Precoded OFDMA with Superimposed Pilots

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ABSTRACT

In this paper, we propose the precoder with superimposed pilots for orthogonal frequency-division multiple access (OFDMA) systems in order to enhance the transmission efficiency of the system and reduce peak-to-average power ratio (PAPR) which is the problem in OFDMA uplink. In wireless communication systems, the way to improve transmission efficiency is 1) to reduce bit error rate (BER) or 2) to increase data rate. In the proposed scheme, we design the precoder and superimposed pilots in the transmitter and use them in the receiver for increasing data rate, caused by the saved transmission bandwidth thanks to the superimposed pilots. In addition, we improve BER performance with the help of the frequency diversity gain caused by precoding. Also using superimposed pilots, we enhance the PAPR performance by increasing the average output power of the signal.

Key Words : Superimposed Pilots, Precoder, Transmission Efficiency, PAPR, OFDMA

Ⅰ. Introduction

In conventional orthogonal frequency-division multiple access (OFDMA) systems, pilots (or preamble) are usually used for estimating each user's channel state information. (CSI)[1]. However, it suffers from the reduction of bandwidth efficiency because the system has to use a portion of bandwidth just for transmitting pilots. In case of CDMA systems, the code dedicated for estimating CSI is assigned. By using this code, they try to minimize the reduction of bandwidth caused by pilots. However, in OFDMA systems, there is no code dedicated for estimating CSI. If the channel is highly time-varing, the system requires more pilots not to degrade the channel estimation performance by sacrificing the bandwidth efficiency due to the increased number of pilots. To solve the problem, many schemes in the literature have focused on how to determine the number and position of pilots to find out the optimal tradeoff between the bandwidth efficiency and channel estimation performance (BER performance)[1].

In addition, the peak-to-average power ratio (PAPR) should be carefully considered in OFDMA uplink because the base station (BS) receives several user's signal which results in high fluctuation in the amplitude of the received signal. In order to reduce PAPR, single-carrier frequency domain equalizer (SC-FDE) is widely considered as a solution for OFDMA uplink[2]. Although it is efficient to reduce PAPR, SC-FDE suffers from more inter symbol interference (ISI) than that of the conventional OFDMA systems.

To overcome the above problems (reduced bandwidth efficiency due to pilots / high PAPR in OFDMA uplink), we propose the precoder with superimposed pilots for OFDMA systems. In the proposed scheme, we design the precoder and superimposed pilots in the transmitter and use them in the receiver for increasing the data rate caused by the saved transmission bandwidth thanks to the superimposed pilots. In addition, we improve the BER performance with the help of the frequency diversity gain due to precoding[3].

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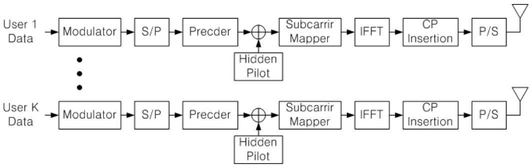
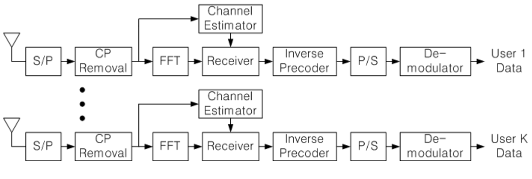
Also using superimposed pilots, we enhance the PAPR performance by increasing the average output power of the signal.

Ⅱ. System Description

Figure 1 shows the overall block diagram of the proposed scheme. In the transmitter, each user's data is modulated, serial-to-parallel converted, and injected to the precoder. Then, superimposed pilots are included to each user and the signal is transmitted based on the conventional OFDMA scheme. In the receiver end, after removing CP, each user's CSI is estimated by using the time-domain received signal and superimposed pilots. After that, each user's modulated symbols are detected by passing through the receiver filter and each user's data is decoded after the inverse precoding.



