Improved Channel Estimation Algorithms based on a Proposed Signal Model for PUCCH Format 3 in LTE-A

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Abstract

SORTD (Space Orthogonal-Resource Transmit Diversity) has already become a better way of transmit diversity for PUCCH format 3 in LTE-A [1]. SORTD technology lies in the characteristic that each antenna port transmits signal by using different cyclic shift [2] to make orthogonal each other. Using the SORTD's feature of incoherence in different antennas, this paper proposes a special form of signal model. Based on this proposed model, we propose a low complexity channel estimator based on LS and cubic spline interpolation, and then we put a LS and DCT algorithm to improve the interpolation performance. Finally, for more accurate estimator we drive the third approach based on MMSE and DCT. A series of theoretical researches and simulation results show that all of them are suitable for the proposed signal model even in the environment of high-speed movement; especially the algorithms with DCT have a better performance.

Keywords: SORTD, PUCCH format 3, channel estimation, DCT

1. Introduction

PUCCH format 3, in the evolution of LTE-Advanced, is used to transmit SR and feedback ACK or NACK of HARQ [3], hence, it is accurate channel estimation of which that is helpful to improve the performance of system. For uplink control channel in the physical layer, what the core problem is not to boost capacity [4] but to employ multi-antenna technology for further optimal performance and extensive coverage. To make the receiver obtain more accurate control information, transmit diversity plays a promising role in the PUCCH. To achieve additional diversity, PUCCH format 3 adopting code-diversity utilizes the transmit diversity named SORTD (Spatial Orthogonal Transmit Diversity), implying that signal on the multiple antenna is modulated by code sequence Orthogonal to each other. When PUCCH format 3 adopting SORTD feedbacks HARQ-ACK information, DRMS of the same SC-FDMA symbol on the two transmitting antenna ports uses different orthogonal resources consisting of cyclic shift and orthogonal cover code to transmit the same uplink control information in the same user equipment. In essence, the PUCCH transmissions from the two antennas will be identical to PUCCH transmissions from two different terminals using different resources. Thus, SORTD creates additional diversity but achieves this by using twice as many PUCCH resources, compared to non-SORTD transmission [1]. To receive accurate uplink control signal and achieve diversity gain, it is crucial to adopt effective channel estimation algorithm.

On the sending side, PUCCH employs SORTD to transmit uplink control signal. On the other hand, on the receiving end, the DMRS received is superimposed by DMRS of the same SC-FDMA symbol on the two sending antennas. Based on this characteristic, an original model can be proposed. With the length of 12 of reference signal (RS) accepted, receiver estimates the channel transmission coefficient of DMRS [2] at the same SC-FDMA symbol on the RB which has 12 subcarriers. So it is essential to estimate Channel transmission coefficient on the other 12 resource element (RE).

Currently, channel estimation to use more interpolation algorithms consist of linear interpolation, curvilinear Interpolation and transform-domain Interpolation processing, while the algorithm based on discrete cosine transform (DCT) [5] has achieved outstanding performance in the OFDM system. For given a sequence of N points [6] [7], the principle of DCT is to extend the sequence of N points into the sequence of 2N points, thus reducing the high frequency component of the signal and making interpolation more effect. Based on the analyses above, this paper proposes three channel estimation algorithms appropriate for in the LTE-A system, PUCCH adopting SORTD transmits uplink control information, namely the three algorithms, respectively, are based on LS and cubic spline interpolation, LS and DCT interpolation and MMSE and DCT interpolation, which are applied to PUCCH format 3 on the two transmitting ports

In order to be closer to the real environment of mobile communication, we have simulated in the case of ETU(Extended Typical Urban) where the mobile speed are 3 km/h and 350 Km/h, respectively, which represents the slowest speed namely people walking and the fast speed namely high-speed rail on the ground. The result shows that the third algorithm has the better performance.

