Novel Channel Estimation Algorithm using Various Filter Design in LTE-Advanced System

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Keywords: Channel Estimation, OFDM, LTE-Advanced.

Abstract: Channel estimation is a major issue in communication system. In this paper, we propose a new idea for channel estimation that uses a Kalman Filter (KF) approach to predict the channel in OFDM symbols with pilot subcarriers where channel affected is by high doppler spread. We design the algorithm considering the lattice-type arrangement of pilot subcarriers in a LTE-Advanced system from 3GPP. In further advancement, we use the filtering of channel impulse response and application of a Wiener Filter for the estimation of the channel frequency response in the rest of the subcarriers.

1 INTRODUCTION

There are several techniques used to estimate the channel in a wireless communication system. The effectiveness of these techniques depends on key factor such as the environment (indoor, outdoor, rural, urban) and the mobility between transmitter and receiver. Primarily, least square (LS) estimation is the most simple of the conventional channel estimations techniques, but it only works well for time-invariant channels or with low Doppler spread. Minimum mean squared error (MMSE) combined with a linear interpolation method is more effective than LS because it considers the channel correlation values. However for time-variant channels, it is necessary to implement techniques able to estimate or predict the variations of the channel in time, such as Wiener and Kalman filters. In this research, we want to proposed a method to estimate and predict the variations of channel in fast fading channels, considering the especial arrangement of reference signals in LTE, since other papers are usually based on block-type or comb-type arrangements.

This paper is divided as follows, section II shows the arrangement of reference signals in 3GPP-LTE advanced, section III briefly describes conventional channel estimation methods, section IV describes our proposal, section V shows our simulation results and finally section VI contains our conclusions.

2 REFERENCE SIGNAL IN LTE-ADVANCED

LTE-Advanced uses signals known by both the transmitted and the receiver, sent in predefined locations. This signals are called downlink reference signals (3 GPP TS 36.211, 2010). By processing the received reference signals, the receiver can estimate the whole channel response for each OFDM symbol.

In the time-domain, for one antenna port, reference signals are transmitted during the first and fifth OFDM symbols of each slot when the normal cyclic prefix (CP) is used and during the first and fourth OFDM symbols when the extended CP is used. In the frequency-domain, they are inserted every six subcarriers.

2.1 Relationship between Coherence Bandwidth and Reference Signals In 3GPP LTE

Table 1: Delay profile for 3GPP LTE channel model.

Channel	Number of Chanel Taps	Delay Spread (r.m.s)	Max. Excess Tap delay
EPA	7	45ns	410 ns
EVA	9	357ns	2510 ns
ETU	9	991ns	5000 ns

Malik S., Moon S., Kim B., Kim C. and Hwang I..
Novel Channel Estimation Algorithm using Various Filter Design in LTE-Advanced System.
DOI: 10.5220/0004026901200125
In *Proceedings of the International Conference on Signal Processing and Multimedia Applications and Wireless Information Networks and Systems* (SIGMAP-2012), pages 120-125
ISBN: 978-989-8565-25-9

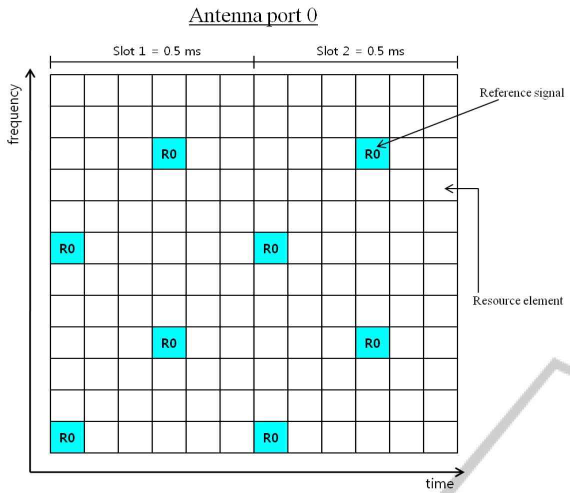

Figure 1: Mapping of Downlink reference signals for one antenna port in extended CP.