(a) Transmitter



(b) Receiver

Fig. 1. The overall block diagram of the proposed scheme

2.1 Transmitting Signal

In the transmitter, the i-th input block $s_k(i)$ of size $M\times 1$ of user *k,* consisting of *M* modulated symbols such as *M*-ary PSK or QAM, is first passed through an $N\times M$ precoder P_k. Then, $N\times 1$ block of the superimposed pilot t_k is added to the precoded symbol block. After generating each user's transmitting signal, all user's signals are combined and IFFT operation is performed to get

$$u(i)=\sum_{k=1}^{K}u_k(i) \tag{1}$$

$$u_k(i)=F^H\Psi_k(P_k s_k(i)+t_k)=A_k s_k(i)+b_k \tag{2}$$

where $u_k(i)$ is user k's transmit signal; Ψ_k denotes the subcarrier mapper of user k; F means the $N\times N$ FFT matrix. In here, $A_k=F_k^H\Psi_k P_k$ and $b_k=F_k^H\Psi_k t_k$. Before transmission, a cyclic prefix (CP) of length L_{CP} is inserted to obtain

$$u_{CP}(i)=T_{CP}u(i) \tag{3}$$

where $T_{CP}=[I_{CP}^T\ I_N^T]^T$,

where $I_{CP}^T=[0_{L_{CP}\times(N-L_{CP})}\ I_{L_{CP}}]^T$; I_{CP} and $0_{L_{CP}\times(N-L_{CP})}$ represent the identity matrix of size L_{CP} and the $L_{CP}\times(N-L_{CP})$ zero matrix, respectively. Then, $u_{CP}(i)$ is parallel-to-serial (P/S) to $u_{CP}(k)$, digital-to-analog (D/A) converted at a rate f_s and transmitted as $u_{CP}(t)$ through the channel.

2.2 Received Signal

At the receiver, we assume perfect timing and carrier synchronization, and symbol rate f_s. After removing CP, we collect received signal vector of user k' as follows:

$$\begin{aligned} r_{CP,k'}(i)&=H_{k'}u(i)+w(i)\\ &=H_{k'}\left(\sum_{k=1}^{K}u_k(i)\right)+w(i) \end{aligned} \tag{4}$$

where $H_{k'}$ is an $N\times N$ circulant matrix with the first column $[h_{k'}^T,0,\cdots,0]^T$; $h_{k'}=[h_{k'}(0),\cdots,h_{k'}(L)]^T$ is $(L+1)\times 1$ channel vector of user k'; $w(i)$ denotes AWGN with variance σ_w^2. By using (2), Eq. (4) can be represented as follows.

$$\begin{aligned} r_{CP,k'}(i)&=H_{k'}\left(\sum_{k=1}^{K}u_k(i)\right)+w(i)\\ &=H_{k'}\left(\sum_{k=1}^{K}A_k s_k(i)\right)+H_{k'}\left(\sum_{k=1}^{K}b_k\right)+w(i)\\ &=H_{k'}\left(\sum_{k=1}^{K}A_k s_k(i)\right)+\left(\sum_{k=1}^{K}B_k\right)h_{k'}+w(i) \end{aligned} \tag{5}$$

where $\boldsymbol{B}_{\boldsymbol{k}}$ is $N \times (L+1)$ circulant matrix with the first column $[\boldsymbol{b}_{\boldsymbol{k}}^T(i), 0, \cdots, 0]^T$; and in deriving (5), we use the commutativity of circular convolution to obtain $\boldsymbol{H}_{\boldsymbol{k}'}\boldsymbol{b}_{\boldsymbol{k}} = \boldsymbol{B}_{\boldsymbol{k}}\boldsymbol{h}_{\boldsymbol{k}'}$ for all k.

