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Performance Evaluation of Pilotless Channel Estimation with Limited Number of Data Symbols in Frequency Selective Channel

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ABSTRACT

In a wireless mobile communication system, a pilot signal has been considered to be a necessary signal for estimating a changing channel between a base station and a terminal. All mobile communication systems developed so far have a specification for transmitting pilot signals. However, although the pilot signal transmission is easy to estimate the channel,(Ed: unclear wording: it is easy to use the pilot signal transmission to estimate the channel?) it should be minimized because it uses radio resources for data transmission. In this paper, we propose a pilotless channel estimation scheme (PCE) by introducing the clustering method of unsupervised learning used in our deep learning into channel estimation.(Ed: highlight- unclear) The PCE estimates the channel using only the data symbols without using the pilot signal at all. Also, to apply PCE to a real system, we evaluated the performance of PCE based on the resource block (RB), which is a resource allocation unit used in LTE. According to the results of this study, the PCE always provides a better mean square error (MSE) performance than the least square estimator using pilots, although it does not use the pilot signal at all. The MSE performance of the PCE is affected by the number of data symbols used and the frequency selectivity of the channel. In this paper, we provide simulation results considering various effects(Ed: unclear, clarify).

Key words*: Channel Estimation, Unsupervised Learning.*

1. INTRODUCTION

The pilot signal transmission in mobile communication systems is essential for estimating the wireless channel between a base station (BS) and a mobile station (MS). The pilot signal is also referred to as a reference signal since it is a signal previously known between the transmitter and the receiver. However, since the pilot signal transmission also consumes radio resources, the transmission of the pilot signal is also a cause of reducing an effective data throughput. Therefore, as long as the performance of the wireless communication system is maintained, minimizing the transmission of the pilot signal maximizes the throughput [1], [2]

Deep learning, on the other hand, has been applied to various fields and presents new solutions [3], [4]. Deep learning algorithms having existed only as theoretical works due to limitations in computational capabilities have actually begun to be implemented in combination with modern computer hardware with computational power [5]. Recently, a deep-learning technique has been applied to QPSK detection [6]. In this paper, we propose a new scheme for the channel estimation utilizing a clustering based unsupervised learning. The clustering based unsupervised learning (CUL) has been originally used for deep learning without reference outputs [7], [8]. Extending its role to the wireless communication areas, the CUL is newly used for extracting reference constellation points from QPSK symbols faded by the multi-path channel in OFDM systems.

In this paper, we propose an algorithm that can estimate a channel with only QPSK data symbols without any pilot signal by applying the clustering technique used in the field of the deep learning (unsupervised learning) to channel estimation. Previously, the possibility that the deep learning can be applied to the symbol detection was studied [9]. However, the conventional work only showed a simple and rough structure for the deep learning detection, and did not provided how to estimate the channel by using the deep learning. On the other hand, the pilotless channel estimation (PCE) scheme proposed in this paper provides detailed channel estimation scheme only using data symbols as input to the clustering algorithm. Through iterative clustering operations, the amplitude and phase of the channel is estimated without assistance of any signaling overheads.

Since the PCE scheme does not consume additional radio resources for the pilot signal, there is an effect of substantially improving the throughput. In addition, due to the characteristics of the clustering technique, the noise reduction effect derived from the averaging operation can be obtained. Thus, it is robust to the noise compared to the conventional pilot based channel estimation technique. The performance of the PCE is compared with the conventional least squares channel estimator (LSE) in

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terms of the mean-squared error (MSE). The PCE estimates the channel using only the data symbols without using the pilot signal at all. Also, to apply PCE to real system, we evaluated the performance of PCE based on resource block (RB) which is a resource allocation unit used in LTE. According to the results of this paper, the PCE always provides better mean square error (MSE) performance than the LSE using pilots, although it does not use the pilot signal at all. The MSE performance of the PCE is affected by the number of data symbols used and the frequency selectivity of the channel. In this paper, we provide simulation results considering various effects.