Table 2: Coherence bandwidth of 20 MHz LTE-Advanced system.

Channel	$B_{(0.9)}$	$B_{(0.5)}$
EPA	1.6 MHz	3.7 kHz
EVA	201.1 kHz	466.9 kHz
ETU	72.4 kHz	168.2 kHz

In LTE-Advanced, the subcarrier space frequency Δf is 15 kHz. Since the reference signals in the frequency domain are located every 6 subcarriers, the reference signal bandwidth is 90 kHz. If the channel frequency response remains constant, the correlation in the frequency domain should have a value close to 1; while we choose a value of 0.5 as an indicator that the channel has changed. Based on this assumptions, we can estimate the coherence bandwidth for both situations using equation (1) (Somasegeran, 2007):

$$\beta \geq \frac{1}{2\pi\tau_s}\arccos(c) \tag{1}$$

where c is the correlation in frequency domain, and τ_s is the root-mean-square (RMS) delay spread given for LTE extended channel models: Extended Pedestrian A (EPA), Extended Vehicular A (EVA) and extended urban (ETU) channels (Table 1).

The results in Table 2 demonstrate that, basically, the channel is constant during the bandwidth corresponding to the spacing of reference symbols in frequency domain; and therefore, the reference signals in LTE-Advanced are able to keep track of the frequency selective fading.

2.2 Relationship between Coherence Time and Reference Signals in 3GPP LTE

For the extended cyclic prefix case, there are 6 symbols in 1 slot (12 symbols per sub frame). Therefore, we can calculate 1 OFDM symbol period as:

$$T_{symb} = \frac{T_{slot}}{N_{symb}} = \frac{0.5ms}{6} = 83.3\mu s$$

Reference signals are transmitted during the first and fourth OFDM symbols in each slot. Therefore, the spacing of reference signals in time domain is:

$$T_{ref} = 3.T_{symb} = 0.25ms$$

Table 3: Maximum doppler frequency for 3 GPP LTE–Advanced channel models.

Channel	Maximum Doppler Frequency (Hz)	UE Maximum Speed (Km/h) *carrier frequency 2 GHz
EPA	5	3
EVA	70	40
ETU	300	160

If the channel is constant in time, the correlation in the time domain should be close to 1; as such we choose a value of 0.5 as an indicator that the channel has changed. Based on these assumptions, we can estimate the coherence time for both situations, using equation (2) and the maximum Doppler frequency corresponding to the LTE-Advanced channel models as shown in Table 3.

$$\Delta t_c = \frac{1}{2\pi f_D}\arccos(c)$$

The results shown in Table 4 demonstrate that the spacing of reference symbols in time is less than the coherence time; therefore, the reference signals in LTE are able to keep track of the time-varying fading channel.

Table 4: Coherence time 20 MHz 3GPP LTE-Advanced system.

Maximum Doppler Frequency	$\Delta t_{(0.9)}$	$\Delta t_{(0.5)}$
$f_D = 5$ Hz	14.4 ms	33.3 ms
$f_D = 70$ Hz	1.0 ms	2.4 ms
$f_D = 300$ Hz	0.2 ms	0.6 ms

The results shown in Table 4 demonstrate that the spacing of reference symbols in time is less than the coherence time; therefore, the reference signals in LTE are able to keep track of a time-varying fading channel.

3 CONVENTIONAL CHANNEL ESTIMATION METHODS

In this section we briefly describe conventional techniques to estimate and/or predict the channel frequency response (CFR).

3.1 LS Channel Estimation

LS is the simplest method to estimate the channel. First, we calculate the CFR only in the subcarriers that contain reference symbols. We do so, by dividing the received reference signals between their transmitted value (Simko, 2009):

$$\hat{H}_{p,LS} = \left[\frac{y_p(1)}{x_p(1)}, \frac{y_p(2)}{x_p(2)} \cdots \frac{y_p(N_p)}{x_p(N_p)} \right] \tag{3}$$

The channel frequency response for the rest of the subcarriers, is estimated with interpolation and extrapolation in frequency and time dimensions.