2.3 Channel Estimation

In the proposed scheme, channel estimation is performed in time domain with the help of superimposed pilots. We already know that the transmitted signal contains all the user's data signal and superimposed pilots. Therefore, in estimating channel using superimposed pilots, data symbol of user k' and other user's transmit signal is considered as interference. In order to mitigate interference, we perform pre-processing with known superimposed pilots as shown below.

$$\begin{aligned} \boldsymbol{y}_{\boldsymbol{k}'}(i) &= \boldsymbol{B}_{\boldsymbol{k}'}^{\boldsymbol{H}} \boldsymbol{r}_{\boldsymbol{CP},\boldsymbol{k}'}(i) \\ &= \underbrace{\boldsymbol{B}_{\boldsymbol{k}'}^{\boldsymbol{H}} \boldsymbol{H}_{\boldsymbol{k}'} \left(\sum_{k=1}^{K} \boldsymbol{A}_{\boldsymbol{k}} \boldsymbol{s}_{\boldsymbol{k}}(i) \right)}_{= \boldsymbol{v}_{\boldsymbol{k}'}(i)} + \boldsymbol{B}_{\boldsymbol{k}'} \left(\sum_{k=1}^{K} \boldsymbol{B}_{\boldsymbol{k}} \right) \boldsymbol{h}_{\boldsymbol{k}'} + \boldsymbol{B}_{\boldsymbol{k}'} \boldsymbol{w}(i) \end{aligned} \quad (6)$$

From (6), we notice that interference, $v_{k'}(i)$, should be 0 as close as possible in order to suppress interference and estimate channel. If we let $\boldsymbol{A}_{k,i}$ be a column-wise circulant matrix with the i-th column of $\boldsymbol{A}_k$ as the first column, which we denote as $\boldsymbol{a}_{k,i}$, we can represent $\boldsymbol{H}_{k'}\boldsymbol{A}_k$ for all k as follows.

$$\begin{aligned} \boldsymbol{H}_{k'}\boldsymbol{A}_k &= [\boldsymbol{H}_{k'}\boldsymbol{a}_{k,1}, \cdots, \boldsymbol{H}_{k'}\boldsymbol{a}_{k,M}] \\ &= [\boldsymbol{A}_{k,1}\boldsymbol{h}_{k'}, \cdots, \boldsymbol{A}_{k,M}\boldsymbol{h}_{k'}] \end{aligned} \quad (7)$$

Here, we use the commutativity of circular convolution $\boldsymbol{H}_{k'}\boldsymbol{a}_{k,i} = \boldsymbol{A}_{k,i}\boldsymbol{h}_{k'}$ for all k and i since $\boldsymbol{H}_{k'}$ is circulant. Based on this, we have that $v_{k'}(i) \to 0$ if $\boldsymbol{B}_{k'}^H \boldsymbol{A}_{k,i} \boldsymbol{h}_{k'} \to 0$, $i \in [1, M]$ and $k \in [1, K]$. Because the latter is to hold true for any $\boldsymbol{h}_{k'}$, we arrive at the following design criterion of precoder and superimposed pilots.

C1. $\boldsymbol{B}_{k'}^H \boldsymbol{A}_{k,i} \to 0, \ \forall i \in [1, M]$ and $k \in [1, K]$ for any channel of order L

In addition, we find that interference caused by other user's superimposed pilots should also be mitigated except for the desired user's superimposed pilots in order for more accurate channel estimation. As a consequence, we can also establish the following design criterion.

C2. $\boldsymbol{B}_{k'}^H \boldsymbol{B}_k \to \begin{cases} c\boldsymbol{I}, & k' = k \, (c : \mathrm{constant}) \\ 0, & k' \neq k \end{cases}$

Keeping in mind the above two criteria, we estimate the channel of each user by using Minimum Mean Square Error (MMSE) approach from (6) as shown below.

$$\boldsymbol{h}_{k'} = \boldsymbol{R}_{h_k} \boldsymbol{B}_{k'}^H \boldsymbol{B}_{k'} \left(\boldsymbol{B}_{k'}^H \boldsymbol{B}_{k'} \boldsymbol{R}_{h_k} \boldsymbol{B}_{k'}^H \boldsymbol{B}_{k'} + \boldsymbol{R}_z \right)^{-1} \boldsymbol{y}_{k'}(i) \quad (8)$$

where $\boldsymbol{R}_z = E\{\boldsymbol{z}(i)\boldsymbol{z}^H(i)\} = \boldsymbol{R}_v + \sigma_w^2 \boldsymbol{B}_{k'}^H \boldsymbol{B}_{k'}$ and $\boldsymbol{R}_v = E\{\boldsymbol{v}(i)\boldsymbol{v}^H(i)\}$.