2. SYSTEM MODEL

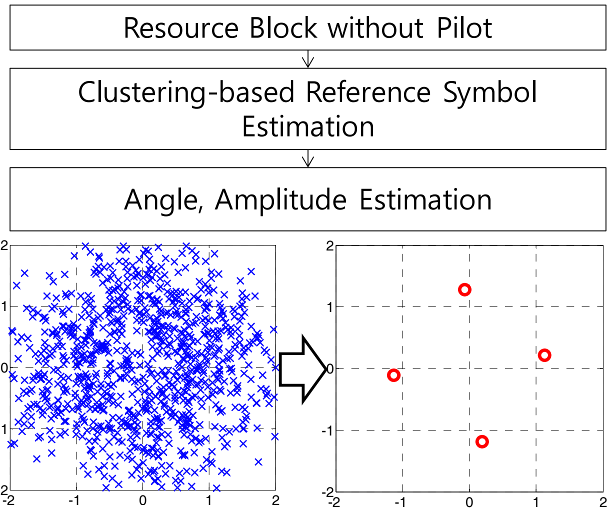

Fig. 1. Channel estimation without pilot signals

A wireless communication system in which data is transmitted in a resource block like the LTE system [10]. In the case of the LTE, 12 subcarriers and 12 OFDM symbols form one resource block except for control signals. However, in this paper, it is assumed that 12 OFDM symbols except two physical downlink control channel (PDCCH) symbols are the minimum resource allocation units allocated to one UE. In general, one resource block includes a plurality of pilot signals, but in this paper, it is assumed that there are resource blocks with no pilot signals.

One resource block is composed of L QPSK symbols. The L QPSK symbols that have passed through the multipath channel are input to the clustering based reference signal estimator. The channel estimator receives L QPSK symbols and outputs four estimated reference symbols as a result. The phase θ and amplitude A of the channel are extracted from the estimated reference symbol. Reconstruct the channel using the extracted phase and amplitude.

Because detailed PCE process has been provided in [6], [12], PCE is briefly summarized. It is emphasized again that the aim of this paper is not to newly propose the PCE but to verify the performance of the PCE in various channel environments. When operating the PCE, any four of the L symbols are first selected. The selected four symbols are referred to as reference symbols. Next, the remaining symbols select one reference symbol whose distance is closest to the selected four reference symbols. Four clusters are formed for each of the first four selected reference symbols. Perform arithmetic averaging on the symbols belonging to each cluster. The new reference symbols are arithmetically averaged over the four clusters. Repeat this process. The phase and amplitude of the reference symbols after the predetermined number of iterations become the phase and amplitude of the channel.

For the performance comparison with the pilotless channel estimation scheme (PCE), a common LTE RB including a common reference signal (CRS) is used. The RB containing CRS is shown in Fig. 2. Fig. 2 shows a PDCCH consisting of two OFDM symbols, and resource elements (RE) for data transmission with the CRS. In the PCE, the CRS is removed in Fig. 2, data symbols are transmitted at the CRS position. And only data symbols transmitted in REs of 12 consecutive subcarriers and 12 consecutive OFDM symbols are used for estimating the channel.

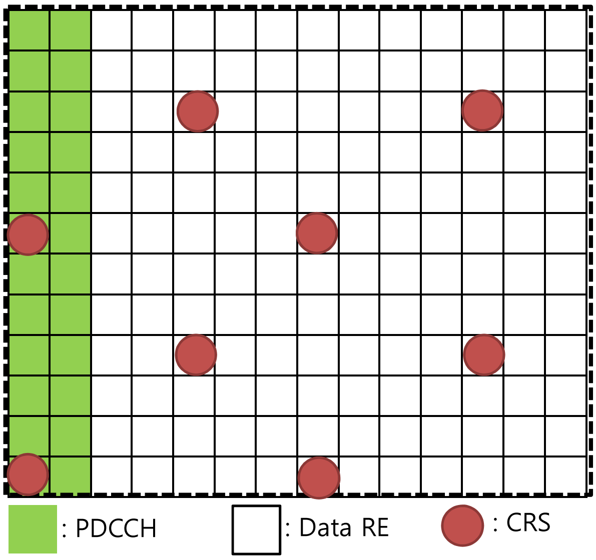

Fig. 2. Resource block including CRS

3. PILOTLESS CHANNEL ESTIMATION

We assume a multipath channel in this wireless communication system using the OFDM transmission. When the maximum path delay of the multipath channel is denoted as $D_{\max}$, the channel in the time domain can be expressed by the following equation.

