Military Technical College
Kobry El-Kobbah,
Cairo, Egypt

6th International Conference
on Electrical Engineering
ICEENG 2008

Channel estimation in mobile WiMAX systems

By

Cheong-Hwan Kim*   Dae-Seung Ban**   Yong-Hwan Lee***

Abstract:

The use of channel adaptive transmission techniques requires accurate channel state information (CSI) which may not easily be achievable particularly near the cell boundary in multi-cell environments. In this paper, we consider the improvement of CSI estimation accuracy by exploiting the preamble signal as well as the pilot signal in ODFM based wireless systems. We first estimate the CSI from both the received preamble signal and the received pilot signal. By exploiting the channel correlation between the preamble and pilot signaling, we combine the two CSIs estimated from the preamble and pilot signals. The combining weight is analytically determined to minimize the mean squared error. For the interference cancellation with the use multiple receive antennas, we also consider the estimation of interference channel in a similar manner. Simulation results show that when applied to the mobile-WiMAX system, the proposed scheme is quite effective near the cell boundary.

Keywords:

Channel estimation, OFDM, other cell interference and WiMAX

---

* School of Electrical Engineering and INMC, Seoul National University, Korea
** School of Electrical Engineering and INMC, Seoul National University, Korea
*** School of Electrical Engineering and INMC, Seoul National University, Korea

This research was supported by Seoul R&BD Program (10544)

1. Introduction:

In recent years, orthogonal frequency division multiplexing (OFDM) has been recognized as one of key transmission techniques for next generation wireless communication systems [1]. It can provide high spectral efficiency and mitigate inter-symbol interference in frequency selective fading environments [2]. However, this may require the use of accurate channel information, which is not easily obtainable especially near the cell boundary in multi-cell environments.

In the downlink of OFDM based wireless systems such as the mobile-WiMAX, the received pilot signal is interfered by the pilot signals transmitted from other cells. This interference makes it difficult to accurately estimate the channel state information (CSI), particularly near the cell boundary [3]. The CSI is indispensable for channel adaptive transceiver techniques such as interference canceller and adaptive antenna array [4]. As a consequence, the performance of the transceiver may significantly deteriorate near the cell boundary.

In practice, the CSI can be estimated from pilot signal using a conventional estimation technique such as the least square (LS) estimation [5]. Since the LS estimation yields a mean-squared error (MSE) inversely proportional to the signal-to-interference plus noise ratio (SINR) [6], it may not work properly near the cell-boundary due to large interference. An iterative interference canceller has recently been proposed in the time domain [7], but it can be applied only to a block type arrangement of pilot signals, where all subcarriers are reserved for pilot signaling at a specific period.

The mobile-WiMAX utilizes preamble signal for the purpose of synchronization, which is orthogonal to those transmitted from neighboring cells [8]. As a consequence, the preamble signal is less interfered than the pilot signal. The signal transmitted through wireless channel experiences correlation in the time and/or frequency domain, yielding channel correlation between the preamble and pilot signal transmission. We consider the estimation of CSI by utilizing the channel correlation between the preamble and pilot signal. The accuracy of the CSI estimation can be improved by combining the CSI estimated from the received preamble and pilot signal. We analytically determine the combining weight to minimize the MSE of the estimation. When the receiver has multiple receive antennas, it can cancel out other cell interference by employing a channel adaptive antenna technique such as the minimum mean squared error (MMSE) nulling scheme [9]. Since the MMSE nulling requires the interfering CSI as well as the target CSI, we consider the estimation of both the CSIs.

The rest of the paper is organized as follows. Section II introduces the downlink model of the mobile-WiMAX system in consideration. Section III describes the proposed scheme, where the target and interfering CSI are estimated by combing the CSI estimated from the received preamble and pilot signal. The performance of the proposed scheme is verified by computer simulation in Section IV. Finally, conclusions are given in Section V.

2. System modeling:

Consider a multi-cell multi-sector structure as illustrated in Fig. 1, where the TBS denotes the target base station (BS) serving the target mobile station (MS) and the IBS denotes an interfering BS causing interference to the MS. Define the target channel and the i-th interference channel by the channel between the TBS and the MS, and the i-th IBS and the MS, respectively. Assume that each cell is divided into three sectors (say, α, β and γ sector), and that the BS has a single transmit antenna and the MS with N receive antennas is located in the β sector of the TBS.