2.4 Receiver Design

At the receiver, the received signal is injected to FFT block and performs subcarrier de-mapping process per each user to obtain

$$\begin{aligned} \widehat{\boldsymbol{x}_{k'}}(i) &= \boldsymbol{\Psi}_{\boldsymbol{k}'}^{\boldsymbol{H}} \boldsymbol{F} \boldsymbol{r}_{\boldsymbol{CP},\boldsymbol{k}'}(i) \\ &= \sum_{k=1}^{K} \boldsymbol{\Psi}_{\boldsymbol{k}'}^{\boldsymbol{H}} \boldsymbol{F} \boldsymbol{H}_{\boldsymbol{k}'} \boldsymbol{F}^{\boldsymbol{H}} \boldsymbol{\Psi}_{\boldsymbol{k}} (\boldsymbol{P}_{\boldsymbol{k}} \boldsymbol{s}_{\boldsymbol{k}}(i) + \boldsymbol{t}_{\boldsymbol{k}}) + \boldsymbol{\Psi}_{\boldsymbol{k}'}^{\boldsymbol{H}} \boldsymbol{F} \boldsymbol{w}(i) \\ &= \boldsymbol{D}_{\boldsymbol{H},\boldsymbol{k}} \boldsymbol{P}_{\boldsymbol{k}} \boldsymbol{s}_{\boldsymbol{k}}(i) + \boldsymbol{D}_{\boldsymbol{H},\boldsymbol{k}} \boldsymbol{t}_{\boldsymbol{k}} + \boldsymbol{w}_{\boldsymbol{F},\boldsymbol{k}}(i) \end{aligned} \quad (9)$$

where $\boldsymbol{D}_{H,k}$ means the diagonalized frequency response of the user k''s channel. In deriving (9), we used the property of subcarrier mapper and de-mapper as follows.

$$\boldsymbol{\Psi}_{k'}^H \boldsymbol{\Psi}_k = \begin{cases} \boldsymbol{I}_M, & k' = k \\ 0, & \mathrm{otherwise} \end{cases} \quad (10)$$

From (9), we notice that the superimposed pilots used for channel estimation is no more utilized in detecting data symbols. Therefore, we eliminate the superimposed pilots from the received signal by using the estimated channel in order to minimize the interference caused by superimposed pilots during data detection to get

$$\boldsymbol{x}_k(i) = \boldsymbol{D}_{H,k}\boldsymbol{P}_k\boldsymbol{s}_k(i) + \underbrace{(\boldsymbol{D}_{H,k} - \hat{\boldsymbol{D}}_{H,k})}_{= \widetilde{\boldsymbol{D}}_{H,k}}\boldsymbol{t}_k + \boldsymbol{w}_{F,k}(i) \tag{11}$$

where $\hat{\boldsymbol{D}}_{H,k}$ is the estimated diagonalized frequency response of the user k''s channel.

As a receiver, we use MMSE approach. Let us define $\boldsymbol{G}_k(i)$ as a coefficient matrix of MMSE receiver of the k-th user. Then, the output of the MMSE receiver can be described as

$$\hat{\boldsymbol{s}}_k(i) = \boldsymbol{G}_k(i)\boldsymbol{x}_k(i) \tag{12}$$

$$\begin{aligned}\boldsymbol{G}_{\boldsymbol{k}}(i) &= \boldsymbol{P}_{\boldsymbol{k}}^{\boldsymbol{H}} \underbrace{\frac{P_s}{M}\widehat{\boldsymbol{D}_{\boldsymbol{H},\boldsymbol{k}}}\left(\frac{P_s}{M}\widehat{\boldsymbol{D}_{\boldsymbol{H},\boldsymbol{k}}}\boldsymbol{P}_{\boldsymbol{k}}\boldsymbol{P}_{\boldsymbol{k}}^{\boldsymbol{H}}\widehat{\boldsymbol{D}_{\boldsymbol{H},\boldsymbol{k}}^{\boldsymbol{H}}} + \boldsymbol{R}_{\eta,\boldsymbol{k}}(i)\right)^{-1}}_{\doteq \boldsymbol{\Lambda}_{\boldsymbol{k}}(i)} \\ &= \boldsymbol{P}_{\boldsymbol{k}}^{\boldsymbol{H}}\boldsymbol{\Lambda}_{\boldsymbol{k}}(i)\end{aligned} \tag{13}$$

