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# LTE-Advanced에 적용되는 빠른 페이딩 채널의 새로운 채널 추정 방법

# ( Novel Channel Estimation Method in Fast Fading Channels Applied to LTE-Advanced )

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## 요 약

높은 도플러 확산에 의한 채널 통계의 정확한 전송 및 추정은 최근 및 미래의 이동 통신 시스템에서 고려되는 주요 문제 중 하나이다. 따라서 기존 채널 추정 기법의 한계를 극복하는 새로운 채널 추정 기술을 연구하는 것이 중요하다. 본 논문에서는 첫 번째 OFDM symbol의 간단한 추정 후 새로운 채널 추정 방법인 파일럿 부반송파와 OFDM symbol의 나머지 채널을 추정하기 위해서 Kalman Filter를 사용하는 것을 제안한다. 또한 지금까지의 대부분 연구에서는 block-type이나 comb-type 파일럿 배열에 초점 맞춰져 있는 것과 달리 LTE-Advanced의 파일럿 부반송파의 lattice-type 배열을 고려하여 설계한다. 이 외에도 결과를 최적화하기 위해서 나머지 부반송파에 대한 채널 주파수 응답을 추정하기 위해 채널 임펄스 응답의 필터링과 Winer Filter를 사용한다.

## Abstract

Accurate transmission and estimation of the channel statistics affected by high Doppler spread is one of the main issues of concern for the latest and future mobile communication systems. Therefore, it is important to research in novel channel estimation techniques that overcome the limitations of conventional methods. In this paper, we propose a novel channel estimation method that, after a simple estimation in the first OFDM symbol, uses Kalman filter to predict the channel in the rest of OFDM symbols with pilot subcarriers. Our method is designed considering the lattice-type arrangement of pilot subcarriers in LTE-Advanced, since most of the studies so far focus on block-type or comb-type pilot arrangements. In addition, to optimize the results, we use the filtering of channel impulse response and Wiener Filter for the estimation of the channel frequency response in the rest of the subcarriers.

**Keywords** : Channel Estimation, OFDM, LTE-Advanced

## Ⅰ. 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

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the most simple of the conventional chanel 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-Advanced, 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.

## Ⅱ. Reference signals 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[1]. By processing the received reference signals, the receiver can estimate the whole channel response for each OFDM symbol.

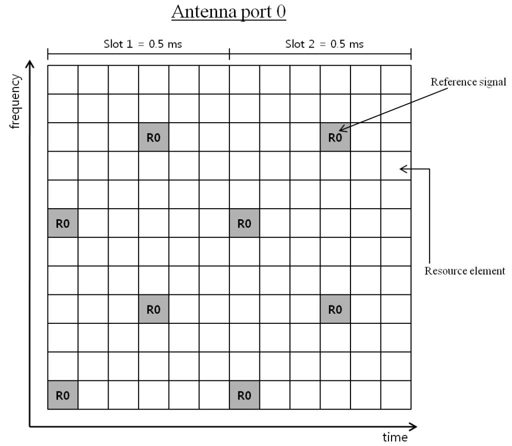

그림 1. 확장된 CP에서 하나의 안테나 포트에 대한 다운링크 레퍼런스 신호 매핑
Fig. 1. Mapping of downlink reference signals for one antenna port in extended CP.

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.

### 1. Relationship between coherence bandwidth and reference signals in 3GPP LTE-Advanced

In LTE-Advanced, the subcarrier space frequency $\Delta f$ is 15 kHz. Since the reference signals in the frequency domain are located every 6 subcarriers, the reference signal bandwidth $B_{ref}$ is 90 kHz. If the Channel Frequency Response (CFR) 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)[2]:

$$B_{(c)} \geq \frac{1}{2\pi\tau_S}\arccos(c) \tag{1}$$

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

표 1. 3GPP LTE-Advanced 채널 모델을 위한 지연 프로파일.
Table 1. Delay profile for 3GPP LTE-Advanced channel models.

| Channel | Number of channel taps | Delay spread (r.m.s.) | Max. excess tap delay |
|---|---|---|---|
| EPA | 7 | 45 ns | 410 ns |
| EVA | 9 | 357 ns | 2510 ns |
| ETU | 9 | 991 ns | 5000 ns |

표 2. 20 MHz LTE-Advanced 시스템의 상관 대역폭.
Table 2. Coherence Bandwidth of 20 MHz LTE-Advanced system.

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

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. Relationship between coherence time and reference signals in 3GPP LTE-Advanced

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

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

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

$$T_{ref}=3\bullet T_{symb}=0.25\,ms$$

If the channel is constant in time, the correlation in the time domain should be 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 time for both situations, using equation (2) and the maximum doppler frequency corresponding to the LTE-Advanced channel models shown in Table 3.

