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Code Orthogonalizing Filter Based Adaptive Array Antenna Using Common Correlation Matrix of Time Domain Signals for Multicarrier DS/CDMA Systems

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SUMMARY In this paper, we propose the code orthogonalizing filter (COF) based adaptive array antenna using sample matrix inversion with common correlation matrix (CCM-SMI) of time domain signals for multicarrier DS/CDMA systems. The conventional array antenna system calculates the weight using the correlation matrix of individual subcarrier's signals. On the other hand, our proposed system calculates the weight using the correlation matrix of time domain signals before FFT operation, so it can reduce the calculation time and the complexity of weight calculation than the conventional scheme, to maintain the system performance. Moreover, we consider the code orthogonalizing filter to reduce the demerit of adaptive array antenna system using sample matrix inversion algorithm with common correlation matrix that requires heavy computational complexity while the signal environment frequently changes. Our proposed system obtains more accurate channel response vector using COF than that of the conventional CCM-SMI based on the matched filter, without increasing the matrix size. The performance is evaluated in term of bit error probability. From the analysis and simulation results, it is shown that our proposed scheme achieves better BER performance than that of the conventional system.

key words: *MC-DS/CDMA, code orthogonalizing filter (COF), sample matrix inversion (SMI), adaptive array antenna, common correlation matrix*

1. Introduction

Mobile radio communication systems are increasingly required to provide a variety of high-quality multimedia services to mobile users. To meet these demands, modern mobile radio transceiver systems must be able to support high capacity, variable bit rate information transmission and high bandwidth efficiency. In the mobile radio environment, signals are usually impaired by fading and multi-path delay phenomenon. In such channels, severe fading of the signal amplitude and inter-symbol-interference (ISI) due to the frequency selectivity of the channel cause an unacceptable degradation of the error performance. Multicarrier modulation is an efficient scheme to mitigate the effect of multi-path channel, since it eliminates ISI by inserting guard interval longer than the delay spread of the channel [1], [2]. Therefore, multicarrier modulation is generally known as an effective technique for high data rate services. The most widely used multicarrier modulation schemes in wireless communication are a spectrally non-overlapped multicarrier modulation for CDMA-2000 and an orthogonal frequency-division multiplexing (OFDM) for broadcasting and mobile communication which use rectangular transmission pulses in each subchannel. Here, we focus on the OFDM-DS/CDMA system, since OFDM is spectrally more efficient. One of the approaches to improve a DS/CDMA system performance is the use of the spatial filtering at a base station with adaptive antenna array [3], [4]. Adaptive array antenna is widely accepted, since it provides many promising features such as high capacity, high spectrum efficiency, and more degrees of freedom to adjust cell coverage characteristics, leading to more efficient use of the radio resources. The promising techniques such as multicarrier modulation scheme and adaptive array antenna can be combined to achieve more improved system performance compared with the conventional system [5]–[7].

Even though the combination of multicarrier modulation and adaptive array antenna has various merit, this combination system has a heavy complexity of weight calculation using various algorithms. There have been many adaptive algorithms for weight updating like LMS (least mean square), RLS (recursive least square), and SMI (sample matrix inversion). The LMS algorithm has been widely used for weight calculation algorithm of an adaptive processor in an antenna array, but it causes signal acquisition and tracking problems due to its slow convergence in a multipath fading channel [8], [9]. The RLS algorithm is known to achieve faster convergence than LMS algorithm, but it is more computationally complex than LMS. The SMI has been known as an approach with high convergence rate. Using the information of the output signal of the matched filter and the reference signal, the optimum weight could be computed by directly calculating the inversion of the covariance matrix [10], [11]. Although it has a rapid convergence property, there are systems in which the reference signal cannot be known at all times while the signal environment frequently changes, the inversion of a large matrix requires heavy compu-

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tational complexity. If we could reduce the calculation matrix size for obtaining the covariance matrix, the SMI algorithm is the simplest algorithm to achieve good convergence property.

