The Analysis and Simulation of Improved Linearly Interpolative Channel Estimation in LTE System

Yung-an KAO and Yu-xiang ZENG
Department of Electrical Engineering Chang Gung University Tao-yuan, Taiwan, ROC

Keywords: LTE, OFDM, Channel estimation.

Abstract. In the previous study, we propose a method to calculate the linear phase factor, and then use it to find the new linear interpolation filter coefficients. This new interpolation filter coefficient can improve the effect of 1-D linear interpolation. But this paper limit the pilot arrangement which is comb-type, and the distance between two pilots is a power of 2. In this paper, we adapt this method for channel estimation in the 3GPP-LTE. This method still has good effect in the LTE even the distance between two pilots is not a power of 2.

Introduction

In wireless communication environment, the transmitted signals are often influenced by the multipath channel. It is necessary for receiver to use equalizer to compensate the multipath channel. In OFDM systems, pilot-based channel estimation is usually adapted, and there are two steps. First step is to estimate frequency response of the pilot subcarriers, the second step is using frequency response of the pilot subcarriers to estimate frequency response of the data subcarriers.

In the OFDM systems, 1-D linear interpolation is the most commonly used channel estimation in the second step. The advantage of 1-D linear interpolation is simple and easier to hardware realization. But when the channel maximum delay becomes large, the effect of the 1-D linear interpolation will decrease. To solve this problem, D. W. Lin [1] proposed the linear phase factor to multiply by the interpolation filter coefficient. In time domain, use the linear phase factor to multiply by the linear interpolation filter coefficient is equal to shifting the 1-D linear phase factor in frequency domain. The appropriate shifting of frequency response will introduce the better performance of the interpolation. But this method [1] uses many statistical calculations, it will have trouble in the hardware realization.

To improve the above problem, Po-Heng Song [2] use the viewpoint of upsampling in discrete-time signal processing [3]. This new algorithm from the upsampling angle is easily to calculate the appropriate linear phase factor. And it has the better performance of the 1-D linear interpolation.

The method [2] did not focus on any wireless communication standards. Its pilot arrangement is comb-type and distance between two pilot subcarriers is a power of 2. But in some wireless communication standards, their distance between two pilot subcarriers are not a power of 2, such as DVB-T [4] and LTE. There are some points which deserve our study when we adopt this method [2] for channel estimation in the 3GPP-LTE system.

We will introduce the pilot arrangement of the LTE in section II. Section III introduces the improved linear interpolation. Section IV presents simulations results and discussion. Section V is the conclusion.

Pilot Arrangement of the LTE

Pilot arrangement often divided into comb-type [5], block-type [6] and scatter-type [7]. LTE is belong to scatter-type. The pilot arrangement of LTE has two kinds, each of them is long cyclic prefix (CP) and short CP. In this paper, we use the long CP pilot arrangement, and distance between two
pilot subcarriers is 6. The pilot arrangement is shown as Figure 1. White squares are data subcarriers, and black slash squares are pilot subcarriers. [8] [9].

![Figure 1. LTE (long CP) pilot arrangement.](image)

After estimating channel frequency of pilot subcarrier, 2-D linear interpolation can be adopted to estimate the frequency response of data subcarrier. 2-D linear interpolation has two methods, one is do the interpolation on the frequency domain and do the interpolation on the time domain (OFDM symbol) afterwards, and the other is do the interpolation on the time domain (OFDM symbol) and do the interpolation on the frequency domain afterwards. For convenience, we use F-T and T-F to represent these two linear interpolation methods respectively. In the aspect of time, the distance of two pilots is 6 OFDM symbols for T-F and the distance of two pilots is 3 OFDM symbols for F-T. When vehicle speed becomes fast, the effect of F-T is better than the effect of T-F. In the aspect of frequency, the distance of two pilots is 6 subcarriers for F-T and the distance of two pilots is 3 subcarriers for T-F. When channel maximum delay becomes large, the effect of T-F is better than the effect of F-T.

**Improved Linear Interpolation**

In F-T method, we first assume $H_{F1}[k]$ is the impulse response of linear interpolation filter. Because the distance between two pilots is 6, $H_{F1}[k]$ will be described to:

$$H_{F1}[k] = \begin{cases} 
1 - |k|/6, & \text{if } |k| \leq 6, \\
0, & \text{otherwise.}
\end{cases}$$

We use the linear phase factor to multiply by the interpolation filter coefficient, and the new linear interpolation filter coefficient $H_{N1}[k]$ will be described to:

$$H_{N1}[k] = H_{F1}[k] e^{-j\frac{2\pi k \tau}{N}},$$

where $N$ is the length of an OFDM symbol, $Np$ is the distance between two pilot subcarriers, $\tau$ is the shift value of the filter frequency response and $k=0, 1, 2...Np-1$.

In the time direction, the interpolation in the frequency domain is already done, so we just estimate OFDM symbol which has no pilot subcarriers. The time domain linear interpolation filter coefficient $H_{F2}[k]$:  

$$H_{F2}[k] = \begin{cases} 
1 - |k|/3, & \text{if } |k| \leq 3, \\
0, & \text{otherwise.}
\end{cases}$$

Because improve method just used in the frequency domain, we do not multiplied by the linear phase factor.
Similarly, in T-F method, we first assume $H_T[k]$ is the linear interpolation filter coefficient. $H_T[k]$ will be described to:

$$H_T[k] = \begin{cases} 
\left|1-k\right|/6, & \left|k\right| \leq 6, \\
0, & \text{otherwise}, 
\end{cases}$$

Because $H_T[k]$ is the time domain linear interpolation filter coefficient. We do not multiply by the linear phase factor. In the frequency direction, the interpolation in the time domain is already done, we just estimate data subcarriers which not known. The frequency domain linear interpolation filter coefficient $H_{T2}[k]$:

$$H_{T2}[k] = \begin{cases} 
\left|1-k\right|/3, & \left|k\right| \leq 3, \\
0, & \text{otherwise}, 
\end{cases}$$

We use the linear phase factor to multiply by the interpolation filter coefficient, and the new linear interpolation filter coefficient $H_{T2}[k, \tau]$ will be described to:

$$H_{T2}[k, \tau] = H_{T2}[k] e^{-j2\pi(k-\tau)N_p}.$$  \hspace{1cm} (2)

$N$ is the length of an OFDM symbol, $N_p$ is the distance between two pilot subcarriers, $\tau$ is the shift value of the filter frequency response and $k=0, 1, 2...N_p-1$.