2. System Model

2.1. The Generation of DMRS

PUCCH transmission from a terminal is always carried out over a single resource block in the frequency domain. In the case of PUCCH transmission, the length of the reference-signal sequence is thus always equal to 12 [1]. UE is based on the parameters configured by reference of network side and broadcast message to determine the parameters of DRMS, including group hopping number u 、 cyclic shift $\alpha_{(\tilde{p})}$ and superimposed orthogonal sequences $\overline{w}^{(\tilde{p})}$ .The demodulation reference signal sequence for PUCCH format 3 is defined by [8]:

$$r_{PUCCH}^{(\tilde{p})} \left(m' N_{RS}^{PUCCH} M_{SC}^{RS} + m M_{SC}^{RS} + n \right) = \frac{1}{\sqrt{p}} \overline{w}^{(\tilde{p})}(m) z(m) r_{u,v}^{(\alpha\tilde{p})}(n) \tag{1}$$

Where $m' = 0,1$; $m = 0,\cdots,N_{RS}^{PUCCH} - 1$; $n = 0,\cdots,M_{SC}^{RS} - 1$.

Where N_{RS}^{PUCCH} indicates the number of reference symbols per slot for PUCCH, and $M_{SC}^{RS} = 12$ presents the number of DRMS's subcarriers for PUCCH. When the UE sends uplink control signals of PUCCH format 3, Due to transmit diversity [8], antenna port $\tilde{p}$ will be mapped into antenna port p_0 and p_1, for corresponding references $n_{PUCCH}^{(3,\tilde{p}_0)}$ and $n_{PUCCH}^{(3,\tilde{p}_1)}$ respectively. The Superposition of orthogonal codes produced by antenna p_0 and p_1 are equal to $[1 \quad 1]$ or $[1]$ [9]. Where $z(m) = 1$ and orthogonal sequences $\left[\overline{w}(0) \cdots \overline{w}\left(N_{RS}^{PUCCH} - 1 \right) \right]$ is seen as Table 1 [10].

Table 1. Orthogonal Sequences $\left[\overline{w}(0) \cdots \overline{w}\left(N_{RS}^{PUCCH} - 1 \right) \right]$ **for PUCCH Format 3**

Normal cyclic prefix	Extended cyclic prefix
[1 1]	[1]

When each antenna port sends the same slot of DMRS, to which corresponding group hopping number will be the same, in other words, the only difference between two antenna ports is the cyclic shift $\alpha_{(\tilde{p})}$ calculated by $n_{PUCCH}^{(3,\tilde{p})}$. And the location of PUCCH demodulation reference symbols per slot can get from the Table 2 [10].

Table 2. The Location of PUCCH Demodulation Reference Symbols per Slot

PUCCH format	Normal CP	Extended CP
1,1a,1b	2,3,4	2,3
2a,2b	1,5	N/A
2,3	1,5	3

The DMRS location for PUCCH in the LTE-A can be seen from Table 2, showing that when UE adopts multiple antennas to transmit uplink control signal of PUCCH format 3, the location of reference signals are the same at the antenna port p_0 and p_1 --for normal CP, DRMS locates the first and fifth OFDM symbol in the each slot; while for the extended CP, DRMS locates the third OFDM symbol in the each slot.
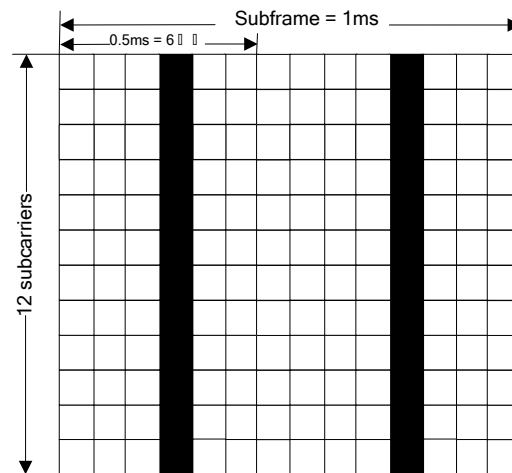
Figure 1. Extend CP for PUCCH format 3