The BS transmits preamble and pilot signals for the purpose of synchronization and channel estimation, respectively, as illustrated in Fig. 2. Since the pilot signals are transmitted to all sectors at the same time through the same frequency band, it can collide with each other. The pilot signal corresponding to the t_p-th OFDM symbol and the f_p-th subcarrier received through the n-th antenna can be represented as

Figure (1): *Multi-cell multi-sector structure*

Figure (2): *Preamble and pilot signal structure*

$$Y(t_p, f_p, n) = H_t(t_p, f_p, n)P_t(t_p, f_p, n) + \sum_{i=1}^{2} H_i(t_p, f_p, n)P_i(t_p, f_p, n) + W(t_p, f_p, n) \tag{1}$$

where $H_t(t_p, f_p, n)$ and $P_t(t_p, f_p, n)$ are respectively the frequency response of the target channel and pilot signal transmitted from the TBS, $H_i(t_p, f_p, n)$ and $P_i(t_p, f_p, n)$ are respectively the frequency response of the i-th interference channel and the pilot signal transmitted from the i-th IBS, and $W(t_p, f_p, n)$ is the frequency response of background noise modeled as a complex zero-mean Gaussian random variable with variance σ_W^2. It can be assumed that the TBS and IBSs transmit the pilot signal with the same average transmit power, i.e., $E\{|P_t(t_p, f_p, n)|^2\} = E\{|P_i(t_p, f_p, n)|^2\} = \sigma_P^2$. For simplicity, the receive antenna index n will be omitted since the estimation procedure for each receive antenna is identical.

Preambles are transmitted at the same time, but through different frequency bands by the sectors, as illustrated in Fig. 2. Consider preambles near the pilot signal $Y(t_p, f_p)$ in the frequency domain (i.e., the preambles at the $(f_p - 1)$-th, f_p-th and $(f_p + 1)$-th subcarriers). For ease of description, assume that the preambles at the $(f_p - 1)$-th, f_p-th and $(f_p + 1)$-th subcarriers are transmitted from sector α, β and γ, respectively. Then, the received preambles transmitted from the TBS and the i-th IBS can be represented as

$$Y(t_1, f_p) = H_t(t_1, f_p) S_t(t_1, f_p) + W(t_1, f_p) \tag{2}$$

$$Y(t_1, f_p + (-1)^i) = H_i(t_1, f_p + (-1)^i) S_i(t_1, f_p + (-1)^i) + W(t_1, f_p + (-1)^i) \tag{3}$$

where $S_t(t_1, f_p)$ and $S_i(t_1, f_p + (-1)^i)$ denote the preambles transmitted from the TBS and the i-th IBS, respectively. It can be assumed that the TBS and IBSs transmit the preamble signal with the same average transmit power, i.e., $E\left\{| S_t(t_1, f_p)|^2\right\} = E\left\{| S_i(t_1, f_p + (-1)^i)|^2\right\} = \sigma_S^2$. Let ρ_t be the correlation coefficient between the channel of the pilot signal and the preamble transmitted from the TBS, defined by

$$\rho_t \quad E\left\{\frac{H_t(t_p, f_p)\left(H_t(t_1, f_p)\right)^*}{\left|H_t(t_p, f_p)\right|^2}\right\} \tag{4}$$

where $E\{\cdot\}$ denotes the expectation and the superscript * denotes complex conjugate. Similarly, let ρ_i be the correlation coefficient between the channel of the pilot signal and the preamble transmitted from the i-th IBS, defined by

$$\rho_i \quad E\left\{\frac{H_i(t_p, f_p)\left(H_i(t_1, f_p + (-1)^i)\right)^*}{\left|H_i(t_p, f_p)\right|^2}\right\}. \tag{5}$$