$$g(t) = \begin{cases} \sum_{n} a_n \delta(t - \tau_n T_s), & n = 0, 1, \ldots, D_{\max} - 1 \\ 0, & n = D_{\max}, \ldots, N - 1 \end{cases} \qquad (1)$$

When using N subcarriers, the frequency domain channel of the equation (1) can be calculated as follows.

$$g_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{D_{\max}-1} a_n e^{-j\frac{2\pi \cdot k \cdot n}{N}}, \qquad (2)$$

where a_n are complex valued-Gaussian random variables with zero mean and unit variance.

In this paper, we basically consider a very low or non-moving environment. Hence, the time index of the channel of subcarrier k is not considered in one RB. In this paper, we present the experimental results based on only one RB with the smallest number of data provided for the PCE clustering operation. Thus, g_k can be expressed as:

$$g_k = A_k e^{\theta_k}, k = 0, 2, ..., N_{PRB} - 1 \qquad (3)$$

N_{PRB} denotes the number of subcarriers included in one RB, and is 12 as shown in the system model. A_k is the amplitude of the k-th subcarrier channel, and θ_k is the phase value of the k-th subcarrier channel.

Generally, in the case of channel estimation using a pilot signal, the frequency difference between adjacent pilot signals is set to be within a coherence bandwidth. For example, in Fig. 2, four pilot signals are transmitted in one RB on the frequency axis. In the case of the PCE, one RB is divided into M regions in the same manner. One region consists of 12 / M adjacent subcarriers. The first subcarrier of the first domain is k = 0. Therefore, when one RB is divided into M regions, the number of symbols provided as inputs to the channel estimation without pilot signal is calculated as follows.

$$L_M = L / M \qquad (4)$$

3.1 PCE in block fading channel

A block fading channel means that the same channel value is applied to all subcarriers in one RB. In this case, it is the same situation that the pilot signal is transmitted in all REs. Although not realistic, many studies assume this environment because this case provides upper bound performance [13]. In case of the PCE, all data symbols of one RB to which the same channel is applied can be utilized as resources for the PCE clustering. It is considered that the best performance of the PCE can be achieved by considering the feature that the accuracy of the PCE is proportional to the amount of input information for the clustering.

When all pilot RB is transmitted, the channel estimation performance of the conventional LSE [13] and PCE is shown in Fig. 3. In the result of Fig. 3, L = 144 and M = 1 are used. For the PCE, the number of clustering repetitions C is 20 times. The performance evaluation with respect to the number of clustering repetitions is provided through the following experimental results of this paper.

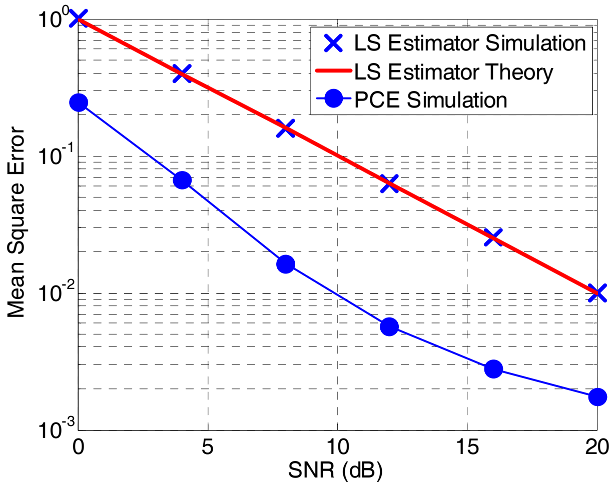

Fig. 3. MSE performance comparison between LSE and PCE

Fig. 3 shows that the performance of the LSE exactly coincides with the 1 / SNR value as shown in previous studies. This result has already been published and is used as reference performance in this paper. Since there is no frequency selectivity because of the block fading channel, the experimental results in Fig. 3 provide the upper bound on the mean square error (MSE) performance. The MSE is measured as follows.

$$MSE = E\left[\left|g_k - \hat{g}_k\right|^2\right] \qquad (5)$$

Next, we evaluate the impact of the number of clustering iterations and region separations on the MSE performance in the same experimental environment. Region separation reduces the number of data symbols which are inputs into the PCE. As defined in (4), the number of data symbols is inversely proportional to the number of region separations.