2.2. Signal Model

On the port p_0 and p_1, let the cyclic-shift length of the length-l SC-FDMA symbols are α_0 and α_1 respectively, that $DMRS = \left[x_0, x_1 e^{j\alpha_0}, x_2 e^{j2\alpha_0}, \cdots, x_{11} e^{j11\alpha_0} \right]^T$ is mapped to p_0 and $DMRS = \left[x_0, x_1 e^{j\alpha_1}, x_2 e^{j2\alpha_1}, \cdots, x_{11} e^{j11\alpha_1} \right]^T$ mapped to p_1. Signal on the receiving antenna is the overlay of signal from two transmission antennas, as follows:

$$Y = \sum_{i=0}^{1} diag \left\{ x_0, x_1 e^{j\alpha_i}, x_2 e^{j2\alpha_i}, \cdots, x_{11} e^{j11\alpha_i} \right\} h_i + z \qquad (2)$$

Where $Y = [Y_0, Y_1, Y_2, \cdots, Y_{11}]^T$, $h_i = \left[h_{i,0}, h_{i,1}, \cdots, h_{i,11} \right]^T$ shows the channel transmission coefficient and $z = [z_0, z_1, \cdots, z_{11}]^T$ refers to the corresponding AWGN of different DMRS.

Based on the characteristic that each antenna port transmits signal by using different cyclic shift to make orthogonal each other, this paper puts a new signal model. Let the difference of cyclic shift of SC-FDMA symbol on the port p_0 and p_1 is α namely $\alpha_1 - \alpha_0 = \alpha$. And the both sides of formula (2) are multiplied by the conjugate of DMRS，namely $diag \left\{ x_0, x_1 e^{j\alpha_i}, x_2 e^{j2\alpha_i}, \cdots, x_{11} e^{j11\alpha_i} \right\}^H$, we can get:

$$\tilde{Y} = \sum_{i=0}^{1} diag\left\{ x_0, x_1 e^{j(\alpha_i - \alpha_0)}, x_2 e^{j2(\alpha_i - \alpha_0)}, \cdots, x_{11} e^{j11(\alpha_i - \alpha_0)} \right\} h_i + \tilde{z} \tag{3}$$

Or get:

$$\tilde{Y} = h_0 + diag\left\{ 1, e^{j\alpha}, e^{j2\alpha}, \cdots, e^{j11\alpha} \right\} h_1 + \tilde{z} \tag{4}$$

Where $\tilde{Y} = diag\left\{ x_0, x_1 e^{j\alpha_i}, x_2 e^{j2\alpha_i}, \cdots, x_{11} e^{j11\alpha_i} \right\}^{H} Y$, $\tilde{z} = diag\left\{ x_0, x_1 e^{j\alpha_i}, x_2 e^{j2\alpha_i}, \cdots, x_{11} e^{j11\alpha_i} \right\}^{H} z$.

3. Channel Estimation Model

Had mentioned above that the signals of two antenna ports are orthorhombic by using different cyclic shift, we have already got the signal model of formula (3). By exploiting the properties of reference signals (RS), we can propose three channel estimation approaches: The first one is a low complexity channel estimator based on LS and cubic spline interpolation; the second one is the channel estimator based on LS and DCT. The last one is channel estimator based on linear minimal mean square error (MMSE) and DCT.

3.1. The Channel Estimator based on LS and Cubic Spline Interpolation

1) Let $F = \begin{bmatrix} 1 & 1 & 1 & \cdots & 1 \\ 1 & e^{j\alpha} & e^{j2\alpha} & \cdots & e^{j11\alpha} \end{bmatrix}^{T}$ and $H = \begin{bmatrix} h_{0,0} & h_{0,1} & h_{0,2} & \cdots & h_{0,11} \\ h_{1,0} & h_{1,1} & h_{1,2} & \cdots & h_{1,11} \end{bmatrix}$, the equation (5) can be obtained by equation (4):

$$\left(\tilde{Y}\right)_j = F_{(i,:)} H_{(:,j)} + \tilde{z} \tag{5}$$

Where $i = j = 1, 2, \cdots, 12$ and $\left(\tilde{Y}\right)_j$ represents the elements at the j_{th} row of $\tilde{Y}$.