3. Conventional LS channel estimation:

Assume that the major interference comes from at most two adjacent sectors. The target and the i-th interference channel can be estimated from the received pilot signal using a conventional LS estimation method as [5]

$$\hat{H}_t(t_p, f_p) = \frac{Y(t_p, f_p)}{P_t(t_p, f_p)} = H_t(t_p, f_p) + \sum_{i=1}^{2} H_i(t_p, f_p) \frac{P_i(t_p, f_p)}{P_t(t_p, f_p)} + \frac{W(t_p, f_p)}{P_t(t_p, f_p)} \tag{6}$$

$$\hat{H}_i(t_p, f_p) = \frac{Y(t_p, f_p)}{P_i(t_p, f_p)} = H_i(t_p, f_p) + H_t(t_p, f_p) \frac{P_t(t_p, f_p)}{P_i(t_p, f_p)} + \sum_{\substack{j=1 \\ j \neq i}}^{2} H_j(t_p, f_p) \frac{P_j(t_p, f_p)}{P_i(t_p, f_p)} + \frac{W(t_p, f_p)}{P_i(t_p, f_p)}. \tag{7}$$

It can be shown that the corresponding MSE of the channel estimation is

$$E\left\{\left|H_t(t_p, f_p) - \hat{H}_t(t_p, f_p)\right|^2\right\} = \sum_{i=1}^{2} \sigma_i^2 + \frac{\sigma_W^2}{\sigma_P^2} \tag{8}$$

$$E\left\{\left|H_i(t_p, f_p) - \hat{H}_i(t_p, f_p)\right|^2\right\} = \sigma_t^2 + \sum_{\substack{j=1 \\ j \neq i}}^{2} \sigma_j^2 + \frac{\sigma_W^2}{\sigma_P^2} \tag{9}$$

where σ_t^2 and σ_i^2 are the gain of the target and the i -th interference channel, respectively. It can be conjectured from (8) and (9) that the LS estimation may not provide good performance near the cell-boundary. Note that this estimation does not exploit the channel correlation not only between the OFDM symbols but also between the subcarriers.

4. Proposed channel estimation:

We consider the improvement of the CSI estimation accuracy in the presence of interference by exploiting the channel correlation properties between the OFDM symbols and between the subcarriers. The target CSI is first estimated from the received preamble signal and from the received pilot signal using a conventional LS method. Then, these two CSIs are combined for better CSI estimation, which is also used for the estimation of interference channel. The interfering CSI is first coarsely estimated by subtracting the estimated target CSI from the received pilot signal, and then re-estimated by combining it with the one estimated from the received preamble signal.

4.1 Channel estimation from the preamble:

The CSI can easily be estimated from the preambles transmitted from the TBS and IBSs using the LS method as

$$\hat{H}_t(t_1, f_p) = \frac{Y(t_1, f_p)}{S_t(t_1, f_p)} = H_t(t_1, f_p) + \frac{W(t_1, f_p)}{S_t(t_1, f_p)} \tag{10}$$

$$\hat{H}_i(t_1, f_p + (-1)^i) = \frac{Y(t_1, f_p + (-1)^i)}{S_i(t_1, f_p + (-1)^i)} = H_i(t_1, f_p + (-1)^i) + \frac{W(t_1, f_p + (-1)^i)}{S_i(t_1, f_p + (-1)^i)}. \tag{11}$$

Unlike in the CSI estimation from the pilot signal, this CSI estimation from the preamble signal is only affected by additive noise.

4.2 Target channel estimation:

The target CSI can be estimated from (6) and (10) as

$$\hat{H}_t(t_p, f_p) = \mathbf{h}_t^T \mathbf{w}_t \tag{12}$$

where $\mathbf{h}_t = \left[\hat{H}_t(t_p, f_p) \quad \hat{H}_t(t_1, f_p) \right]$, $\mathbf{w}_t$ is a weight vector to be determined and the superscript T denotes transpose. Let $\mathbf{R}_t$ and $\mathbf{P}_t$ be the auto-covariance matrix and cross-covariance vector of the target channel respectively defined by

$$\mathbf{R}_t \quad E\left\{\mathbf{h}_t \mathbf{h}_t^*\right\} = \begin{bmatrix} E\left\{\left|\hat{H}_t(t_p, f_p)\right|^2\right\} & E\left\{\hat{H}_t(t_p, f_p)\left(\hat{H}_t(t_1, f_p)\right)^*\right\} \\ E\left\{\hat{H}_t(t_1, f_p)\left(\hat{H}_t(t_p, f_p)\right)^*\right\} & E\left\{\left|\hat{H}_t(t_1, f_p)\right|^2\right\} \end{bmatrix} \tag{13}$$

$$\mathbf{P}_t \quad E\left\{\mathbf{h}_t \left(H_t(t_p, f_p)\right)^*\right\} = \begin{bmatrix} E\left\{\hat{H}_t(t_p, f_p)\left(H_t(t_p, f_p)\right)^*\right\} \\ E\left\{\hat{H}_t(t_1, f_p)\left(H_t(t_p, f_p)\right)^*\right\} \end{bmatrix}. \tag{14}$$