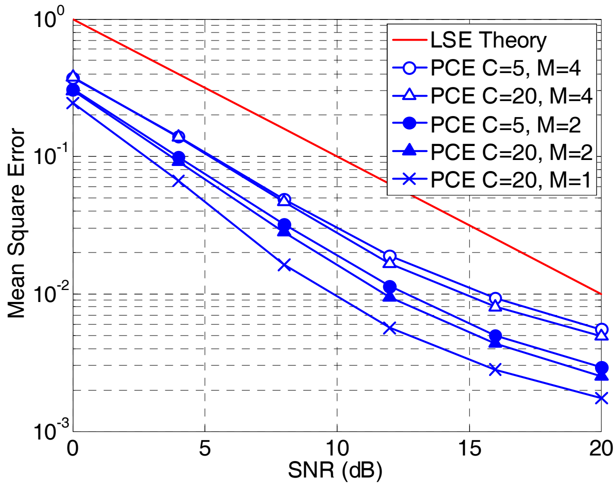

Fig. 4. MSE performance of PCE with various C and M values

In Fig. 4, we need to observe the MSE performance change according to the number of clustering iterations and the number of channel estimation region separation. First, we examine the change of MSE performance according to C

value related to computational complexity. In the result of Fig. 4, C = 5 and C = 20 are used. The information used in clustering is that there are four reference symbols. If M = 1, 4 symbols out of 144 QPSK symbols are arbitrarily selected and reference symbols are detected using a clustering algorithm. Since all the received symbols are repeatedly used for the operation of measuring the distance from the four reference symbols whose values are constantly updated during the operation of the algorithm. Hence, the computational complexity of the PCE detection is larger than that of the general QPSK maximum likelihood (ML) detection. Therefore, the clustering operation should be minimized as long as the specific MSE quality is maintained. Decreasing C from 20 to 5 means that the computational complexity has decreased to exactly 1/4. Even though the computational complexity is greatly reduced, the performance difference at the MSE is very small at low SNR, and it can be confirmed that it is 0.3dB or less even at high SNR. Importantly, the MSE performance of the PCE is better than the LSE by 5dB, regardless of the computation.

Next, we discuss the change of MSE performance of the PCE with increase of M value. The increase of M from 1 to 2 and 4 implies that the amount of data symbols input to the clustering algorithm is reduced by 2 and 4 times, respectively. As mentioned above, the performance of the clustering algorithm is improved when the amount of input data symbols increases. Since the block fading channel is assumed in Fig. 4, estimating the channel by classifying the frequency domain to estimate the same channel value may be meaningless in terms of improving the MSE. However, it is meaningful that MSE performance deterioration observed when operating the PCE with only a smaller amount of data symbols than one RB can be observed. As can be seen in Fig. 4, each half of the amount of data symbols required for clustering results in an MSE performance loss of about 2.5 dB. From these results it is clear that the reduction of the number of data symbols used as input to the clustering algorithm has a greater impact on the channel estimation performance degradation. Therefore, it is confirmed that increasing the number of data symbols and decreasing the number of clustering iterations are effective to reduce PCE performance deterioration.

3.2 PCE in frequency selective fading channel

In case of using 1024 points fast Fourier transform (FFT), power spectral density (PSD) of the channel $g_{k,k=0,1,\ldots,11}$ in an RB composed of 12 subcarriers can be shown in Fig. 5 depending on $D_{\max}$ value. PSD is a widely known means for measuring the magnitude of the frequency response of a signal [11]. The case of $D_{\max}$ = 1 is the block fading channel in which the results of Fig. 3 and 4 are derived. The block fading channel has the same amplitude and phase for all subcarriers. Since the coherence bandwidth is generally defined as 1 / $D_{\max}$, the frequency selectivity of the channel increases as the $D_{\max}$ value increases [11]. As can be seen in Fig. 5, it can be seen that as the $D_{\max}$ increases, the PSD of the channel changes significantly. On the other hand, PSD slightly changes for different subcarriers if the value of $D_{\max}$ is relatively small. It is only an accidental result that the PSD appears to increase monotonically in Fig. 5. The purpose of this figure is to show that the PSD variation is not large when the $D_{\max}$ value is small.