where P_s means the transmit power per each user and

$$\boldsymbol{R}_{\eta,k}(i) = E\{\boldsymbol{\eta}_k(i)\boldsymbol{\eta}_k^{H(i)}\}$$
$$\boldsymbol{\eta}_k(i) = \widetilde{\boldsymbol{D}}_{H,k}(i)(\boldsymbol{P}_k\boldsymbol{s}_k(i) + \boldsymbol{t}_k) + \boldsymbol{w}_{F,k}(i)$$

(14)

Let us define $\tilde{\boldsymbol{s}}_k(i) = \boldsymbol{s}_k(i) - \hat{\boldsymbol{s}}_k(i)$ as the symbol estimation error of user k. Then, the corresponding symbol error covariance matrix $\boldsymbol{R}_{\tilde{s},k}(i)$ are given as

$$\begin{aligned}\boldsymbol{R}_{\tilde{s},k}(i) &= E\{\tilde{\boldsymbol{s}}_k(i)\tilde{\boldsymbol{s}}_k^H(i)\} \\ &= \left(\frac{M}{P_s}\boldsymbol{I}_M + \boldsymbol{P}_k^H\hat{\boldsymbol{D}}_{H,k}^H\boldsymbol{R}_\eta^{-1}\hat{\boldsymbol{D}}_{H,k}\boldsymbol{P}_k\right)^{-1}.\end{aligned} \tag{15}$$

From (14) and (15), we know that $\boldsymbol{R}_{\tilde{s},k}(i)$ is diagonalized and the error variance of all the transmitted symbol of user k are same if $\boldsymbol{P}_k\boldsymbol{P}_k^H = M/N\boldsymbol{I}_N$ and $\boldsymbol{t}_k\boldsymbol{t}_k^H = P_t/N\boldsymbol{I}_N$ are guaranteed. If the precoder and superimposed pilots satisfy the above two constraints, they can support an averaging effect of symbol estimation errors in frequency domain and spread user k's symbol power over the transmission bandwidth occupied by user k. Therefore, it provides a high degree of frequency diversity. In addition, note that the precoder should satisfy orthogonality property ($\boldsymbol{P}_k^H\boldsymbol{P}_k = \boldsymbol{I}_M$) in order to re-combine symbol power of user k spreaded over the user k's bandwidth without causing interferences to other symbols.

From the above, we can establish the following criterion of designing precoder and superimposed pilots.

C3. $\boldsymbol{P}_{\boldsymbol{k}}\boldsymbol{P}_{\boldsymbol{k}}^{\boldsymbol{H}} \rightarrow \frac{M}{N}\boldsymbol{I}_{\boldsymbol{N}},\ \boldsymbol{P}_k^H\boldsymbol{P}_k \rightarrow \boldsymbol{I}_M,\ \boldsymbol{t}_k\boldsymbol{t}_k^H \rightarrow \frac{P_t}{N}\boldsymbol{I}_N$

2.5 Peak-to-Average Power Ratio (PAPR)

In this section, we think of the PAPR problem. PAPR is defined as the ratio between the peak power and the average power of the signal as follows.

$$PAPR = \frac{\max_k\{|\boldsymbol{u}(u)|^2\}}{E\{|\boldsymbol{u}(i)|^2\}} \tag{16}$$

Therefore, reducing PAPR is to decrease the peak power$\left(\max_k\{|\boldsymbol{u}(u)|^2\}\right)$ or increase the average power $\left(E\{|\boldsymbol{u}(i)|^2\}\right)$. In the PAPR reduction schemes reported in the literature, attention has been decreasing the peak power. However, we argue that since the power amplifier(PA) in the communication system is peak power limited, and its efficiency is determinated by the average output power, it makes sense to investigate PAPR reduction methods that aim at increasing the average power while keeping the peak power fixed. In the proposed scheme, we can increase the average power by using the power allocated to superimposed pilots. Therefore, we insist that PAPR can be reduced by means of superimposed pilots. Through simulation, we verify the PAPR reduction capability of superimposed pilots.