Then, it can be shown that

$$\mathbf{R}_t = \begin{bmatrix} \sigma_t^2 + \dfrac{\sigma_W^2}{\sigma_P^2} + \sum_{i=1}^{2} \sigma_i^2 & \sigma_t^2 \rho_t \\ \sigma_t^2 \rho_t^* & \sigma_t^2 + \dfrac{\sigma_W^2}{\sigma_S^2} \end{bmatrix} \tag{15}$$

$$\mathbf{P}_t = \begin{bmatrix} \sigma_t^2 \\ \sigma_t^2 \rho_t^* \end{bmatrix}. \tag{16}$$

The optimum combining vector $\mathbf{w}_t$ for the target CSI can be determined by [10]

$$\mathbf{w}_t = \mathbf{R}_t^{-1} \mathbf{P}_t = \begin{bmatrix} \sigma_t^2 + \dfrac{\sigma_W^2}{\sigma_P^2} + \sum_{i=1}^{2} \sigma_i^2 & \sigma_t^2 \rho_t \\ \sigma_t^2 \rho_t^* & \sigma_t^2 + \dfrac{\sigma_W^2}{\sigma_S^2} \end{bmatrix}^{-1} \begin{bmatrix} \sigma_t^2 \\ \sigma_t^2 \rho_t^* \end{bmatrix}. \tag{17}$$

The corresponding MSE of the target CSI estimation can be represented as [10]

$$\varepsilon_t^2 \quad E\left\{\left|H_t(t_p, f_p) - \tilde{H}_t(t_p, f_p)\right|^2\right\} = \sigma_t^2 - \mathbf{P}_t^H \mathbf{R}_t^{-1} \mathbf{P}_t \tag{18}$$

where the superscript H denotes conjugate transpose.

4.3 Interference channel estimation:

Since the target channel behaves as noise to the estimation of the interference CSI, the interference CSI can be estimated by using the target CSI in (12) as

$$\begin{aligned} \hat{H}_i'(t_p, f_p) &= \frac{Y(t_p, f_p) - \tilde{H}_t(t_p, f_p) P_t(t_p, f_p)}{P_i(t_p, f_p)} \\ &= H_i(t_p, f_p) + \frac{\left(H_t(t_p, f_p) - \tilde{H}_t(t_p, f_p)\right) P_t(t_p, f_p)}{P_i(t_p, f_p)} + \sum_{\substack{j=1 \\ j \neq i}}^{2} H_j(t_p, f_p) \frac{P_j(t_p, f_p)}{P_i(t_p, f_p)} + \frac{W(t_p, f_p)}{P_i(t_p, f_p)}. \end{aligned} \tag{19}$$

The interference channel can further be re-estimated as

$$\tilde{H}_i(t_p, f_p) = \mathbf{v}_i^T \mathbf{w}_i \tag{20}$$

where $\mathbf{v}_i = \left[\hat{H}_i'(t_p, f_p) \quad \hat{H}_i(t_1, f_p + (-1)^i)\right]$ and $\mathbf{w}_i$ is a weight vector for the i-th interfering CSI. The auto-covariance matrix and cross-covariance vector of the i-th interference channel can respectively be represented as

$$\mathbf{R}_i \quad E\left\{\mathbf{v}_i \mathbf{v}_i^*\right\} = \begin{bmatrix} \varepsilon_t^2 + \left(1 - 2\,\mathrm{Re}\left\{\mathbf{w}_t(1)\right\}\right)\left(\dfrac{\sigma_W^2}{\sigma_P^2} + \displaystyle\sum_{i=1}^{2} \sigma_i^2\right) & \sigma_i^2 \rho_i \left(1 - \mathbf{w}_t(1)\right) \\ \sigma_i^2 \rho_i^* \left(1 - \mathbf{w}_t(1)\right)^* & \sigma_i^2 + \dfrac{\sigma_W^2}{\sigma_S^2} \end{bmatrix} \tag{21}$$