Recently, many schemes have been proposed to reduce the complexity of weight calculation to maintain the system performance. Wong proposes the novel scheme to reduce the complexity of weight calculation for adaptive array antenna using coherent bandwidth grouping method for OFDM [12]. But this system performance is degraded as the subcarrier group size is increased, since the same weight is used in several carrier group. Watanabe and Yonezawa propose a combination scheme of two different adaptive algorithms for simplicity of weight calculation and improving the system performance [13], [14], and Vook proposes the modified SMI for improving the tracking performance while maintaining the weight calculation complexity [15]. But these systems are complex as before like conventional system. Park and Hara propose an adaptive array antenna algorithm to reduce the complexity and obtain an optimum weight fastly with common correlation matrix for DS/CDMA system [16], [17]. When we adopt this scheme that uses the SMI algorithm with common correlation matrix (CCM-SMI), to a multicarrier DS/CDMA systems, the complexity of weight calculation of a multicarrier DS/CDMA systems also increases, since the common correlation matrix is calculated from the frequency domain signals after FFT operation. It means that the weights are calculated by using the individual subcarrier signal's correlation matrix, so it is necessary to calculate the inversion of matrix of subcarrier to obtain the correlation matrix. Moreover, when the number of users and multipath increases, the performance of array antenna with common correlation matrix is degraded seriously because of increase of the multiple access interference (MAI). Park considers the large number of pilot signals to solve above-mentioned problem [16]. With increasing the pilot signals, it is shown good BER performance is obtained where its transmission rate is also degraded, so there is no meaning as mobile communication system.

Code orthogonalizing filter (COF), which is one of the possible way to increase the system performance in multipath time variant channel, controls its tap weight vector of spreading code sequences so as to have the orthogonality against all the interference signals [18], [19]. However, in the COF, when a new user is added, adjustment of coefficients of spreading code sequences and its training for convergence are necessary again. Since our proposed system also considers the spatial filtering at a base station with adaptive antenna array, so our proposed system can obtain fast adjustment and convergence of coefficients, and good channel response vector without increasing the number of pilot signals. Therefore, the combination of COF and adaptive array antenna reduces their demerits and obtains synergism of the COF and array antenna.

In this paper, we propose the code orthogonalizing filter based adaptive array antenna with common correlation matrix of time domain signals for Multicarrier DS/CDMA Systems. Since time and frequency domain signals are basically same signals, so we can calculate the correlation matrix using the time domain signals. In this case, we can more easily calculate the optimum correlation matrix with the inversion of time domain signals than that of frequency domain signals that be transformed from the same time domain signals by FFT operation. Moreover, we can obtain optimum correlation matrix using the time domain signal with same size of the frequency domain signal for obtaining optimum correlation matrix of individual subcarreir, so we can obtain the optimum weight with small matrix calculation about No. of subcarriers of frequency domain calculation over one. And our proposed system obtains more accurate channel response vector using the COF than that of the conventional CCM-SMI based on the matched filter, without increasing the matrix size and number of pilot signals. Furthermore, beamforming operation is done more accurately than that of the conventional system with MF, so our proposed system can obtain better system performance than that of the conventional system. This paper is organized as follows. The conventional and proposed systems are described in Sects. 2 and 3. In Sect. 4, we analyze the performance of adaptive array antenna with common correlation matrix. In Sect. 5, we show the simulation results. Finally, the conclusion is given in Sect. 6.

2. Conventional Array Antenna Using CCM-SMI Algorithm

The block diagram of the conventional array antenna system using CCM-SMI algorithm is shown in Fig. 1. In the conventional system, the received signals at the N antenna from M users are first transformed by FFT operation. After FFT, the signals are fed into the m-th MC-DS/CDMA receiver module which consists of S

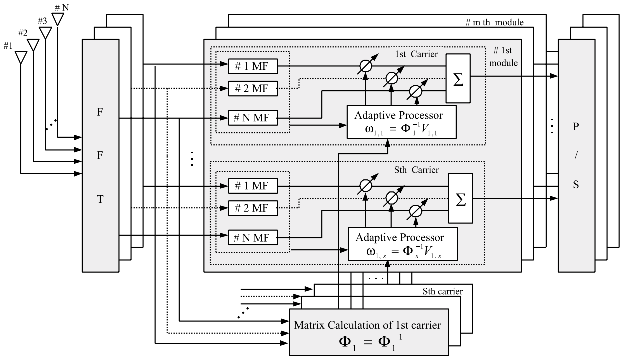

Fig. 1 Conventional adaptive array antenna with common correlation matrix of the frequency domain signal after FFT operation for MC-DS/CDMA system.

