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A New Channel Estimation Method Based on Per-path Interference Cancellation for Cdma Downlink System

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Abstract: Since the auto-correlation of the Training Sequence (TS) is not perfect and the Channel Impulse Response (CIR) estimated by this TS will exists the inter-path interference at User Equipments (UE). If there is only one user at this slot, then there only exists the intra-user interference, such as GSM/EDGE system. If there is more than one user at this slot, then there exist the intra- and inter-user/cell interference, such as TD-SCDMA, CDMA2000, WCDMA systems. To mitigate this kind of interference, interference cancellation based on chip level methods are conventionally adopted, whose complexity is very high. To overcome the complexity problem in previous method, a lower complexity method named Per-Path Interference Cancellation (PPIC) has been proposed. Meanwhile, this method also has much higher estimation accuracy but its iteration time is very lager in some scenario, such as stronger interference or low SNR. In this study, a new iteration method based on per-path interference cancelation has been proposed. Take TD-SCDMA system for example, the simulation results show that the proposed method only needs less iteration times and obtains better estimation accuracy compared with the PPIC method.

Key words: CMDA, channel estimation, per-path interference cancellation

INTRODUCTION

Channel estimation (CHE) model plays a very important role in the communication system, since the performances of the equalizer (EQ) and the decoder model are all depended on its estimation accuracy, especially for Code Division Multiple Access (CDMA) system. This study takes Time Division-Synchronous Code Division Multiple Access (TD-SCDMA) system for example which is one of the 3G wireless standards. The TD-SCDMA system has several key technologies, such as smart antenna (Winters, 1998) and Joint Detection (JD) (Cao *et al*., 2004; Vollmer *et al*., 2001) which are however quite sensitive to the accuracy of channel estimation accuracy compared with other systems.

In the same cell, the TD-SCDMA network has the same basic midamble with some different shifted version. These neighbor cells employ different basic midamble sequences with non-zeros inter-correlation coefficient for downlink slot bursts. While UE stays the edge of the cell, the UE receives the signal from serving cell and the neighbor cells at the same time and suffers the interference for the non-orthogonality among basic midamble sequences for the serving cell and neighbor cells.

These Channel Estimation (CHE) algorithms for TD-SCDMA system have been studied widely. Some algorithms only suit for single cell scenarios, since they have poor estimation accuracy in multi-cell scenarios for treating the inter-cell interfering signal as white noise. The well-known algorithm, proposed by Steiner in study (Steiner and Jung, 1994), belongs to this kind algorithm. It takes advantage of the Toeplitz characteristic of the channel estimation matrix and applied the FFT and IFFT in the implement. Since it has moderate estimation accuracy and low computational complexity it is widely adopted in current TD-SCDMA systems. To obtain better accuracy of CIR in multi-cell scenarios, a multi-cell joint channel estimation algorithm was proposed in study (Song and Li, 2008; Song *et al*., 2008). This algorithm takes the users of neighbor cells having strong interference into the channel estimation matrix to improve the accuracy of channel estimation but it requires matrix inversion whose size is proportional to the number of cells, causing high complexity.

In order to get higher estimation accuracy with lower computational complexity in multi-cell scenarios, Per-Path Interference Cancellation (PPIC) algorithm has been proposed in (Zhang *et al*., 2011) which cancels the interference path-by-path instead of chip-by-chip. It

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firstly estimates the initial CIR of each cell and then cancels the interference component per path based on inter-path influence weights. The worst disadvantage of this algorithm is the higher iteration times, since it doesn't consider the receiver and transmitter pulse shaping filter which will expand the CIR. In this study, the RRC filter will be considered in PPIC algorithm which can obtained better estimation accuracy with less iteration times compared to PPIC algorithm from the simulation results both in the AWGN and fading channel.

SYSTEM MODEL

In TD-SCDMA system, the data are transmitted in the form of burst, whose structure is shown as Fig. 1. The burst consists of two data symbol fields with length of 352 chips, respectively, a midamble sequence of 44 chips and a guard period of 16 chips. Among these parts, midamble sequence is used for channel estimation (3GPP, 2002).

There are 128 non-orthogonal basic midamble sequences which are divided into 32 groups. In each cell, the base station choose one out of the four basic midamble sequences in a given group and the midamble sequence of different users active in the same time slot are cyclically shifted versions of one basic midamble sequence.

The received sample rate midamble sequence is:

$$y(n)=\sum_{j=0}^{N_c-1}\sum_{k\in K_j}\sum_{i=0}^{L_{j,k}-1}\gamma_{j,k,i}\left[p\left(n-\tau_{j,k,i}\right)*m_{j,k}(n)\right]+w(n) \quad (1)$$