2) Let $T = 2\pi / \alpha$, if T is simplified into the simplest fraction and then assign its numerator to T' , the row in the matrix F will have a periodical change with T' . The first T' rows of F assigned to matrix F' , $F' = \begin{bmatrix} 1 & 1 & 1 & \cdots & 1 \\ 1 & e^{j\alpha} & e^{j2\alpha} & \cdots & e^{j(T'-1)\alpha} \end{bmatrix}^{T}$ will be obtained. The equation (5) could be substituted into Equation (6):

$$\left(\tilde{Y}\right)_j = F'_{(i,:)} H_{(:,j)} + \tilde{z} \tag{6}$$

Where $j = 1, 2, \cdots, 12$, $i = (j-1) \bmod (T') + 1$.

3) Let $P = F'H$, but $\bar{P}$ is composed of element (i, j) satisfying equation $i = (j-1) \bmod (T') + 1$, which can be described as follows:

$$\left[\bar{P}\right]_{i,j'} = [P]_{i,j} \tag{7}$$

Where $i = 1, 2, \cdots, T'$; $j' = 1, 2, \cdots, 12/T'$; $j = (j'-1)T' + i$ $i = 1, 2, \ldots, T'$. When $T' = 2$, the relationship between matrix P and $\bar{P}$ is depicted in Figure 2, the sections marked as black are the elements in the matrix $\bar{P}$.
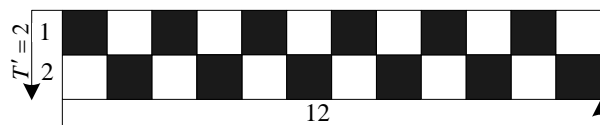

Figure 2. Relationship between P and $\bar{P}$ when $T' = 2$

4) The equation can be rewritten as

$$\left(\tilde{Y} \right)_j = \left[\overline{P} \right]_{i,j'} + \left(\tilde{z} \right)_j \tag{8}$$

Where $j = 1,2,\cdots,12$; $i = (j-1) \bmod (T') + 1$; $j' = (j-i)/T' + 1$.

5) Based on the equation (8), $\hat{\overline{P}}$ can be obtained by LS [11] approach

$$\hat{\overline{P}} = \left[\tilde{\overline{Y}}_1, \tilde{\overline{Y}}_2, \cdots, \tilde{\overline{Y}}_{T'} \right]^T \tag{9}$$

Where $\tilde{\overline{Y}}_k$ is the $(12/T') \times l$ matrix, and the equation $\left(\tilde{\overline{Y}}_k \right)_l = \left(\tilde{Y} \right)_j$ will be established when $l = 1,2,\cdots,12/T'$; $k = 1,2,\cdots,T'$; $j = (l-1)T' + k$.

6) When $\hat{\overline{P}}$ namely the estimated value of $\overline{P}$ is obtained, the some values in the matrix P Will be got. We can get $\hat{P}$ according to the frequency similarity between adjacent subcarriers. Meanwhile, $\hat{P}$ will be acquired by cubic spline interpolation algorithm.

7) Finally basing on $P = F'H$, we can get the estimated value $\hat{H}$ of matrix H , that is

$$\hat{H} = \left(F' \right)^H \hat{P} \tag{10}$$

Hence the acquisition of $\hat{H}$ can help us obtain the channel transmission coefficient of SC-FDMA symbol on the transmitting antenna ports p_0 and p_1 of corresponding receivers.

3.2. The Channel Estimation Approach based on LS and DCT

Exploiting Discrete Cosine Transform (DCT) to substitute the Cubic Spline Interpolation at the first channel estimation method, namely the 6th step on the first method is replaced by the steps as follows, and the rest of steps remain the same.

Performing DCT transform of matrix $\hat{\overline{P}}$ in the equation (9), we can get matrix $\hat{\overline{P}}^d$, that is.

$$\hat{\overline{P}}^d = D \hat{\overline{P}}^T \tag{11}$$

Where $[D]_{k,l} = w_k \cos \left(\left(l + \frac{1}{2} \right) \frac{pk}{M} \right)$, $k,l = 0,1,\cdots,12/T' - 1$, and it is noted that $w_k = 1/\sqrt{12}$ when $k = 0$, whereas $w_k = 1/\sqrt{6}$ when $k \neq 0$, $M = 12/T'$.