matched filter for S subcarriers and are despread by the spreading code. The despreaded subcarrier signals are beamformed by the adaptive processor. The weights are chosen to minimize the mean square error (MMSE) between the beamformer output and the reference signal. The weight updating algorithms originate from the adaptive filter theory [20]. The conventional sample matrix inversion with common correlation matrix (CCM-SMI) algorithm calculates the weight of s-th carrier for m-th user using the output signal of the FFT operation block and the reference signal, the optimum weight could be computed by directly calculating the inversion of the covariance matrix.

$$\Phi_s^{-1} = X_s X_s^{\dagger} \tag{1}$$

$$V_{m,s} = \overline{X}_{m,s} R_{m,s}^{*} \tag{2}$$

$$\omega_{m,s} = \Phi_s^{-1} V_{m,s} \tag{3}$$

where X_s is the FFT transformed s-th subcarrier's signal, $\overline{X}_{m,s}$ is the despreaded signal by the matched filter for m-th user's s-th carrier, $R_{m,s}$ is the received pilot signal for m-th user's s-th carrier, Φ_s^{-1} is the covariance matrix using the common correlation matrix of frequency domain signal after FFT operation for s-th carrier, $V_{m,s}$ is the channel response vector for m-th user's s-th carrier, and the superscript $\dagger$ and $*$ are transpose and conjugate operator, respectively. From Eq. (3), the data $Y_{m,s}$ for m-th user's s-th carrier can be represented by

$$Y_{m,s} = \omega_{m,n} \overline{X}_{m,s}. \tag{4}$$

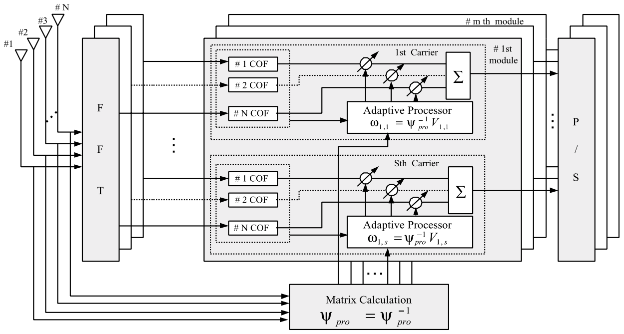

Fig. 2 Proposed adaptive array antenna with common correlation matrix of the time domain signal before FFT operation for MC-DS/CDMA system.

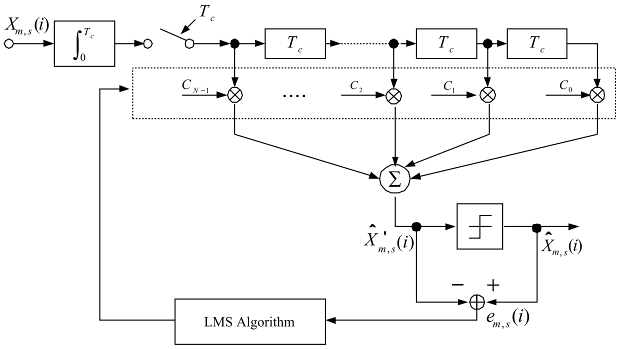

Fig. 3 Block diagram of code orthogonalizing filter.

3. Proposed System

In the conventional system, the system performance depends on the channel response vector. However, the conventional system is based on the matched filter (MF). So we consider the code orthogonaling filter (COF) to improve the accuracy of calculation for the channel response vector. Moreover, if we could calculate the covariance matrix from the time domain signals instead of the frequency domain signals, we can reduce the complexity of the weight calculation. Since our proposed system calculates the covariance matrix using the common correlation matrix of time domain signal before FFT operation, the weight can be used for various users and subcarriers with one time calculation from the time domain signals and the complexity of the covariance matrix calculation can be reduced without any degradation of the system performance. The block diagram of the proposed system is shown in Fig. 2. In the proposed system, the covariance matrix is calculated by using common correlation matrix of time domain signals received at the N antenna before FFT operation.

$$\Psi_{pro}^{-1} = X_{IFFT} X_{IFFT}^{\dagger} \tag{5}$$

where $X_{IFFT} = \sum_{j=1}^{N} X_{j,IFFT}$ is the received time domain signal's vector form at N array antenna, and Ψ_{pro}^{-1} is the covariance matrix using the common correlation matrix of time domain signal before FFT operation. The received signals at the N antenna from M users are transformed by FFT operation. After FFT, the signals are fed into the m-th MC-DS/CDMA receiver module which consists of S code orthogonalizing filters for S subcarriers and are despread by the spreading code. Figure 3 shows the block diagram of code orthogonalizing filter. Code orthogonalizing filter adaptively controls the tap coefficents of spreading sequences to orthogonalize to receieved sequences. So we can despread the received data accurately. Since the channel response vector is calculated from the despreaded data, we can have more accurate channel response vector. From this reason, we can reduce the problem of conventional SMI and CCM-SMI that the performance is degraded in multiuser case with time variant channel. Our proposed weight could be computed by Eq. (5).