표 3. 3GPP LTE-Advanced 채널 모델을 위한 최대 도플러 주파수.
Table 3. Maximum Doppler frequency for 3GPP LTE-Advanced channel models.

| Channel | Maximum Doppler Frequency (Hz) | UE maximum speed (km/h) *carrier freq. 2 GHz |
|---|---|---|
| EPA | 5 | 3 |
| EVA | 70 | 40 |
| ETU | 300 | 160 |

표 4. 20MHz 3GPP LTE-Advanced 시스템의 상관 시간.
Table 4. Coherence time of 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 |

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

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-Advanced are able to keep track of the time-varying fading channel.

## Ⅲ. Conventional Channel Estimation Methods

In this section we briefly describe conventional techniques to estimate and/or predict the CFR.

### 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[3]:

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

The CFR for the rest of the subcarriers, is

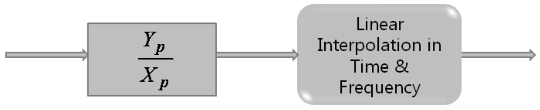

그림 2. LS 채널 추정 블록 다이어그램.
Fig. 2. Block diagram of LS channel estimation.

estimated with interpolation and extrapolation in frequency and time dimensions.

## 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 (CIR) that minimizes the mean square error between the actual and estimated CIR[4].

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

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

where $\sigma^2$ 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 $(\bullet)^H$ denotes Hermitian transpose. By replacing $(XX^H)^{-1}$ in (4) with its expectation $E\left[(XX^H)^{-1}\right]$, the MMSE channel estimator in frequency domain can be expressed as:

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

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

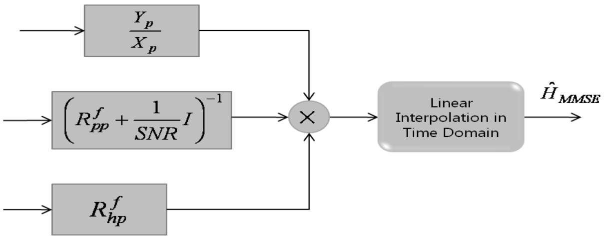

그림 3. MMSE 채널 추정 블록 다이어그램.
Fig. 3. Block diagram of MMSE channel estimation.

## 3. Wiener Filter

The Wiener Filter (WF) uses the same principle than MMSE method[5] 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:

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

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

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

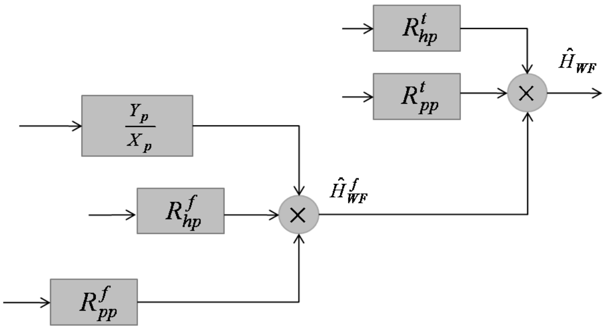

그림 4. 2×1-차원 WF 블록 다이어그램.
Fig. 4. Block diagram of 2×1-dimensional WF.

## 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.

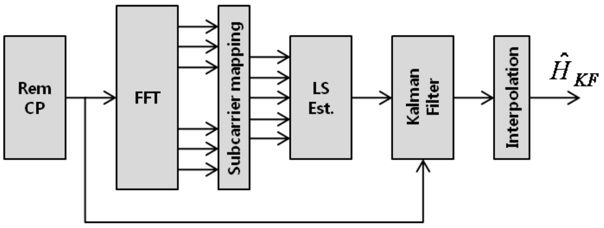

그림 5. KF와 block-type 파일럿 배열을 사용한 시스템.
Fig. 5. System using KF and block-type pilot arrangement.

The principle behind KF applied to channel estimation is that we can represent the CFR at time, as an infinite order autoregressive (AR) process[6].