Taking the inverse expanding DCT of matrix $\hat{\overline{P}}^d$ can obtain matrix $\hat{P}$, that is

$$\hat{P} = D_E^{-1} \hat{\overline{P}}^d / N \tag{12}$$

Where $\left[D_E^{-1} \right]_{k,l} = w_l \cos \left(\left(\frac{k}{12} + \frac{1}{2M} \right) pl \right)$; $k = -(T'-1),\cdots,11$; $l = 0,1,\cdots,12/T' - 1$; $M = 12/T'$. Let $A = D_E^{-1} D$ and the sum of the elements which are in each row of matrix A are equal, so the N in the equation (12) is the sum.

Using matrix W_i to extract 12 points from the matrix $\hat{P}$, the estimated value $\hat{P}$ of matrix P can be obtained, that is:

$$\left(\hat{P}(i,:) \right)^T = \Omega_i^T \hat{P}(:,i) \tag{13}$$

Where $\Omega = \left[O_{12 \times (T'-i)} I_{12 \times 12} O_{12 \times (i-1)} \right]$, $i = 1,\cdots,T'$.

At last, the DMSR of SC-FDMA symbol on the two transmitting antenna port p_0 and p_1 can be gotten.

3.3. The Channel Estimating Approach based on MMSE and DCT

The way to use MMSE instead of LS can estimate matrix $\bar{P}$ for more accuracy of channel estimation. In other words, the approach basing on MMSE and DCT is that apply the following step (1) to replace the step (5) in the second approach and the rest unchanged.

Using MMSE algorithm in the equation (8) to estimate $\tilde{\bar{P}}$, that is

$$\tilde{\bar{P}} = \left[\Gamma_1 \tilde{Y}_1, \Gamma_2 \tilde{Y}_2, \cdots, \Gamma_{T'} \tilde{Y}_{T'} \right]^T \tag{14}$$

Where Γ_k is a diagonal matrix of size $(12/T') \times (12/T')$ and $k = 1, 2, \cdots, T'$. Therefore, the estimated value of matrix P can be expressed as:

$$\hat{P} = \left[\Omega_1 D_E^{-1} \Gamma_1 \tilde{Y}_1, \Omega_2 D_E^{-1} \Gamma_2 \tilde{Y}_2, \cdots, \Omega_{T'} D_E^{-1} \Gamma_{T'} \tilde{Y}_{T'} \right] \tag{15}$$

4. Simulations and Analyses

4.1. Simulation Environment

In accordance with the principle of channel estimation algorithm above, this paper not only uses MATLAB to simulate and verify but also compares the BER of HARQ-ACK when PUCCH uses single antenna and SORTD to send signals. In the process of simulation, the antennas are configured to receive $2T \times 2R$ or $1T \times 2R$ and the channel model is the overlay of ETU (Extended Typical Urban) model [1] and AWGN. Since the effect of the Channel estimation algorithm on system performance changes over SNR, MATLAB simulation must do 1000 times each SNR which equals to send 1000 uplink sub-frames and transmit 22 bits HARQ-ACK every time, which benefits to reduce the randomness. In order to examine the performance of three channel estimation approaches under the different movement speed namely 3Km/h and 350Km/h. The detail parameters are given by "Table 3".

Table 3. Simulation Parameters

simulation parameter	Value
carrier frequency	2GHz
Bandwidth	5MHz
cyclic prefix	Normal CP
FFT size	2048
MIMO allocation	2T× 2R or 1T× 2R
Channel model	ETU
The number of simulation times per SNR	1000
Movement speed	3/350 Km/h
PUCCH format	PUCCH format 3