$$\mathbf{P}_i \quad E\left\{\mathbf{v}_i H_i^*(t_p, f_p)\right\} = \begin{bmatrix} \sigma_i^2 \left(1 - \mathbf{w}_t(1)\right) \\ \sigma_i^2 \rho_i^* \end{bmatrix} \tag{22}$$

where $\mathbf{w}_t(1)$ denotes the first element of $\mathbf{w}_t$. Hence, the optimum combining vector $\mathbf{w}_i$ for the i-th interfering CSI is determined by

$$\mathbf{w}_i = \mathbf{R}_i^{-1}\mathbf{P}_i = \begin{bmatrix} \varepsilon_t^2 + \left(1 - 2\,\mathrm{Re}\{\mathbf{w}_t(1)\}\right)\left(\frac{\sigma_W^2}{\sigma_P^2} + \sum_{i=1}^{2}\sigma_i^2\right) & \sigma_i^2\rho_i\left(1-\mathbf{w}_t(1)\right) \\ \sigma_i^2\rho_i^*\left(1-\mathbf{w}_t(1)\right)^* & \sigma_i^2 + \frac{\sigma_W^2}{\sigma_S^2} \end{bmatrix}^{-1} \begin{bmatrix} \sigma_i^2\left(1-\mathbf{w}_t(1)\right) \\ \sigma_i^2\rho_i^* \end{bmatrix}. \quad (23)$$

The corresponding MSE of the i-th interference CSI estimation is represented as

$$\varepsilon_i^2 \quad E\left\{\left|H_i(t_p, f_p) - \hat{H}_i(t_p, f_p)\right|^2\right\} = \sigma_i^2 - \mathbf{P}_i^H \mathbf{R}_i^{-1}\mathbf{P}_i. \quad (24)$$

5. Performance evaluation:

The performance of the proposed scheme is verified by computer simulation when applied to the mobile-WiMAX system, where the MS has two receive antennas to cancel out other cell interference through a MMSE nulling scheme. The simulation parameters are summarized in Table 1 [8]. It is assumed that the gain of two interfering channels is the same (i.e., $\sigma_1^2 = \sigma_2^2$) and the symbol distance in the time domain between the preamble and pilot signal is $d_t = t_p - t_1$. As in [11], the normalized MSE, which is normalized with respect to the channel gain, is used as a performance measure of the estimator.

Table (1): *Simulation parameters*

Parameters	**Values**
Carrier frequency	2.3 GHz
Bandwidth	10 MHz
Number of subcarriers	1024
OFDM symbol duration (T_s)	115.2 μs
Channel	Rayleigh fading
Power delay profile	Pedestrian A
Doppler spectrum	Jakes' model
Number of receive antennas (N)	2
Modulation	QPSK
Channel coding	Repetition code with code rate 1/12
Interpolation scheme	Linear interpolation

Fig. 3 depicts the normalized MSE of the proposed estimation scheme according to the SINR when the MS has a mobility of $30\,km/h$ and $d_t = 10$. It can be seen that the LS scheme accuracy is significantly affected by the SINR, but the proposed scheme is not. This is mainly due to the use of adaptive weight minimizing the MSE. It can also be seen that the proposed scheme noticeably outperforms the LS estimation scheme.

Fig. 4 depicts the MSE of the proposed scheme normalized with respect to the channel gain according to the user mobility and symbol distance in the time domain. It can be seen that the LS scheme provides performance almost independent of the user mobility, but the proposed scheme is susceptible to the mobility because it exploits the channel correlation between the preamble and the pilot, which is affected by the mobility and the symbol distance. Nevertheless, the proposed scheme outperforms the LS estimation.