Ⅲ. Design of Precoder and Superimposed Pilots

In this section, we design the precoder and superimposed pilots satisfying design criteria based on poly-phase sequences which have near-optimal auto- and cross-correlation properties [4].

[Step 1] Make p-ary m-sequence of length $N_l = p^r - 1$, where p and r (>1) denote the prime number and an integer, respectively.

[Step 2] Generate N_l numbers of poly-phase sequence set C as follows.

$$C = [c_0, c_1, \cdots, c_{N_l-1}]$$

$$c_i = [c_i(0), c_i(1), \cdots, c_i(N_l-1)]$$

$$c_i(n) = \frac{1}{\sqrt{N_l}} exp[j2\pi(s(n)/p + i \cdot n/N_l)]$$

[Step 3] Design the precoder and superimposed pilots using poly-phase sequences as shown below.

$$P_k = \left[c_0, c_1, \cdots, c_{N_l-2}\right] \Leftrightarrow A_k{}' = \Psi_k P_k$$

$$t_k = c_{N_l-1} \Leftrightarrow t_k{}' = \Psi_k t_k \quad (k = 1, \cdots, K)$$

Now, we validate whether the designed precoder and superimposed pilots agree with the design criteria needed for channel estimation and symbol detection by providing a design example. Table 1 shows an example of design parameters.

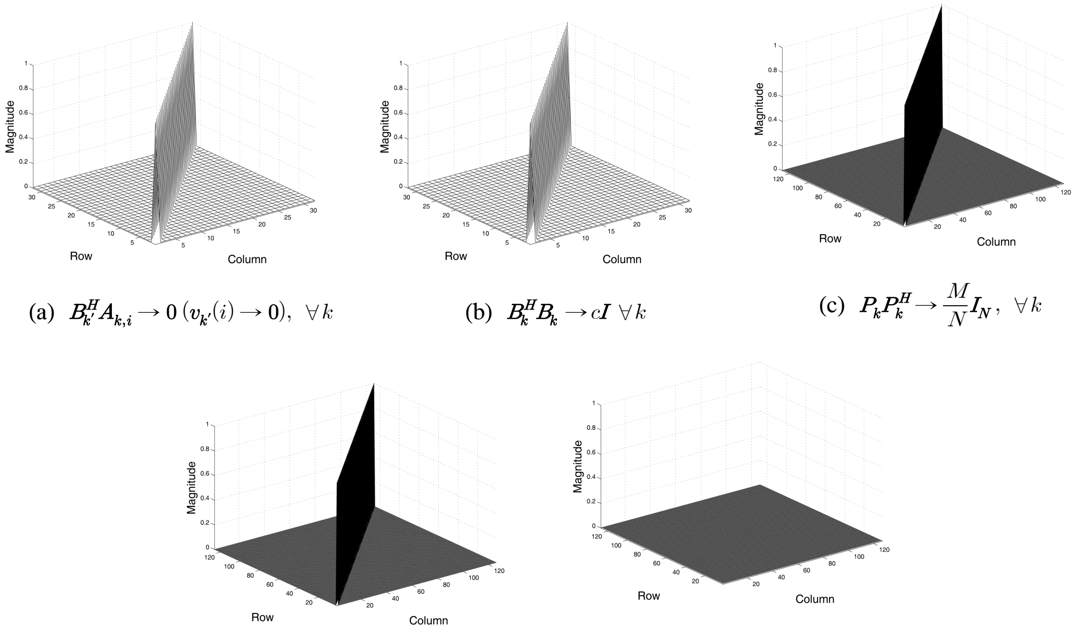
With this example, we confirm the suitability of designed precoder and superimposed pilots. Figure 2 shows the graphical confirmation of design criteria. From the figure, we can say that the proposed precoder with superimposed pilots suitably satisfy the design criteria needed for channel estimation and symbol detection.

