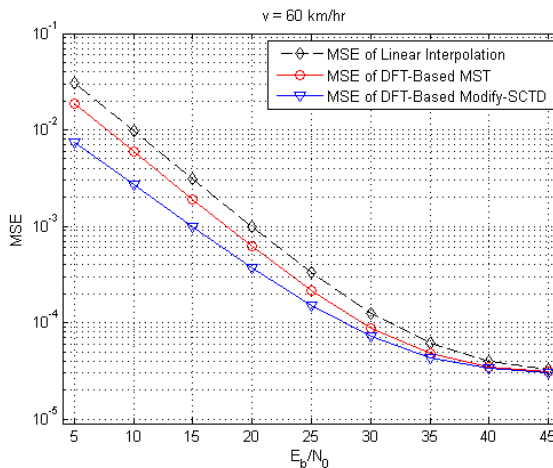
**Figure 9. Comparisons of different time domain processing methods and linear interpolation in 30 km/hr****Figure 10. Comparisons of different time domain processing methods and linear interpolation in 60 km/hr**

Figure 9 and Figure 10 present the comparison of MSE demonstrations about DFT-Based methods with different time domain processing and linear interpolation at 30 km and 60 km speed per hour, respectively.

Simulation results show that in low E_b/N_0 , the DFT-Based methods have good MSE performance than the linear interpolation ones. That is, the result of channel estimation using DFT-Based methods is closer to real channel than

linear interpolation. The modified SCTD with sifting estimate CIR is superior to MST without sifting in the MSE performance. The difference is 2.5dB when MST is 10^{-3} .

VI. CONCLUSION

In this paper, we present a DFT-Based OFDM channel estimation scheme for the WiMAX system. To verify the effective of the proposed scheme, the realistic ITU-R M.1225 Vehicular channel A model is been adopted in the simulation of this paper.

In the proposed channel estimation method for the 802.16e system, the frequency response is arranged to have equal-spacing. Secondly, VCFR is added in to mitigate the edge effect. Finally, the whole method is combined with the modified SCTD algorithm. Simulation results show that the proposed DFT-Based channel estimation scheme can improve the performance of WiMAX systems.

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