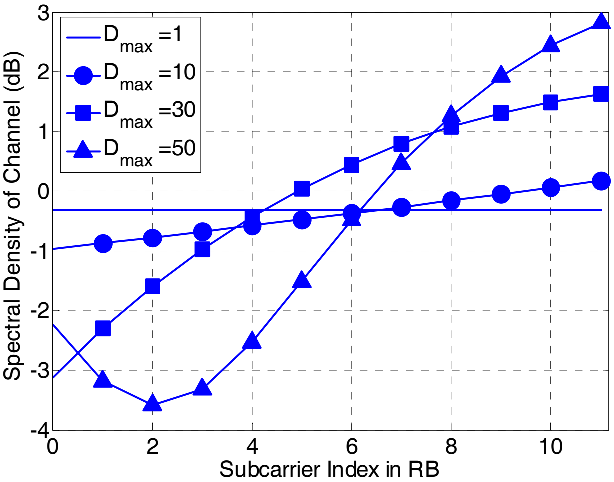

Fig. 5. Spectral density of multi-path channel in an RB

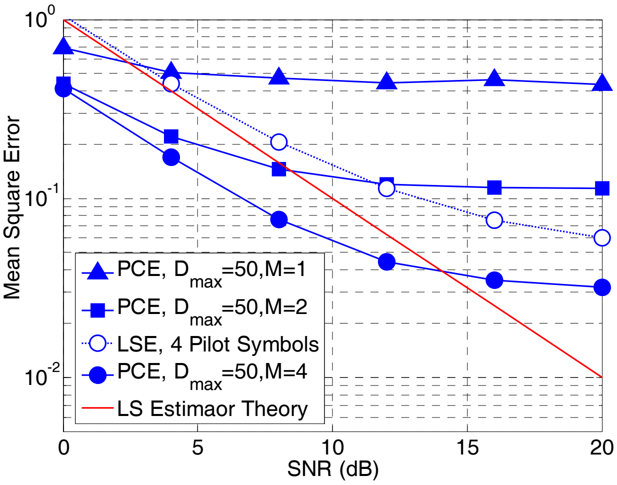

Fig. 6. PCE MSE performance when Dmax=50

In Fig. 4, the PCE with M = 1 shows the best MSE performance. This is because the number of data symbols used for the clustering is the highest. Fig. 4 shows the experimental results in the absence of the frequency selectivity, so the performance depends on the number of data symbols used by the PCE. However, the actual wireless communication channel is different from the block fading channel. The MSE of the PCE and the LSE is shown in Fig. 6 in the case of $D_{\max}$ = 50, where frequency selectivity is severe.

First, the MSE performance of LSE in Fig. 6 is obtained by using the pilot signals transmitted in one RB shown in Fig. 2. However, the MSE of the LSE is obtained only for the symbol and the subcarrier for which pilots signal exist. Therefore, the MSE performance of LSE in this simulation is the same as the theoretical MSE performance. In the simulation for he PCE, a signal block consisting of L_M subcarriers and 12 OFDM symbols is used for the PCE. M signal blocks are sequentially used in the PCE, and M estimated channel values are derived. For example, when the channel $g_{k,k=0,1,\ldots,11}$ and $M=4$, the PCE derives estimated channel values $\hat{g}_{m=0}$, $\hat{g}_{m=1}$, $\hat{g}_{m=2}$,and $\hat{g}_{m=3}$ for $g_{k,k=0,1,2}$, $g_{k,k=3,4,5}$, $g_{k,k=6,7,8}$ and, $g_{k,k=9,10,11}$, respectively. In this simulation considering M signal blocks for the PCE, MSE equation in (5) is changed to as follows:

$$MSE(M) = \frac{1}{N_{PRB}} \sum_{m=0}^{M-1} \sum_{k=0}^{\frac{N_{PRB}}{M}-1} \left| \hat{g}_m - g_{m \cdot \frac{N_{PRB}}{M}+k} \right|^2 \tag{6}$$