$$\overline{V}_{m,s} = \widehat{X}_{m,s} R_{m,s}^{*} \tag{6}$$

$$\omega_{m,s,pro} = \Psi_{pro}^{-1} \overline{V}_{m,s} \tag{7}$$

where $\widehat{X}_{m,s}$ is the despreaded signal by COF for m-th user's s-th carrier, $R_{m,s}$ is the received pilot signal for m-th user's s-th carrier, $\overline{V}_{m,s}$ is the channel response vector for m-th user's s-th carrier, respectively. From Eq. (7), the detected data $Y_{m,s}$ for m-th user's s-th carrier can be represented by

$$Y_{m,s,pro} = \omega_{m,s,pro}\widehat{X}_{m,s}. \tag{8}$$

Since our proposed covariance matrix is calculated from the time domain signals, it is possible to use for calculation the weights of whole user's carrier. Moreover, we use the COF to improve the accuracy of channel response vector. It means that our proposed system obtains more accurate channel response vector using COF than that of the conventional CCM-SMI based on the matched filter, without increasing the matrix size. From above mentioned reasons, we can achieve better system performance than that of conventional system. Now, we consider the effect if the receiver input data is shorter than the correlation matrix size like 2.048×10^4. The SMI algorithm calculates the weight using the inversion of the covariance matrix. In this case, system requires buffer memory to store a block or a burst of the input signal, and processing delay. Our system also requires buffer memory to store a block or a burst of the input signal like SMI algorithm. When we consider the shorter input data in the receiver than the correlation matrix size like 2.048×10^4, our system can solve the weight directly with shorter matrix than the 2.048×10^4 matrix size. And, our system shows worse BER performance than that with 2.048×10^4 matrix size case, since it is not enough to calculate the optimum weight directly with shorter matrix than the correlation matrix. However, our proposed system requires smaller matrix size than that of the conventional system, so the system complexity can be reduced.

4. Performance Analysis

4.1 Weight Convergence

We will compare the characteristic of weight convergence of CCM-SMI and our proposed scheme with common correlation matrix of time domain signal. In the conventional CCM-SMI, the weight $\omega_{1,1,CCM}$ of 1 user's 1st carrier can be presented by [17]

$$\begin{aligned}\omega_{1,1,CCM} &= \Phi_1^{-1}V_{1,1}\\ &= (E[X_1X_1^{\dagger}])^{-1}V_{1,1}\\ &= \left(\sum_{m=1}^{M}\sum_{s=1}^{S}E[|\varphi_{m,s}|^2]V_{m,s}V_{m,s}^{\dagger}\right)^{-1}V_{1,1}\\ &= \left(GV_{1,1}V_{1,1}^{\dagger}+\sum_{m=2}^{M}\sum_{s=2}^{S}V_{m,s}V_{m,s}^{\dagger}\right)V_{1,1}\end{aligned} \tag{9}$$

since, $E[|\varphi_{m,s}|^2] = [G : (m,s = 1,1), 1 : m,s \neq 1,1]$ where G is the processing gain, and Φ_1 is the covariance matrix for 1st carrier. In our proposed scheme,

$$\begin{aligned}&\omega_{1,1,pro}\\ &= \Psi_{pro}^{-1}V_{1,1}\\ &= (E[X_{IFFT}X_{IFFT}^{\dagger}])^{-1}V_{1,1}\\ &= \left(\sum_{m=1}^{M}\sum_{s=1}^{S}\alpha^2E[X_{m,s}X_{m,s}^{\dagger}]\right)^{-1}V_{1,1}\\ &= \left(\sum_{m=1}^{M}\sum_{s=1}^{S}\alpha^2E[|\varphi_{m,s}|^2]V_{m,s}V_{m,s}^{\dagger}\right)^{-1}V_{1,1}\\ &= \left(\alpha^2GV_{1,1}V_{1,1}^{\dagger}+\alpha^2\sum_{m=2}^{M}\sum_{s=2}^{S}V_{m,s}V_{m,s}^{\dagger}\right)V_{1,1}\\ &= \alpha^2(\omega_{1,1,CCM})\end{aligned} \tag{10}$$

where Ψ_{pro} is the covariance matrix that is calculated by our proposed scheme, α is the IFFT operation term. From Eqs. (9) and (10), our proposed scheme's weight and conventional CCM-SMI's weight are basically same combining ratio with scalar times difference. It means that our proposed scheme can achieve the same convergence characteristic.