where, N_c is the number of cells in the system K_j is the set of midamble shifts transmitted from cell j and is a subset of al the possible midamble shifts $K = \{1, 2,..., K_{cel}\}$ where K_{cel} depends on the midamble configuration; $\gamma_{j,k,i}$ is the complex channel coefficient of the i-th propagation path corresponding to midamble shift k of cell j; $\tau_{j,k,i}$ is the delay of the i-th propagation path corresponding to midamble shift k to cell j and this study makes the simplification that this delay is rounded to the nearest sample; p(n) is the transmit pulse shaping filter response which is defined as an RRC with roll-off factor 0.22 w(n) is the Additive White Gaussian Noise (AWGN); $L_{j,k}$ is the CIR length for the shift k of cell j and this study assume the all shifts have the same CIR length; $m_{j,k}$ is the midamble sequence for shift k of cell j. For each cell, the midamble sequence is a cyclically shifted version of a basic midamble sequence such that:

$$m_{j,k}(n)=m_j^{'}\left(\mathrm{mod}\left(n+(k-1)W\right),128\right) \quad (2)$$

where, n∈[0, 1, 2, 127], m_j is the basic midamble of the cell j and:

$$W=\left\lfloor\frac{128}{K_{cell}}\right\rfloor$$

To keep the normalization of the CIR, the $\gamma_{j,k,i}$ has the following limitation:

$$\sum_{j=0}^{N_c-1}\sum_{k\in K_j}\sum_{i=0}^{L_{j,k}-1}\left\|\gamma_{j,k,i}\right\|^2=1 \quad (3)$$

The equation (1) can be written in matrix format as:

$$\begin{aligned}y&=\sum_{j=0}^{N_c-1}PM_j^{'}G_j+w\\&=P\left[M_0\quad M_1\quad\ldots\quad M_{N_c-1}\right]\begin{bmatrix}G_0\\G_1\\ \\G_{N_c-1}\end{bmatrix}+w\\&=PMG+w\end{aligned} \quad (4)$$

where P is the 128×1287 matrix with row n+1 being the cyclically shifted version of row n and the first row representing the RRC filter response; M is the:

$$128\times\left(\sum_{k\in K_j}L_{j,k}*N_c\right)$$

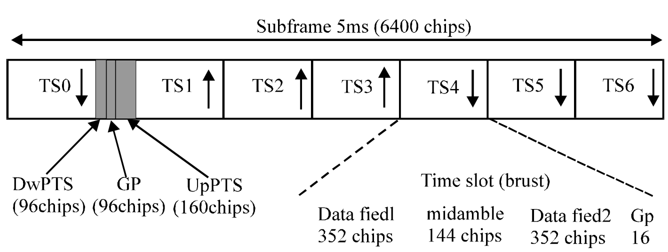

Fig. 1: Subframe structure of TD-SCDMA

matrix of shifted midamble sequences where each column is the basic midamble sequence shifted by $(k-1)W+\tau_{j,k,i}$; Γ is the:

$$\left(\sum_{k\in K_j} L_{j,k} * N_c\right)\times 1$$

vector of channel coefficients $\gamma_{j,k,i}$.

In the real communication system, the channel estimation wanted by the equalizer is a joint channel response including the transmit/receive pulse shaping filter and other filter response. To simplify the analysis, only consider the transmit/receive pulse shaping filter \expect of other filter. So the wanted CIR of the cell j is:

$$h_j = G_j \otimes p_{tx} \otimes p_{rx} \tag{5}$$

where, p_{tx} and p_{rx} are the transmit/receive pulse shaping filter, respectively.

MULTI-CELL MATCHING PURSUIT

The matching pursuit algorithm is a well-know method for iteratively solving the problem of modeling an observed signal as the weighted sum of a set of basis vectors. In the context of channel estimation we begin by starting with the initial estimation $f = M^H P^T y$ = MHz and then iterating:

$$\begin{aligned}
&\text{for}\quad i = 0 : L_{max}\\
&\quad \text{if}\quad \left(f^H f \le \text{threshold}\right)\quad \text{break;}\\
&\quad \hat{\tau}_i = \arg\max_n\left(\left\|f(n)\right\|^2\right)\\
&\quad \hat{\gamma}_i = f(\hat{\tau}_i)\\
&\quad f = f - M^H P^T P m_{\hat{\tau}_i}\hat{\gamma}_i\\
&\text{end}
\end{aligned}$$

where, $m_{\hat{\tau}_i}$ is the midamble vector corresponding to the delay $\hat{\tau}_i$ which is also the column of matrix M corresponding to the delay $\hat{\tau}_i$.

This study applies this algorithm named MC-MP in the TD-SCDMA system and whose details are described as follows:

- Calculate the initial estimation of MC-MP

$$f = M^H P^T y \tag{6}$$

Note that $P^T y$ term is simply the output of the front-end matched filtering and is not performed explicitly in the channel estimation; rather the input to the channel estimation is the output of the front-end filtering and is:

$$z = P^T y \tag{7}$$

- Find the cell index of the cell with the maximum path power:

$$\left[k_{cell}^{max}, n_{path}^{max}\right] = \arg\max_{k,n}\left(\left\|f\right\|^2\right) \tag{8}$$

where, k_{cell}^{max} is the cell index of the cell with the maximum path power and n_{path}^{max} is the path index of the path with the maximum path power in the certain cell. Then, get the maximum path by using k_{cell}^{max} and n_{path}^{max} as follows:

$$h_{max} = f\left(f, k_{cell}^{max}, n_{path}^{max}\right) \tag{9}$$

- Calculate the correlation between midamble of the cell with the maximum path power and midamble of all cells

$$?_k = m_{k_{cell}^{max}} \otimes m_k \tag{10}$$

- Recovering the signal corresponding to the maximum path power

$$r_{rec} = h_{max} \cdot m_{k_{cell}^{max}} \otimes f_{rrcCoef} \tag{11}$$

where, $f_{rrcCoef}$ is the coefficient of the RRC filter.