### 4.2. The Analysis of Simulation Result

Figure 3 and figure 4 denote the BER of the HARQ-ACK information when PUCCH format 3 uses SORTD and single antenna to transmit HARQ-ACK and the channel estimation applies these three channel estimation approaches proposed in

the paper when PUCCH format 3 uses SORTD to transmit HARQ-ACK. As can be seen from Figure 3 and Figure 4, Firstly, BER of HARQ-ACK information decreases with the increase of SNR-that is the larger SNR is, the better performance of this channel estimation approach; Secondly, on the condition of a certain SNR if using three kinds of approaches to estimate channel, PUCCH format 3 estimates smaller BER of HARQ-ACK information by SORTD than by single antenna, and the BER obtained by estimation approach based on MMSE and DCT is the smallest, the approach based on LS and DCT takes the second place, the last one is approach based on LS and SPLINE interpolation; What is more, when SNR is bigger than 5dB, these three channel estimations approaches all can obtain approximately zero BER, that is HARQ-ACK information almost can be correctly received by base station. Finally, when SNR is 1dB, according to these approaches the BER of HAQ-ACK information all can remain 0.1 no matter in the high or low speed mobile situation.

In short, Compared Figure 3 with Figure 4, we find that in the case of the same SNR the BER obtained in the high speed mobile situation is higher than in low speed mobile situation but the difference is less than 0.1 dB. This shows that these approaches all can acquire a better the performance of channel estimations matter in the high or low speed mobile situation.
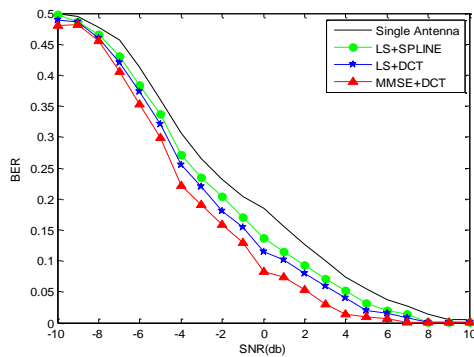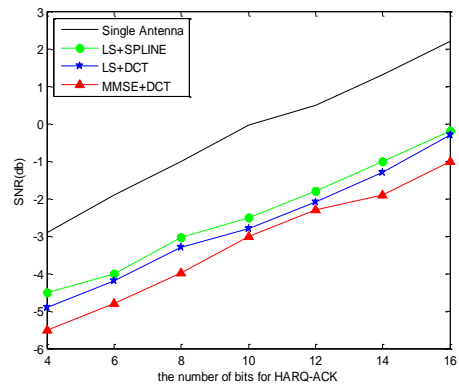

Figure3. Performance Comparison of 3 km/h Moving Speed
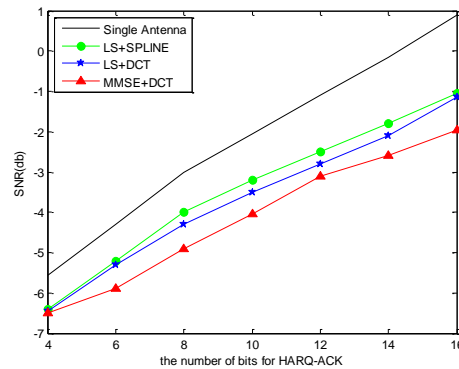
Figure5. Performance Comparison of 3 km/h Moving Speed
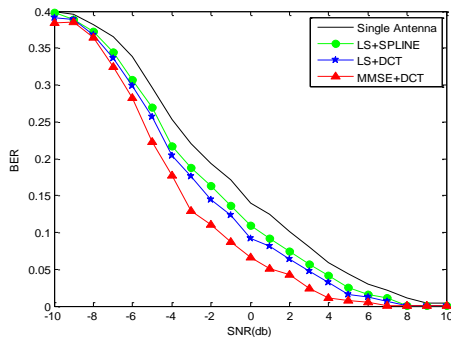
Figure4. Performance Comparison of 350 km/h Moving Speed

Figure6. Performance Comparison of 350 km/h Moving Speed

Figure 5 and Figure 6 respectively express on the condition that the mobile speed are 3 km/h and 350 km/h, PUCCH format 3 utilizing the way to SORTD and single antenna to transmit HARQ-ACK information in varying length satisfies minimum requirement of SNR when receiver obtains less than 0.1dB of BER. Channel estimation based on SORTD employs three approaches mentioned in the paper to make an overall comparison with single antenna transmission. There are several information we can see from Figure 5 and Figure 6: Firstly, for purpose of less than 0.1 BER of HARQ-ACK information, the minimum value of SNR increase with the increase of the number of HARQ-ACK bits, that is to obtain the same BER, SNR required increases with the loads of HARQ-ACK. Secondly, when the length of HARQ-ACK information is a certain value, in order to obtain the same performance the SNR required of HARQ-ACK by single antenna is obviously bigger than by SORTD. Among the three estimations, the SNR required is lowest by the estimation based on MMSE and DCT, and estimation based on LS and DCT takes the second place, while the highest demand on the SNR is the estimations based on LS and Cubic spline interpolation.