In the Formula (1) and (2), we can find the appropriate $\tau$ will improve the effect of linear interpolation. We use formula (3) and 4 step to calculate the error energy. Minimize error energy will obtain the optimal value of $\tau$.

$$E_{err}(\tau) = \sum_{n=0}^{N(N_p-1)/2} \left|\hat{H}_p[n](1-\hat{H}_{N1}[n, \tau]/N_p)\right|^2 + \sum_{n=N_p/2}^{N-1} \left|\hat{H}_p[n](1-\hat{H}_{N1}[n, \tau]/N_p)\right|^2 + \sum_{n=N_p/2+1}^{N(N_p-1)/2} \left|\hat{H}_p[n]\hat{H}_{N1}[n, \tau]/N_p\right|^2.$$ \hspace{1cm} (3)

$H_{N1}[m, \tau]$ is the $N$ point FFT of the linear interpolation filter coefficient $H_{N1}[k, \tau]$. Define $H_p[k]$ as:

$$H_p[k] = \begin{cases} 
\hat{H}[k], & \text{for } k \in \text{pilot subcarrier index}, \\
0, & \text{for } k \in \text{data and guard band subcarrier index}, 
\end{cases}$$

$\hat{H}[k]$ is the channel frequency response which on the pilot subcarrier.

Step 1: Calculate the channel responses on pilot subcarrier and obtain $H_p[k]$. 
Step 2: $H_p[m]$ is obtained by $N$ point FFT of $H_p[k]$, and first let $\tau = 0$. 
Step 3: If $E_{err}(\tau) > E_{err}(\tau+1)$, let $\tau = \tau + 1$ and go back to Step3. If $E_{err}(\tau) < E_{err}(\tau+1)$, then go to Step 4. 
Step 4: We have better $\tau$ now, use formula (1) and (2) to calculate the new linear interpolation filter coefficient $H_{N1}[k, \tau]$ and $H_{T2}[k, \tau]$.

We use method here in detail in [2], we do not discuss here.

**Simulation Results and Discussion**

We use time-variant channel which proposed from COST207 [10]. And Table 1 is the simulation parameter. Table 2 is the channel model of the Hilly Terrain 12. 

In Figure 2, we compare our method and 1-D linear interpolation when vehicle speed is 60km/hr. Both of them use the F-T. Blue line is tradition 1-D linear interpolation, and green line is our method. In this simulation environment, 1-D linear interpolation is saturated at about 0.0024 after SNR > 25, and our method is still decrease. Figure 3 is the comparison chart between our method and 1-D linear interpolation when vehicle speed is 15km/hr and use the T-F method. Blue line is tradition 1-D linear
interpolation, and green line is our method. In this simulation environment, our method has a little better than tradition 1-D linear interpolation.

**Conclusion**

In this paper, we according to pervious improve method for 1-D linear interpolation, we adapt this method for channel estimation in the 3GPP-LTE. In the simulation result, we can find this method is still better than 1-D linear interpolation in the LTE system.

![Figure 2. BER simulation results of tradition linear interpolation (F-T), and proposed method (F-T) when vehicle speed is 60km/hr.](image1)

![Figure 3. BER simulation results of tradition linear interpolation (T-F), and proposed method (T-F) when vehicle speed is 60km/hr.](image2)

<table>
<thead>
<tr>
<th>Table 1. Simulation parameter.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFT point</td>
</tr>
<tr>
<td>Guard interval points</td>
</tr>
<tr>
<td>Guard band</td>
</tr>
<tr>
<td>Modulation</td>
</tr>
<tr>
<td>OFDM symbol</td>
</tr>
</tbody>
</table>
Table 2. Channel model of the Hilly Terrain 12.

<table>
<thead>
<tr>
<th>path No.</th>
<th>Propagation delay(μs)</th>
<th>Path power (lin.)</th>
<th>category of the PSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
<td>0.1</td>
<td>-10</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
<td>0.16</td>
<td>-8</td>
</tr>
<tr>
<td>3</td>
<td>0.4</td>
<td>0.25</td>
<td>-6</td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
<td>0.4</td>
<td>-4</td>
</tr>
<tr>
<td>5</td>
<td>0.8</td>
<td>1.0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>2.0</td>
<td>1.0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>2.4</td>
<td>0.4</td>
<td>-4</td>
</tr>
<tr>
<td>8</td>
<td>15.0</td>
<td>0.16</td>
<td>-8</td>
</tr>
<tr>
<td>9</td>
<td>15.2</td>
<td>0.13</td>
<td>-9</td>
</tr>
<tr>
<td>10</td>
<td>15.8</td>
<td>0.1</td>
<td>-10</td>
</tr>
<tr>
<td>11</td>
<td>17.2</td>
<td>0.06</td>
<td>-12</td>
</tr>
<tr>
<td>12</td>
<td>20.0</td>
<td>0.04</td>
<td>-14</td>
</tr>
</tbody>
</table>

References