Fig. 5 depicts the packet error rate (PER) of the proposed scheme. We assume that the BS transmits a packet comprising 4 OFDM symbols and 14 contiguous subcarriers. We also assume that the packet is allocated at the position where the distance from preamble is from 3 to 6 symbols in the time domain at Mode A and from 23 to 26 symbols in the time domain at Mode B, respectively. It can be seen that the performance of the LS scheme is significantly degraded. It can also be seen that the proposed scheme outperforms the LS scheme especially at Mode A due to the high channel correlation.

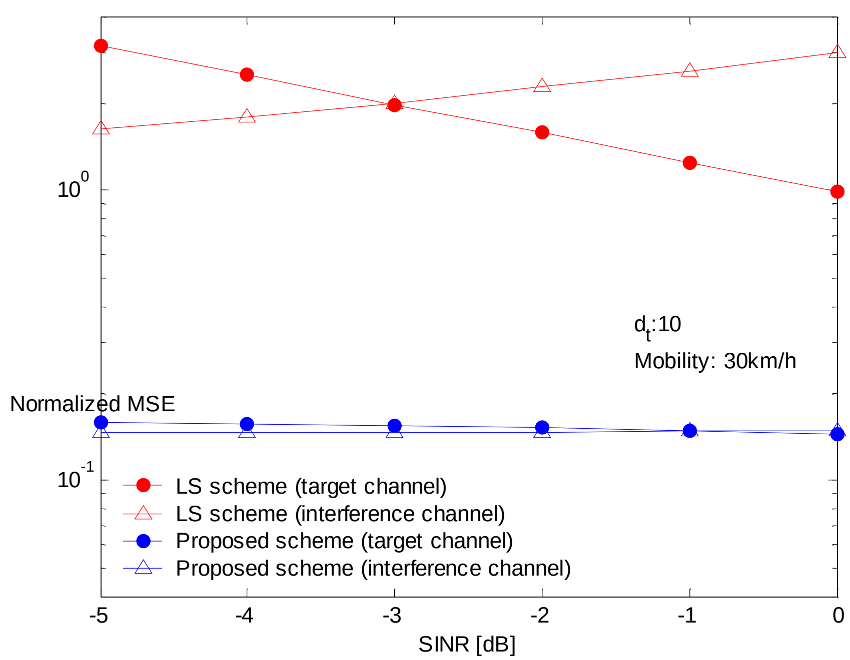
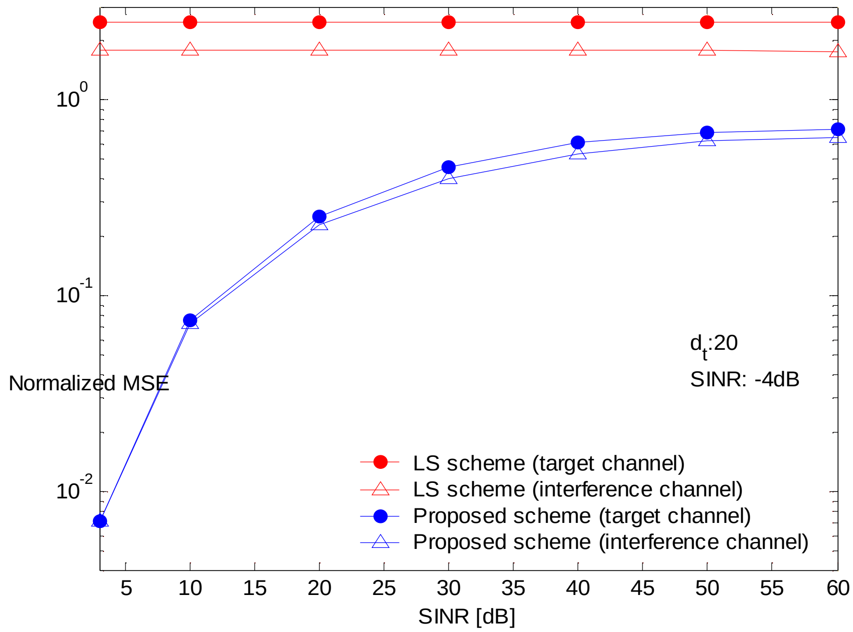
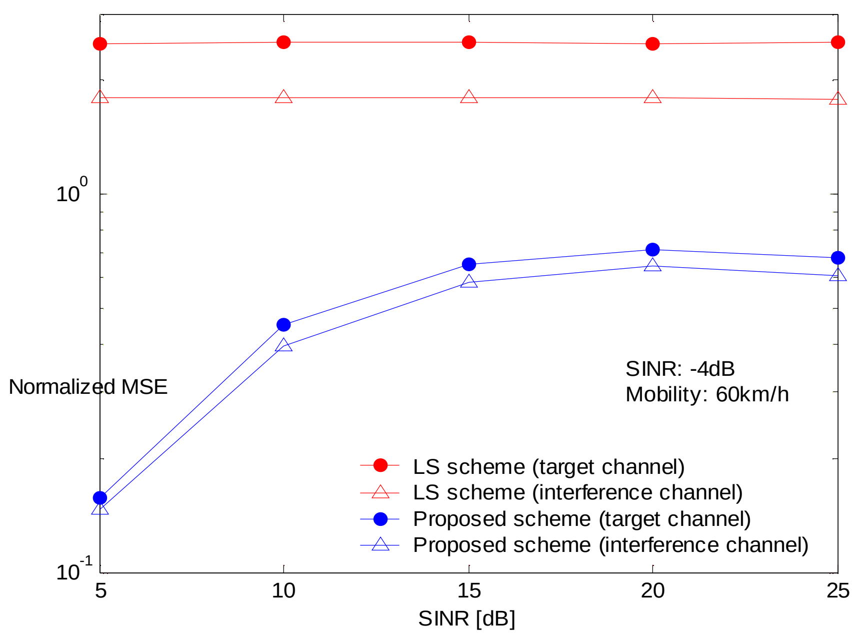