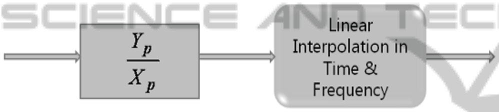

Figure 2: Block Diagram of LS Channel Estimation

3.2 MMSE Channel Estimation

Another method to estimate the channel is the MMSE algorithm which has better performance than LS but is computationally more complex. MMSE calculates the channel impulse response that minimizes the mean square error between the actual and estimated channel impulse response (Hou and Liu).

The channel in the frequency domain can be estimated with equation (4):

$$\hat{H}_{p,MMSE} = R_{hp} \left[R_{pp} + \sigma^2 (XX^H)^{-1} \right]^{-1} \hat{H}_{p,LS} \tag{4}$$

where σ^2 is the noise variance, R_{hp} is the cross-correlation matrix between all subcarriers and the subcarriers with reference signals within the same OFDM symbol, R_{pp} is the autocorrelation matrix of the subcarriers with reference signals within the same OFDM symbol, and the superscript $(\cdot)^H$ denotes Hermitian transpose. By replacing $(XX^H)^{-1}$ in (4) with its expectation $E[(XX^H)^{-1}]$, the MMSE channel estimator in frequency domain can be expressed as:

$$\hat{H}_{p,MMSE} = R_{hp} \left[R_{pp} + \frac{\beta}{SNR} I_p \right]^{-1} \hat{H}_{p,LS} \tag{5}$$

where is a constant depending on the type of modulation and β is the identity matrix. We can estimate the channel for the other resource elements using linear interpolation in time domain.

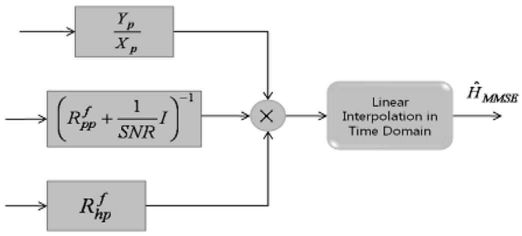

Figure 3: Block diagram of MMSE channel estimation.

3.3 Wiener Filter

The Wiener Filter (WF) uses the same principle than MMSE method (Qin et al., 2007) and it also eliminates noise effects in the channel estimation. WF allows us to keep track of the variations of the CIR in time-variant channels because it uses both the time and frequency correlations.

To simplify the complexity, the 2-dimensional WF is decompose into two separated WF's; one in the frequency domain and one in the time domain.

First, we obtain directly the channel estimation in frequency domain for the OFDM symbols with reference signal as:

$$\hat{H}^f_{p,MMSE} = R^f_{hp} \left[R^f_{pp} + \frac{\beta}{SNR} I_p \right]^{-1} \hat{H}_{p,LS} \tag{6}$$

Then we estimate the total channel frequency for all OFDM symbols using WF in time domain:

$$\hat{H}_{WF} = R^t_{pp} \left[R^t_{pp} + \frac{\beta}{SNR} I_p \right]^{-1} \hat{H}^f_{WF} \tag{7}$$

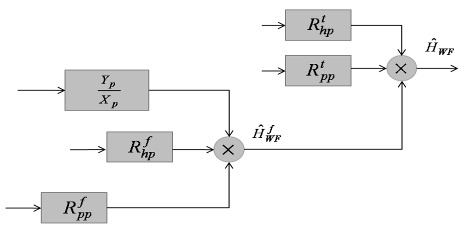

Figure 4: Block diagram 2x1 dimensional WF.

3.4 Kalman Filter

The purpose of the Kalman Filter (KF) is to use measurements observed over time, containing noise, and produce values that are closer to the true values of the measurements and their associated calculated values. In this section, we study the KF that is used to predict variations of the channel in time domain and which can also be applicable to frequency domain.

The principle behind KF applied to channel estimation is that we can represent the channel frequency response, at time, as an infinite order autoregressive (AR) process (Karakaya et al., 2009).

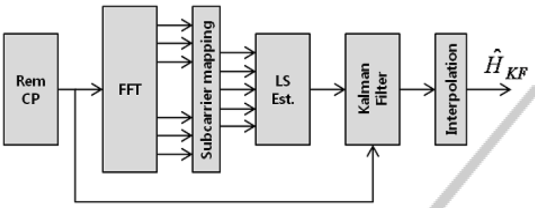

Figure 5: System using KF and block type pilot arrangement.