- Add the valid path into CIR buffer

$$Cir_{buffer} \leftarrow h_{max} \cdot f_{rrcCoef} \tag{12}$$

- Calculate the interference signal which is the function of the recovering signal and all midamble of cells

$$\begin{aligned}
S_k &= m_k \otimes r_{rec}\\
&= m_k \otimes h_{max} \cdot m_{k_{cell}^{max}} \otimes f_{rrcCoef}\\
&= h_{max} \cdot ?_k \otimes f_{rrcCoef}
\end{aligned} \tag{13}$$

- Cancel the effect of the maximum path on all paths

$$f_{update} = f - \sum_{k=0}^{N_c-1} S_k \tag{14}$$

- Iterate the steps 1) to 7) until the stop criteria

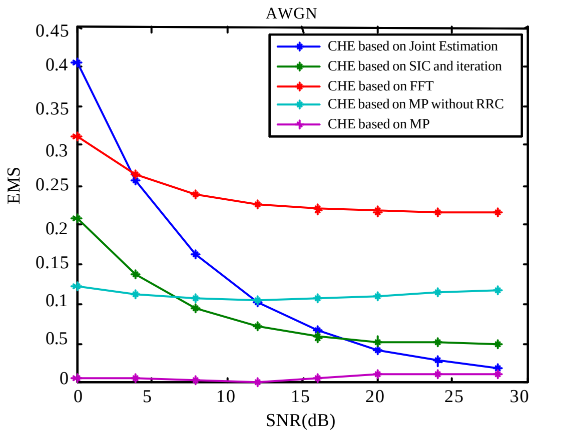

Fig. 2: These MSE of these different CHE algorithm under AWGN channel

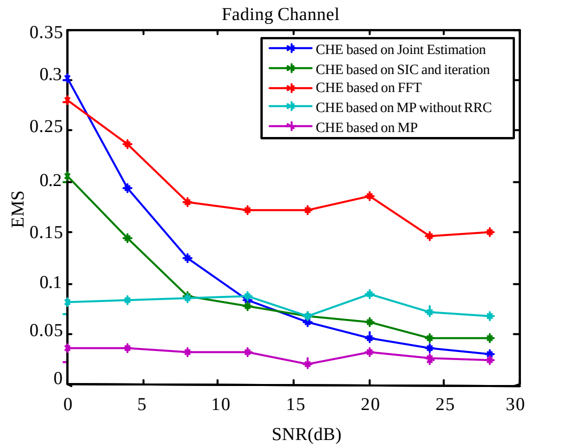

Fig. 3: These MSE of these different CHE algorithm under Fading channel

To improve the performance, this study modified the stop criteria into the following conditions:

- The residual power is bigger than the last which instructs the interference becomes more serious than last time
- The minus between the residual power of the present and the last is smaller than a threshold which instructs the interference cancel effect is little
- The iteration time is bigger a threshold

SIMULATIOIN

This section evaluates the improved algorithm proposed by this study, compared with other CHE algorithms. The Mean Square Error (MSE) method is applied to evaluate the channel estimation accuracy and the MSE is analyzed under the AWGN and fading channel. The network is configured with two cells, one service cell equipped with 2 users and one neighbor cell with 1 user.

Table 1: Iteration number comparison with MP algorithm with and without RRC filter

ISNR(dB)	0	4	8	12	16	20	24
AWGN							
M1	7.43	7.97	7.55	8.31	8.21	9.15	8.04
M2	2.63	3.36	3.43	3.88	3.77	4.14	3.58
Fading							
M1	9.6	10.64	11.42	11.85	11.87	11.95	12.32
M2	4.41	4.59	4.51	4.37	4.17	4.04	4.00

MSE calculates the average complex magnitude error between the estimated CIR and the ideal CIR and the lower MSE, the estimation is higher. It's defined as:

$$\text{mse} = \sqrt{E\left[\left(\hat{h} - h\right)^2\right]} \tag{15}$$

The simulation results are shown in the Fig. 2 and 3 which indicate that our proposed algorithm labeled with MP with RRC has the lowest MSE and the MP algorithm has the highest channel estimation accuracy compared with other algorithms, such as joint estimation algorithm, SIC iteration algorithm.

Otherwise, the iteration number is a good way to evaluate the complexity of algorithm. The Table 1 shows that our proposed algorithm can obtain better estimation accuracy by using less iteration number compared with previous MP algorithm.

CONCLUSION

This study modified the traditional MP algorithm by using the RRC filter which can decrease the iteration times and improve the estimation accuracy at the same time compared with the PPIC method. The above conclusion is validated by these simulation results both in the AWGN and fading channel.

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