Table. 1. Parameters for designing precoder and superimposed pilots.

Parameter	p	r	N_l	L	K
Value	2	7	127	11	2

Ⅳ. Simulation Results

In this section, we study he performance of the proposed scheme and compare it with other schemes. As mentioned before, the purpose of the proposed scheme is to increase data rate, reduce the BER and PAPR of OFDMA systems with the help of precoder and superimposed pilots.



(a) $B_{k'}^H A_{k,i} \to 0\ (v_{k'}(i) \to 0),\ \forall k$

(b) $B_k^H B_k \to cI\ \forall k$

(c) $P_k P_k^H \to \frac{M}{N} I_N,\ \forall k$

(d) $P_k^H P_k \to I_M,\ \forall k$

(e) $t_k t_k^H \to \frac{P_t}{N} I_N,\ \forall k$

Fig. 2 The graphical confirmation of design criteria of the proposed precoder with superimposed pilots

Therefore, we use the Normailzed Transmission Efficiency (NTE) which is averaged to the number of users and PAPR as a performance measure. NTE is defined as

$$NTE = \frac{1}{N_{user}} \sum_{k=1}^{N_{user}} (1 - BER_k) \cdot \frac{N_{data}}{N_{tot}} \tag{17}$$

where BER_k dentoes the bit error rate of user k; N_{user}, N_{data} and N_{tot} represent the number of user, number of data subcarrier per user, and number of total subcarrier per user, respectively.

In addition, we also utilize conventional OFDMA systems which use pilot subcarriers for channel estimation[5]. Table 2 shows the system parameters used for simulations.

In the case of the proposed scheme, pilots are contained in all the data subcarriers. Therefore, the amounts of pilots are controlled by the power allocated to superimposed pilots while the number of pilot subcarriers are controlled in the conventional scheme.

The total transmit power of the proposed scheme is same with the conventional one. As a channel model, i.i.d 12-tap exponential decay channel is used for performance evaluation and the channel is set to time-varying for each OFDM symbol.

Table. 2. System parameters

Parameter	Proposed	Conventional	
		Case I	Case II
Modulation	QPSK		
No. data symbol per user	126	127	
No. data subcarrier per user	127	115	95
No. pilot subcarrier per user	128	12	32
No. null subcarrier per user	1		
No. used subcarrier per user	128		
No. of user	2		
Channel	I.i.d 12-tap Exp.		
CP length	12		

Figure 3 and 4 show the channel estimation performance and NTE of the proposed and conventional system, respectively. The total transmit power is set to 1. In the case of proposed scheme, the power allocated to superimposed pilots are 50% and 70% of total transmit power (P_t= 0.5, 0.7). The number of pilot subcarriers is set to 12 and 32 in the case of conventional scheme (N_p= 12, 32).

As shown in the figure, the channel estimation performance of the proposed scheme is better than that of the conventional one in low SNR region. However, we notice that the error floor is occurred in high SNR (more than 25dB) because