4.2 COF

From Eqs. (9) and (10), the performance of array antenna with common correlation matrix depends on the following condition.

$$E[|\varphi_{m,s}|^2]=[G : (m,s = 1,1), 1 : m,s\neq 1,1]. \tag{11}$$

When the number of users and multipath increase, the performance of array antenna with common correlation matrix is degraded seriously because of increasing the multiple access interference (MAI). Since COF adaptively controls the tap coefficients of spreading sequences to orthogonalize to receive sequences, the COF can achieve better system performance than that of matched filter (MF). In Fig.3, the tap coefficients of spreading code sequences are controlled to minimize the error signal $e_{m,s}(i)$ between the transverse filter output $\widehat{X}'_{m,s}(i)$ and the decided signal $\widehat{X}_{m,s}(i)$ by using LMS algorithm. The signals of the i-th bit are given by

$$\widehat{X}'_{m,s}(i) = c_{m,s}^{\dagger}(i)X_{m,s}(i) \tag{12}$$

$$e_{m,s}(i) = \widehat{X}_{m,s}(i) - \widehat{X}'_{m,s}(i) \tag{13}$$

where vector $c_{m,s}(i)$ and vector $X_{m,s}(i)$ are represented as the tap coefficient vector $C_{m,s}$ and the received signal vector $X_{m,s}$ of the i-th bit, respectively. The tap coefficients of the COF is updated as

$$c_{m,s}(i+1) = c_{m,s}(i) + \mu e_{m,s}(i)X_{m,s}(i) \tag{14}$$

where μ is the step size for LMS algorithm. From Eq. (14), we can obtain better detected signals by using the COF than the MF. So we can achieve better system performance than that of the conventional system.

5. Computer Simulated Results

In this section, we show the results of computer simulation using rectangular array of isotropic four antenna elements as Fig. 4, and element spacing of the array is a half wavelength of the carrier frequency. Table 1 shows the simulation parameters. Each frame consists of $N_p = 4$ pilot signal and $N_d = 36$ data signal as Fig. 5. Data modulation and spreading modulation are QPSK and BPSK, respectively. The spreading sequence is orthogonal gold sequence and its processing gain is $G = 64$ chips per symbol. Figure 6 shows the BER performance of various correlation matrix sizes for F_d=20, 80 Hz, and 5 users. Our proposed system achieves the best performance when the correlation matrix size is fixed at 2.048×10^4 chips per one weight like that of the conventional system. It means that the conventional system needs the calculation capacity about 2.048×10^4 chips × No. of Carriers to achieve the best performance, but our proposed system needs only 2.048×10^4 chips per one weight. So we can reduce the complexity of weight calculation about 1/No. of carriers. In this paper, we use the correlation matrix sizes to calculate the weight like 2.048×10^4 chips per one weight and 2.048×10^4 chips per carrier in our proposed system and CCM-SMI, respectively. Figure 7 shows the convergence characteristic of our proposed system and the code orthogonalizing filter for 10 users, $F_d = 20$ Hz. When a new user is added, the code orthogonalizing filter adjustment of coefficients of spreading sequences and its training for convergence are necessary again. In COF case, the training for convergence is required about 200 iteration times. On the other hand, our proposed system obtains about 35 iteration times. Since our proposed system also considers the spatial filtering at a base station with adaptive antenna array, our proposed system can obtain fast adjustmet and convergence of coeffients. Therefore, the combination of COF

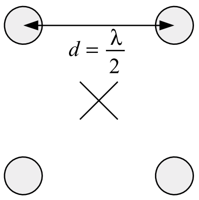

Fig. 4 The configuration of array antenna.

Table 1 Simulation parameters.