Where, k and A are the order and the coefficient of the AR process, respectively. V is a white Gaussian noise with zero mean and variance σ^2. For the case of first order AR process $\sigma_v^2 = 1 - J_0^2(2\pi f_D T_{symb})$ and $A = J_0(2\pi f_D T_{symb}) I_{N_p}$.

In order to reduce the computational complexity, only the first order AR process, i.e., is considered. Therefore, we can represent the vector form of the channel frequency response at time *n* as:

Then, the channel estimate can be obtained by a set of recursions (Ling and Ting, 2006):

$$M_n = AP_{n-1}A^H + \sigma_v^2 I_{N_p}$$
$$G_n = X_p[n] M_n (X_p[n])^H + R$$
$$K_n = M_n (X_p[n])^H G_n^{-1}$$
$$e_n = Y_p[n] - X_p[n] A \hat{H}_p[n-1]$$
$$\hat{H}_p = A\hat{H}_p[n-1] + K_n e_n$$
$$P_n = (I - K_n X_p[n]) M_n$$

The received symbol at time can be expressed in the form of a linear regression model.

4 PROPOSED CHANNEL ESTIMATION SCHEME

In this section introduce and explain the proposed method to predict the channel in high Doppler spread.

Fig. 6 shows the New Channel Estimator's block diagram that was designed considering the lattice-type reference signals arrangement of 3GPP LTE (so far most of the studies focus on block-type or comb type pilot arrangements).

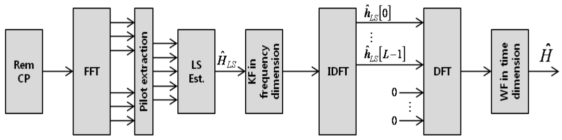

Figure 6: Block diagram of the new channel estimator.

After FFT, the reference signals or pilots of the first OFDM symbols are extracted and we can estimate the channel frequency response (CFR) using a simple method, such as LS. Using the recursions of KF, we can estimate the variation of CFR for the later OFDM symbols containing reference signals. Then, we transform the CFR into CIR and eliminate the taps with index larger than *L*; this way we eliminate the noise contained in those taps. Finally, we transform the CIR to CFR and estimate the channel for the rest of the subcarriers using WF in time dimension.

5 SIMULATION RESULTS

In this section we show the performance analysis of channel estimation methods. The simulations are performed in MATLAB using the simulation parameters of 3GPP LTE-Advanced shown in Table 5. The time variant channel is modelled according to the values given for LTE extended channel models in Table 1 and the maximum Doppler Frequency values for each channel given in Table 3. The frequency power spectrum follows the Jakes model. Following the results of section II, we assume the channel to be constant for 1 OFDM symbol.

Fig. 7 shows the BER performance of different channel estimation methods in EPA channel with max. Doppler Frequency of 5Hz. For this case, the motion speed is low; therefore, as shown in sections II, the channel suffers little variation in time within one subframe and techniques like LS or MMSE with linear interpolation produce good results.

Fig. 8 shows the BER performance of different channel estimation methods in EVA channel with max. Doppler frequency of 70Hz. In this case, the mobile user moves with medium speed; therefore, as shown in section II, the channel suffers more variation in time within one subframe compared to the case of EPA. We can observe that the BER obtained with LS and MMSE starts to separate from the actual value, but WF and New CE produce more accurate results.

Fig. 9 shows the BER performance of different channel estimation methods in ETU channel with max. Doppler frequency of 300Hz. In this case, the mobile user moves with very high speed; therefore, as shown in section II, the channel suffers significant variations in time, even within one subframe. We can observe that the effectiveness of LS and MMSE is affected by the high Doppler spread; therefore it is necessary to employ techniques that consider the time correlation of the channel. We demonstrate through this simulation that our proposed technique, New CE, produces the best results for high Doppler spread environments.

Table 5: Simulation parameters.