Figure (3): *MSE performance according to the SINR*

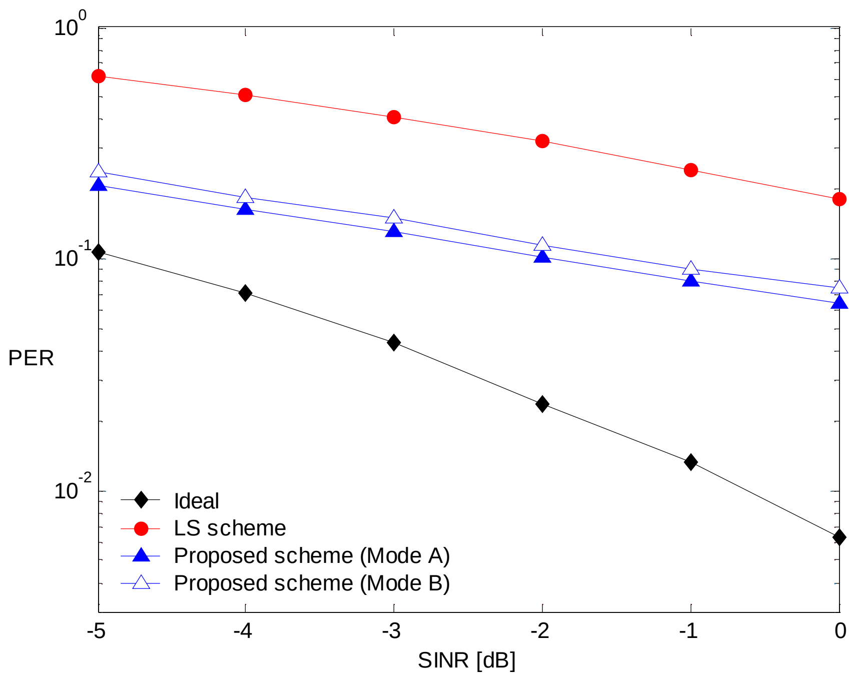


(a): *MSE according to the mobility*

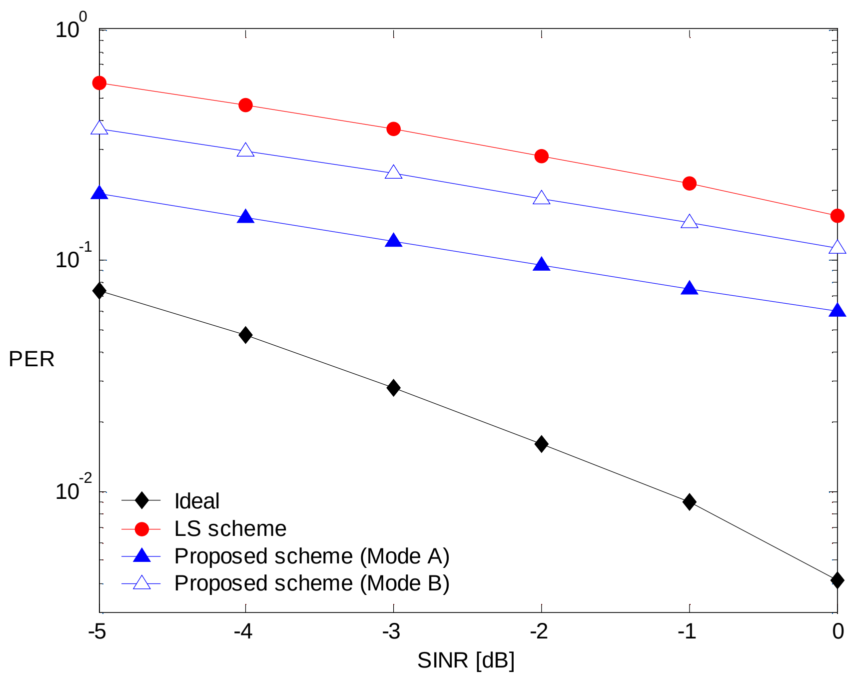


(b): *MSE according to the symbol distance in the time domain*

Figure (4): *MSE performance according to the channel correlation between preamble and pilot signal*



(a): *PER when user mobility is* $3 km/h$



(b): *PER when user mobility is* $60 km/h$

Figure (5): *PER according to the SINR*

6. Conclusions:

In this paper, we have proposed a channel estimation scheme that utilizes the preamble as well as the pilot signal. The proposed scheme estimates the channel by combining the CSI estimated from the received preamble and pilot signal. The combining weight is analytically determined to minimize the MSE of the channel estimation. When the proposed scheme is applied to the mobile-WiMAX system, the simulation results show that the proposed scheme is quite effective in the cell boundary, especially highly correlated channel environments.

References:

[1] S. Hara and R. Prasad, *Multicarrier Techniques for 4G Mobile Communications*, Artech House, first edition, 2003.

[2] M. Engels, *Wireless OFDM Systems: How To Make Them Work?*, Kluwer Academic Publishers, 2002.