Transmission rate	2 Mbps
Spreading code	Ortho. gold sequence
Processing gain	64
Carrier number	4
Modulation (Data)	QPSK
Modulation (Spreading)	BPSK
Frame size	40 symbols ($N_p = 4$, $N_d = 36$)
Channel model	2-Rayleigh wave model (1 chip delay)
Doppler frequency	20, 80 Hz
Step size of COF (μ)	10^{-5}

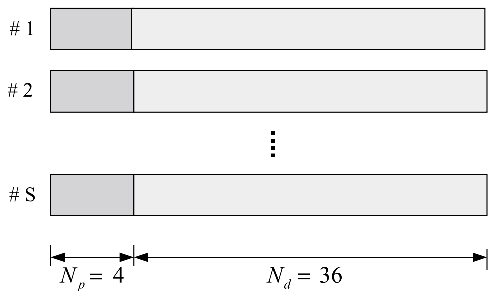

Fig. 5 The simulated packet structure.

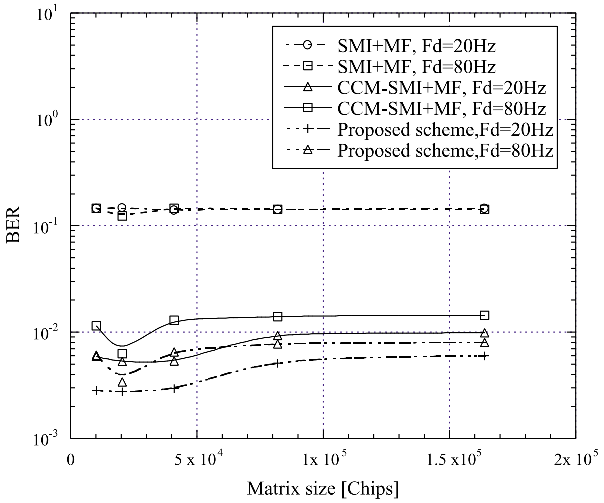

Fig. 6 BER performance of various correlation matrix size, F_d=20 Hz and 80 Hz, and No. of users=5.

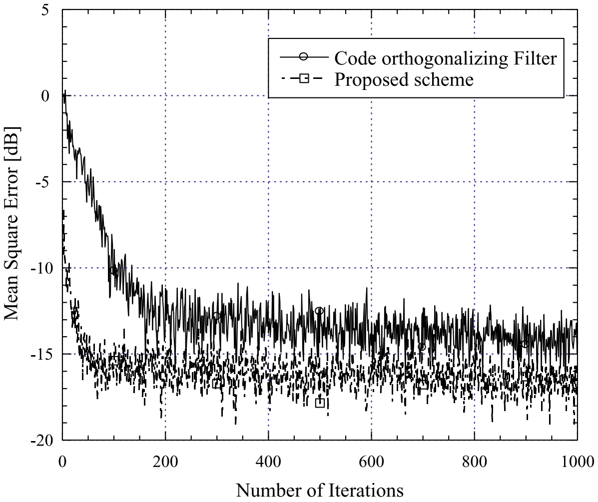

Fig. 7 The convergence characteristic of our proposed system and code orthogonalizing filter for 10 users, $F_d = 20$ Hz.

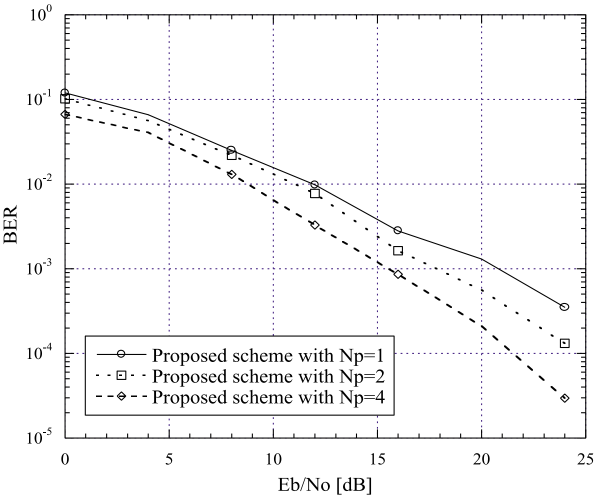

Fig. 8 BER performance of various number of pilot signal. It is plotted as the parameter of N_p inserted after every $N_s = 36$ data symbols of individual carrier for 5 users and Doppler frequency $F_d = 20$ Hz.