Parameter	Value
Bandwidth	20 MHz
Sample frequency	30.72 MHz
Subframe duration	1 ms
Subcarrier spacing	15 kHz
FFT size	2048
Occupied subcarriers	1200 + DC subcarrier = 1201
No. subcarriers/RB	12
No. of RB's/subframe	100
CP size (samples)	512 (extended CP)
No. of OFDM symbols/subframe	12 (extended CP)
No. of reference signals per RB	8
Modulation scheme	QPSK
Noise	AWGN
No. of antennas	1x1
Channel estimation Techniques	LS with linear interpolation, MMSE, Wiener Filter, Creative CE
Channel models	3GPP LTE extended channel models: EPA, EVA, ETU

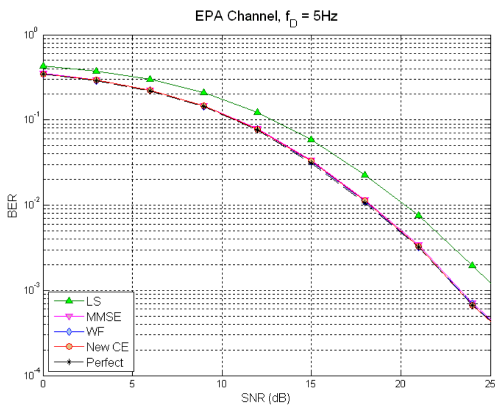

Figure 7: BER Performance using different channel estimation methods in EPA channel with maximum Doppler frequency of 5 Hz.

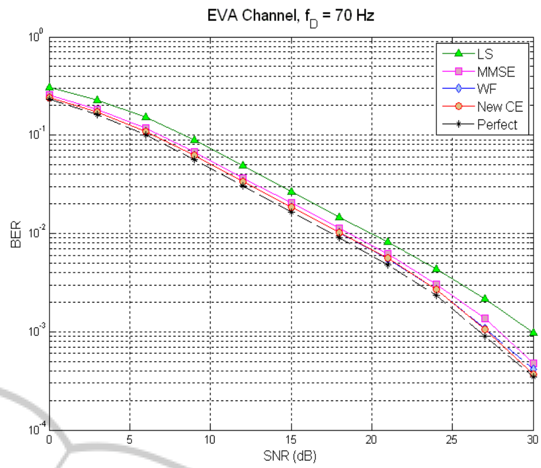

Figure 8: BER performance using different channel estimation methods in EVA channel with maximum Doppler frequency of 70Hz

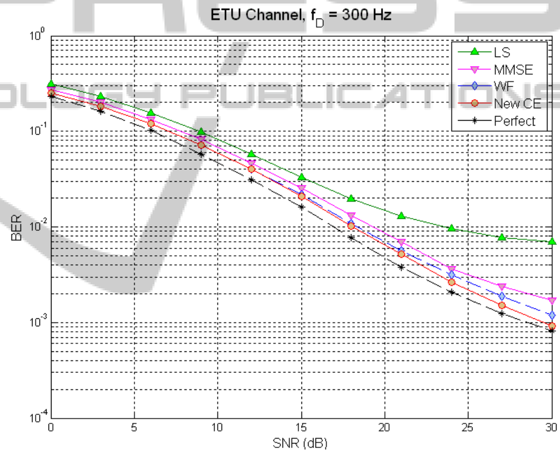

Figure 9: BER performance using different channel estimation methods in Rayleigh ETU channel; with maximum Doppler frequency of 300 Hz.

6 CONCLUSIONS

In this paper we proposed a novel channel estimation method to improve transmission and reception of data in high speed environments. We designed our system considered the especial arrangement of reference signals in 3GPP LTE-Advanced and demonstrated through MATLAB simulations that the BER performance result in high Doppler spread is very close to the case of ideal channel estimation.

ACKNOWLEDGEMENTS

This research was supported by the MKE(The Ministry of Knowledge Economy), Korea, under the ITRC (Information Technology Research Center) support program supervised by the NIPA(National IT Industry Promotion Agency)" (NIPA-2012-H0301-12-3005).This study was financially supported by Chonnam National University, 2011.

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