The number of data symbols used for the clustering is inversely proportional to M. Therefore, the estimation accuracy of the PCE decreases. However, as M increases, channel estimation corresponding to frequency selectivity gets more precise because the bandwidth of the channel to be estimated by the PCE decreases. In Fig. 6, if one RB is operated in one region without considering frequency selectivity, the PCE provides the lowest performance in terms of the MSE. In this case, the frequency selectivity has a greater impact on the MSE than the number of data symbols used by the PCE.

If M increases from 1 to 2 and 4, MSE performance is improved. The reason why the MSE of the PCE is not improved even though the SNR is increasing is that the number of data symbols used in the PCE is insufficient. When M = 4, the MSE performance of the PCE exceeds the performance of the all pilot LSE when the SNR is below 14dB. Compared with the case of using the same pilot symbol as in Fig. 2, it can be seen that PCE provides excellent performance in terms of MSE versus LSE when M = 4. Because of the frequency selectivity, it should be noted that the performance of all pilot LSEs is deteriorated even when pilot symbols are used.

From the results shown in Fig. from 3 to 6, we have found that the MSE performance of the PCE is determined by the number of data symbols used as input to the clustering algorithm, and by the estimation region separation considering frequency selectivity. Also, the MSE performance of the PCE in all cases is confirmed to be superior to that of the LSE. In numerical results, we investigate the effect of estimation region separation on PCE performance according to frequency selectivity through simulation.

In Fig. 7, $D_{\max}$ = 10 and $D_{\max}$ = 50 represent a situation where the frequency selectivity is not large and relatively severe situations, respectively. When the fluctuation of the channel in the frequency domain is not large, the best MSE performance comes from the estimation region separation number of 2. When the number of estimation region separations increases, the channel estimation performance deteriorates due to a shortage of data symbols used in the PCE. On the other hand, if frequency selectivity is severe, increasing the number of estimation separation regions is effective in improving MSE. Although the number of estimation separation regions increases, the computational complexity for PCE is the same. Therefore, the number of estimation region separations should be determined considering the frequency domain characteristics of the channel.

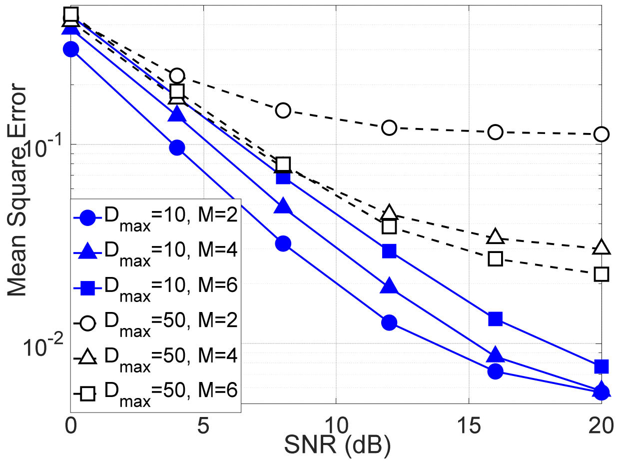

Fig. 7. PCE MSE performance based on selection of M

4. CONCLUSION

In this paper, we propose a pilotless channel estimation scheme (PCE) by introducing the clustering method of unsupervised learning used in our deep learning into channel estimation. The PCE estimates the channel using only the data symbols without using the pilot signal at all. Also, to apply PCE to real system, we evaluated the performance of PCE based on resource block (RB) which is a resource allocation unit used in LTE. According to the results of this paper, the PCE always provides better mean square error (MSE) performance than the LSE using pilots, although it does not use the pilot signal at all. The MSE performance of the PCE is affected by the number of data symbols used and the frequency selectivity of the channel. In this paper, we provide simulation results considering various effects.

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