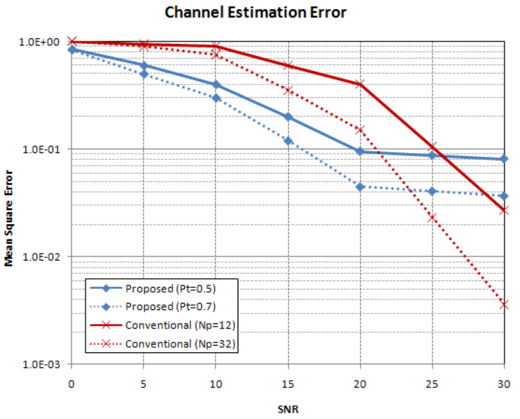


Fig. 3. The comparison of the channel estimation performance

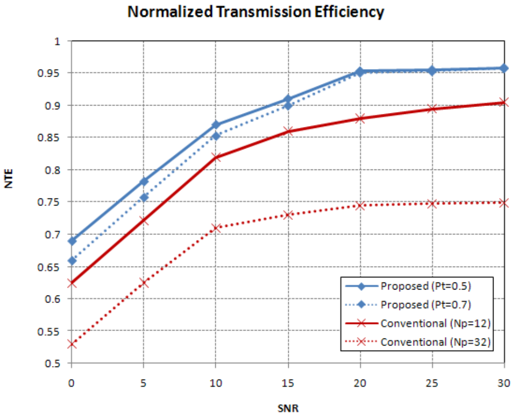


Fig. 4. The comparison of the transmission efficiency

we do not eliminate the interference caused by data symbol perfectly. Nevertheless, we can see that the NTE of the proposed scheme is always higher than that of the conventional one. In addition, we can also notice that the transmission efficiency of P_t=0.5 is better than that of P_t=0.7 even though the channel estimation performance is worse. This is because the BER performance is getting poor if the power loaded to superimposed pilots is larger than the power loaded to data symbol within the fixed total transmitted power.

Next, we investige the improved BER performance of the proposed scheme with the help of the frequency diversity gain caused by precoding. As shown in figure 5, the performance of the proposed scheme is much better if the cahnnel is known. This is because the proposed precoder can support an averaging effect for noise in the frequency domain, can spread each symbol over the enire transmission bandwidth, and can achieve a high degree of frequency diversity through precoding. Even in the case of the unknown channel, the proposed scheme shows better performance than the conventional scheme.

Finally, we compare the PAPR of proposed and conventional systems. As shown in figure 6, the PAPR of the proposed scheme is lower than that of the conventional one. Especially, as the power allocated to the superimposed pilot is getting more, the PAPR performance is getting better because the average output power is increasing.

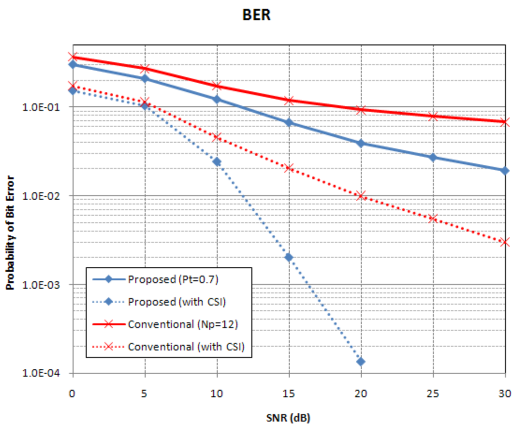


Fig. 5. The comparison of BER performance

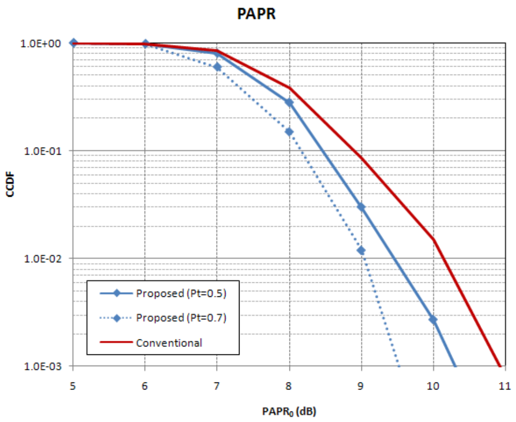


Fig. 6. The comparison of the PAPR performance

Ⅳ. Conclusions

In this paper, we proposed the precoder with superimposed pilots for OFDMA systems in order to enhance the transmission efficiency of the system and reduce PAPR which is the problem in OFDMA uplink. Under the derived design criteria, we designed precoder and superimposed pilots based on poly-phase sequences. Through simulations, we investigated the characteristics of the proposed scheme and showed its improved NTE and PAPR performances over the conventional OFDMA scheme.

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