$$H_p[n] = \sum_{i=1}^{k} A[i]\, H_p[n-1] + V[n]$$

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 $\sigma^2$. 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 CFR at time $n$ as:

$$H_p[n] = A\, H_p[n-1] + V_p[n]$$

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

$$Y_p[n] = X_p[n]\, H_p[n-1] + W_p[n]$$

Then, the channel estimate $\hat{H}_p$ can be obtained by a set of recursions[7]:

$$M_n = A P_{n-1} A^H + \sigma_v^2 I_{N_p}$$

$$G_n = X_p[n]\, M_n (X_p[n])^H + R$$

$$\boldsymbol{K}_n = M_n (X_p[n])^H G_n^{-1}$$

$$e_n = Y_p[n] - X_p[n]\, A \hat{H}_p[n-1]$$

$$\hat{H}_p = A \hat{H}_p[n-1] + K_n e_n$$

$$P_n = (\boldsymbol{I} - \boldsymbol{K}_n \boldsymbol{X}_p[n])\, M_n$$

## Ⅳ. Proposed Channel Estimation Methods

In this section introduce and explain the proposed method to predict the channel in high conventional Fig. 6 shows the New Channel Estimator's block diagram that was designed considering the lattice-type reference signals arrangement of 3GPP LTE-Advanced (so far most of the studies focus on block-type or comb-type pilot arrangements). After FFT, the reference signals or pilots of the first OFDM symbols are extracted and we can estimate the 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.

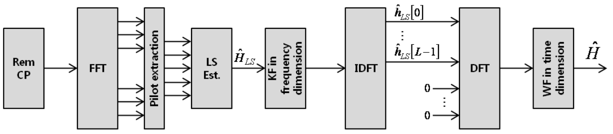

그림 6. 새로운 채널 추정 블록 다이어그램.
Fig. 6. Block diagram of the New Channel Estimator.

## Ⅳ. 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 modeled according to the values given for LTE-Advanced extended channel models in Table 1 and the maximum doppler

표 5. 시뮬레이션 파라미터 (3GPP LTE-Advanced).
Table 5. Simulation parameters (3GPP LTE-Advanced).

| | |
|---|---|
| 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. of subcarriers/PRB | 12 |
| No. of available PRBs | 100 |
| CP size (samples) | 512 (extended CP) |
| No. of OFDM symbols/subframe | 12 (extended CP) |
| No. of reference signals per PRB | 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-Advanced extended channel models:<br>EPA, EVA, ETU |

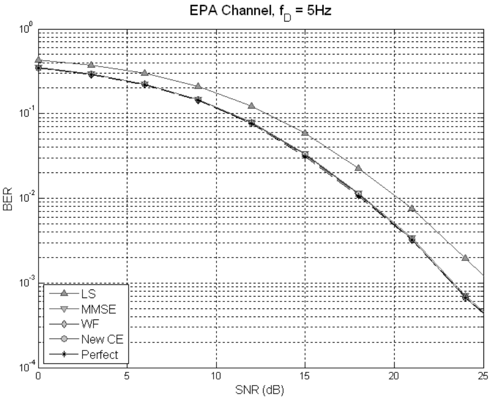

그림 7. 최대 도플러 주파수 5Hz인 EPA 채널에서 서로 다른 채널 추정 기법을 이용한 BER 성능
Fig. 7. BER performance using different channel estimation methods in EPA channel with max. Doppler frequency of 5Hz.

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.

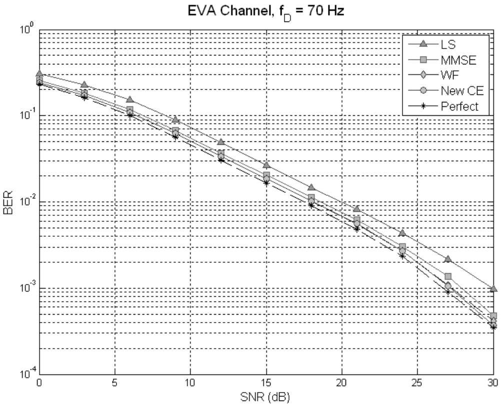

그림 8. 최대 도플러 주파수 70Hz인 EVA 채널에서 서로 다른 채널 추정 기법을 이용한 BER 성능.
Fig. 8. BER performance using different channel estimation methods in EVA channel with max. Doppler frequency of 70Hz.

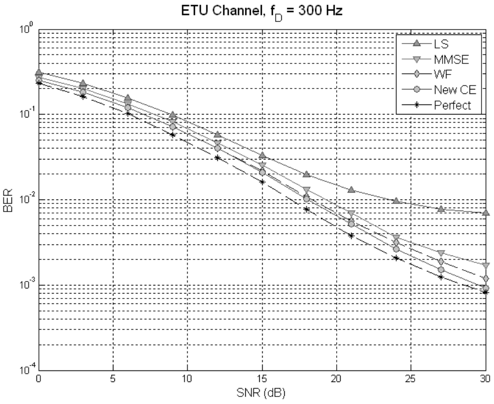

그림 9. 최대 도플러 주파수 300Hz인 ETU 채널에서 서로 다른 채널 추정 기법을 이용한 BER 성능
Fig. 9. BER performance using different channel estimation methods in ETU channel with max. Doppler frequency of 300Hz.

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 Channel

Estimation (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.

## V. Conclusion

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.

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