[3] T. H. Kwon, H. J. Song, and D. S. Hong, "Robust Channel Estimation in Multicell OFDM(A) Downlink Systems with Propagation Delay," in *Proc. IEEE VTC'2007 spring*, pp. 1450–1454, Apr. 2007.

[4] T. Tang and R. W. Heath, "Space-Time Interference Cancellation in MIMO-OFDM Systems," *IEEE Trans. Vehic.*, vol. 54, no. 5, pp. 1802–1816, Sept. 2005.

[5] W. G. Jeon, K. H. Paik, and Y. S. Cho, "An Efficient Channel Estimation Technique for OFDM Systems with Transmitter Diversity," in *Proc. IEEE PIMRC'2000*, pp. 1246–1250, Sept. 2000.

[6] M. Bossert, A. Donder, and V. Zyablov, "Improved Channel Estimation with Decision Feedback for OFDM Systems," *IEE Electron. Lett.*, vol. 2, no. 11, pp. 1064–1065, May 1998.

[7] K. Hayashi and H. Sakai, "Downlink Channel Estimation for Multi-cell Block Transmission Systems with Cyclic Prefix," in *Proc. IEEE VTC'2007 spring*, pp. 1776–1780, Apr. 2007.

[8] IEEE P802.16e, *Draft IEEE standard for local and metropolitan area networks*, Sept. 2004.

[9] D. Tse and P. Viswanath, *Fundamentals of wireless communication*, Cambridge University Press, 2005.

[10] S. Haykin, Adaptive Filter Theory, Prentice Hall, fourth edition, 2002.

[11] H. D. Shin and J. H. Lee, "Channel Reliability Estimation for Turbo Decoding in Rayleigh Fading Channels with Imperfect Channel Estimates," *IEEE Commun. Lett*. vol. 6, no. 11, Nov. 2002.