Shortly, in the case of the same length of HARQ-ACK, in order to obtain the same BER, the SNR required in the high speed mobile environment is bigger than in the low speed mobile situation, but the difference is not more than 2 dB. This shows that these approaches all can acquire a better the performance of channel estimation no matter in the high or low speed mobile situation.

5. Conclusion

This paper takes theoretical analysis as the starting point, based on the characteristics that PUCCH channel uses SORTD to transmit HARQ-ACK in the LTE-A system and the two transmitting antennas exploit different RS to make the signal on the two antennas orthorhombic, a new signal model is proposed. Based on this model we again put three channel estimation approaches, namely the estimation based on LS and cubic spline interpolation, the estimation based n LS and DCT and the last one based on the MMSE and DCT. These algorithms are simulated in the speed of 3 km/h and 350 km/h, the result indicates that these three estimations are all suitable for employing SORTD to transmit uplink control signal on the PUCCH in the LTE-A system.

Acknowledgement

References

[1] S. Sesia, I. Toufik and M. Baker, LTE: The UMTS Long Term Evolution, John Wiley and Sons **(2009)**, pp. 585-590

[2] 3GPP TS 36.211 v11.4, Evolved Universal Terrestrial Radio Access (E-UTRA), Physical channels and modulation, **(2013)** .

[3] Z. Shen, A Papasakellariou, Montojo J, Gerstenberger D&Xu F, Overview of 3GPP LTE-advanced carrier aggregation for 4G wireless communications. Communications Magazine, **(2012)** February, vol. 50, No. 2, pp. 122-130

[4] M. Hasan, Performance Comparison of Wavelet and FFT Based Multiuser MIMO OFDM over Wireless Rayleigh Fading Channel. International Journal of Energy, Information & Communications, **(2012)** Nov, vol. 3, no. 4, pp. 1-2

[5] M F, Abdullah Ghanim. M F L, Yonis A Z, Software Implementation and Comprehensive Performance of Uplink Channel on Mobile 4th Generation Technology[J], International Journal of Smart Home , **(2013)** May , Vol. 7, No. 3, pp. 1-4

[6] R. C. de Lamare., Adaptive and Iterative, Multi-Branch MMSE Decision Feedback Detection Algorithms for Multi-Antenna Systems, **(2013)** October, Vol. 12, No. 10, pp. 5294-5308

[7] S. J. Haghighi, S. Primak, Effects of Side Information on Complexity Reduction in Superimposed Pilot Channel Estimation in OFDM Ssytems, **(2010)** May, Vol. 11, No. 2, pp. 1-5

[8] S. C. Chan , X. X. Yang., Improved approximate QR-LS algorithms for adaptive filtering. IEEE Transactions on Circuits and Systems-Ⅱ: Express Briefs, **(2004)** May, Vol. 51, No. 1, pp. 29-39

[9] Hasan M. Performance Comparison of Wavelet and FFT Based Multiuser MIMO OFDM over Wireless Rayleigh Fading Channel. International Journal of Energy, Information & Communications, **(2012)** November, Vol. 3, No. 4, pp. 3-5

[10] 3GPP TS 36.211, Access E U T R. Physical Channels and Modulation. **(2009)** December

[11] Meili Zhou,Bin Jiang,Wen Zhong. Efficient Channel Estimation for LTE Uplink, Wireless Communications & Signal Processing, **(2009)** November, Vol. 11, No. 4, pp. 13-25

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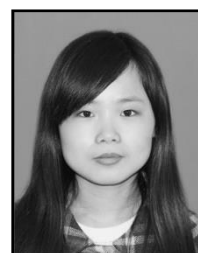
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