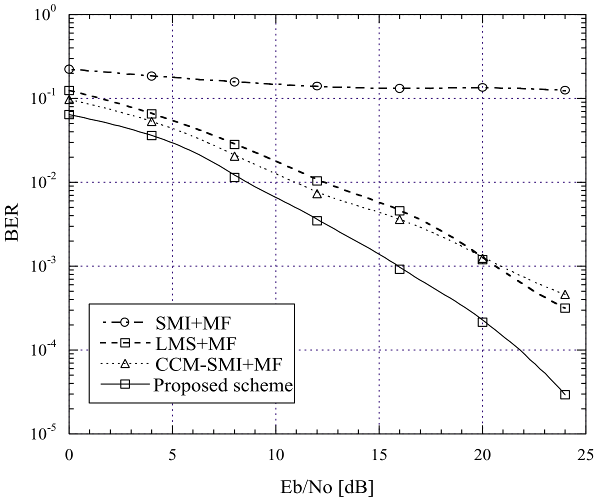

Fig. 9 BER performance of SMI, LMS, CCM-SMI, and our proposed systems for 5 users case, $F_d = 20$ Hz.

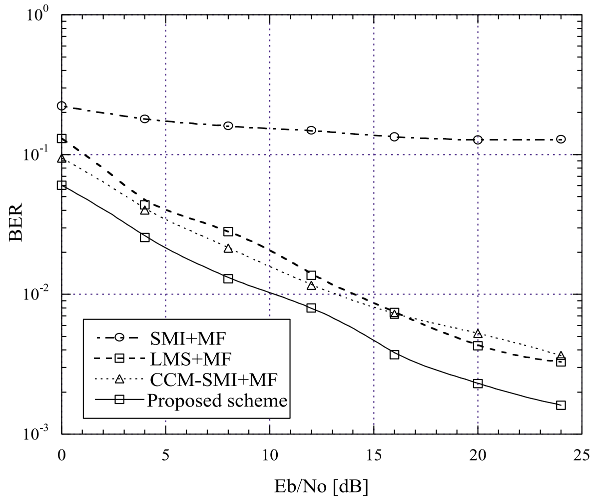

Fig. 10 BER performance of SMI, LMS, CCM-SMI, and our proposed systems for 5 users case, $F_d = 80$ Hz.

and adaptive array antenna reduces theirs demerits and obtains synergism of COF and array antenna. The roles of pilot signal in our proposed system are to calculate the tap coefficients of spreading sequences orthogonal to the receive sequences, and obtain the channel response vector to make an optimum weight for array antenna system. In this case, we need to clarify the BER performance of various number of pilot signals. Figure 8 shows the BER performance of various number of pilot signals. It is plotted as the parameter of N_p inserted after every $N_s = 36$ data symbols of individual subcarrier for 5 users, and $F_d = 20$ Hz. The pilot symbol pattern is randomly assigned to each user from the patterns of (1,1), $(-1, 1)$ for two pilot symbols, and (1,1,1,1), $(1, -1, 1, -1)$, $(1, 1, 1, -1)$, $(1, -1, -1, -1)$ for four pilot symbols. This is because the cross-correlation from the other user's interference signals and multipaths of the desired signal should be average over the pilot signals. With increasing N_p, the BER performance of our proposed system is improved. At the average BER of 10^{-3}, the required E_b/N_0 decreases by about 3.5 dB when N_p increases from one to two. Moreover, as N_p increases from two to four, the required E_b/N_0 at the average BER of 10^{-3} decreases about 2 dB. From this result, we use N_p=4 in the following simulation for evaluation BER performance. Since the COF is a kind of the decision feedback type, it has the problem of the performance degradation when the decision result is not true in low E_b/N_0. However, modern wireless communication systems can accept the high power pilot signal to improve channel estimation against the effect of noise and fading as shown in [21]. Here, the transmit power of pilot signal to data signal is set to 5 dB in this evaluation to achieve high power pilot signal condition. Thus, our system can eliminate the above-mentioned problem of the COF. Figures 9 and 10 show the BER performance of SMI, LMS, CCM-SMI, and our proposed system. Our proposed system can achieve better BER performance than that of the conventional system. The conventional SMI scheme achieves the worst BER performance. This is because the conventional SMI scheme calculates the weight using the strong desired signal's covariance matrix from the MF's output signal, so the covariance matrix includes the error of despreading in time variant channel with multiuser case. But CCM-SMI scheme does not use the despreaded signal, so CCM-SMI achieves better BER performance than that of the SMI. The LMS algorithm achieves worse BER performance than that of the CCM-SMI until 20 dB. This is because LMS has signal acquisition and tracking problems due to its slow convergence. Our proposed scheme achieves the best BER performance. Since the

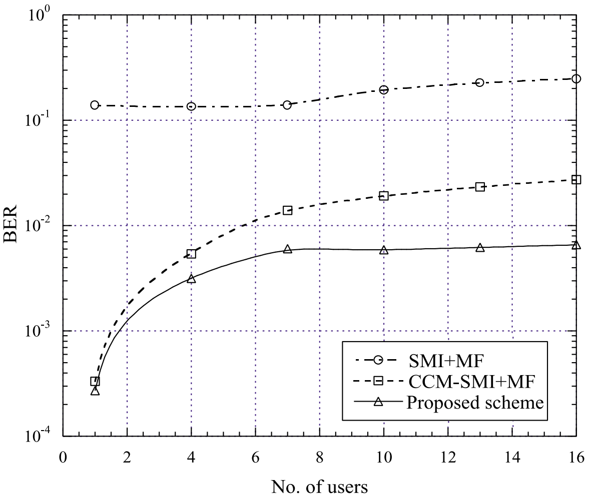

Fig. 11 BER performance of SMI, LMS, CCM-SMI, and our proposed sytems for various number of users for $E_b/N_o = 15$ dB.

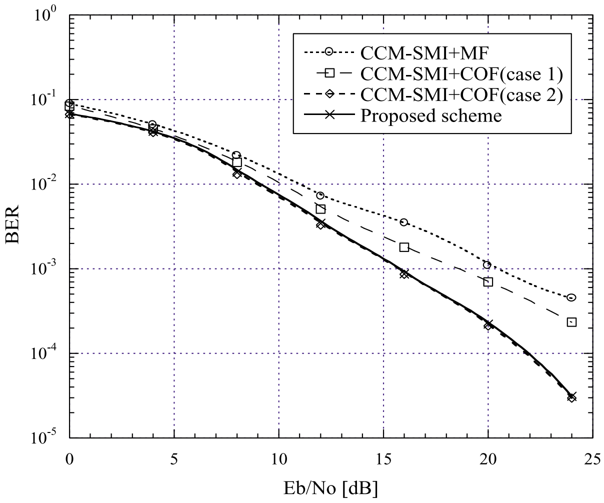

Fig. 12 BER performance of CCM-SMI+MF, CCM-SMI +COF with total correlation matrix size as 2.048×10^4 (case 1), CCM-SMI+COF with individual subcarrier's correlation matrix size as 2.048×10^4 (case 2), and our proposed system for 5 users case, $F_d = 20$ Hz.

COF reduces the MAI than that of the MF based system, our proposed system uses the accurate channel response vector which is calculated from the COF's output signal for beamforming. So we can achieve better BER performance than that of the conventional system. Figure 11 shows the BER performance of SMI, LMS, CCM-SMI, and our proposed systems for various number of users for $E_b/N_o = 15$ dB. Our proposed system can accept more users than that of CCM-SMI at the BER of 6×10^{-3}. Moreover, our system achieves better BER performance with increasing the number of users without any performance degradation than that of the CCM-SMI. This is because our proposed system obtains the accurate channel response vector, so beamforming operation is more accurately done compared to the conventional system. Figure 12 shows the BER performance of CCM-SMI+MF, CCM-SMI+COF with total correlation matrix size as 2.048×10^4 (case 1), CCM-SMI+COF with individual subcarrier's correlation matrix size as 2.048×10^4 (case 2), and our proposed system for 5 users case, $F_d = 20$ Hz. If the CCM-SMI uses the COF with individual subcarrier's correlation matrix size as 2.048×10^4 (case 2), case 2 achieves the same BER performance like our proposed system. However, CCM-SMI+COF with total correlation matrix size as 2.048×10^4 (case 1) shows worse BER performance than that of our proposed system, since case 1 calculates the individual subcarrier's weight with the individual subcarrier's matrix size like 2.048×10^4/No. of carriers. In this case, it is not enough to calculate the optimum weight. So our proposed system achieves good BER performance with small matrix size.

6. Conclusion

The performance of code orthogonalizing filter based adaptive array antenna with common correlation matrix of time domain signal has been analyzed and simulated in Rayleigh fading channel. From the simulation results, it is shown that our proposed system achieves better BER performance than that of the conventional system. Moreover, our proposed system achieves better BER performance with increasing the number of users without any performance degradation than that of the CCM-SMI.

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