Frequency-domain Soft Interference Cancellation for Multicode CDMA Transmissions

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Abstract— **Frequency-domain equalization (FDE) based on minimum mean square error (MMSE) criterion can significantly improve the BER performance of DS- and MC-CDMA signal transmissions in a severe frequency-selective fading channel. However, since the frequency-distorted signal cannot be completely equalized, the residual inter-code interference (ICI) limits the BER performance improvement. In 4G systems, much higher variable rate data services than in the present 3G systems are required. Orthogonal multicode transmission technique has flexibility in offering variable rate services. However, the BER performance degrades as the number of parallel codes increases. In this paper, we propose a frequency-domain soft interference cancellation (FDSIC) for multicode DS- and MC-CDMA signal transmissions and their achievable BER performances are evaluated by computer simulation.**

Keywords- *DS-CDMA, MC-CDMA, Frequency-domain equalization(FDE), Multicode, Interference cancellation*

I. INTRODUCTION

In the next generation mobile communication systems, much higher variable data rate services (e.g., higher than several 10Mbps) than in the present third generation (3G) systems are required. Wideband direct sequence code division multiple access (DS-CDMA) with coherent rake combining has been adopted in the 3G systems for data transmissions of up to a few Mbps [1]. The transmission channels of 4G systems become severely frequency-selective and the transmission performance significantly degrades due to large inter-path interference (IPI) even if coherent rake combining is used [2]. Recently, it has been shown [2]-[4] that the application of frequency-domain equalization (FDE) based on the minimum mean square error (MMSE) criterion, similar to multi-carrier (MC)-CDMA [5], can significantly improve the bit error rate (BER) performance of DS-CDMA. Multicode DS- and MC-CDMA have flexibility in offering variable rate data services by simply changing the number of parallel orthogonal spreading codes [6],[7]. However, the frequency-distorted signal cannot be completely equalized by the use of FDE and the residual inter-code interference (ICI) degrades the BER performance as the number of parallel codes increases. Various ICI cancellation techniques have been proposed to solve this problem [8]-[10].

In this paper, we propose a frequency-domain soft interference cancellation (FDSIC) and evaluate by computer simulation the achievable BER performances of multicode DS- and MC-CDMA in a frequency-selective Rayleigh fading channel. Joint equalization and ICI cancellation is carried out in the frequency-domain. The equalization and cancellation weights are obtained taking into account the residual ICI using the soft interference replica. The soft replica is generated based on the log-likelihood ratio (LLR) so that the error propagation due to decision feedback can be reduced. The remainder of this paper is organized as follows. The multicode CDMA signal transmission system model is presented in Sect. II. FDSIC is proposed in Sect. III and the MMSE-FDE and cancellation weights are derived in Sect. IV. In Sect. V, the computer simulation results for the BER performances are presented. The paper is concluded in Sect. VI.

II. MULTI-CODE CDMA SIGNAL TRANSMISSION SYSTEM MODEL

The transmitter/receiver structure for the multicode CDMA with MMSE-FDE is illustrated in Fig. 1. Throughout the paper, the chip-spaced discrete time representation is used.

We consider the transmission of one block of N_c chips, where N_c denotes the block length of fast Fourier transform (FFT). At a transmitter, a binary data sequence is transformed into data-modulated symbol sequence and then converted to C parallel streams by serial-to-parallel (S/P) conversion. Then the qth symbol stream $d^q(n)$, n=0~(N–1) and N=N_c/SF, is spread using an orthogonal spreading code $c^q_{ort}(t)$, t=0~(SF–1). Here, SF represents the spreading factor. The C chip streams are added and multiplied by a scramble sequence $c_{scr}(t)$. Random chip interleaver is used in order to reduce the effect of error propagation due to decision feedback for the interference replica generation. N_c-point inverse FFT (IFFT) is applied to obtain the MC-CDMA signal. The multi-code CDMA signal $s(t)$, t=0~(N_c–1), can be expressed using the equivalent baseband representation as

$$s(t)=\begin{cases}\sqrt{\dfrac{2E_s}{T_cSF}}\displaystyle\sum_{q=0}^{C-1}d^q\left(\left\lfloor\frac{t}{SF}\right\rfloor\right)\cdot c^q(t) & ,\mathrm{DS-CDMA}\\[2ex] \sqrt{\dfrac{2E_s}{N_cT_cSF}}\displaystyle\sum_{k=0}^{N_c-1}\left\{\sum_{q=0}^{C-1}d^q\left(\left\lfloor\frac{k}{SF}\right\rfloor\right)\cdot c^q(k)\right\}\exp\left(j2\pi k\frac{t}{N_c}\right) & \\ & ,\mathrm{MC-CDMA}\end{cases},\quad(1)$$

where

$$c^q(t)=c^q_{ort}(t\bmod SF)\cdot c_{scr}(t)\quad(2)$$

and E_s represents the symbol energy, T_c the chip length, and $\lfloor x\rfloor$ the largest integer smaller than or equal to x. Before transmission, the last N_g chips of the N_c-chip block is copied and inserted, as a cyclic-prefix, into the guard interval (GI) placed at the beginning of the block.

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Assuming that the channel has L independent propagation paths with chip-spaced distinct time delays, the impulse response $h(t)$ of the channel can be expressed as [11]

$$h(t)=\sum_{l=0}^{L-1}h_l\delta(t-\tau_l)\ ,(3)$$

where h_l and τ_l are the lth path gain and time delay, respectively, with $\sum_{l=0}^{L-1}E[|h_l|^2]=1$ (here, $E[.]$ is the ensemble average operation). The received signal $r(t)$ can be expressed as

$$r(t)=\sum_{l=0}^{L-1}h_l s(t-\tau_l)+\eta(t)\ ,(4)$$

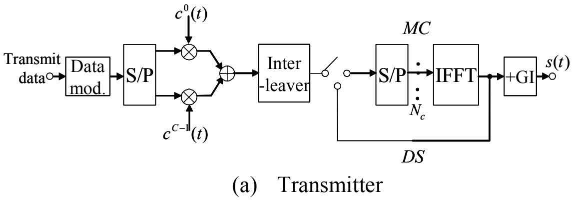
where $\eta(t)$ represents the zero-mean noise process having variance $2N_0/T_c$ with N_0 representing the single-sided power spectrum density of the additive white Gaussian noise (AWGN). Here, we have assumed block fading, where path gains remain constant over the time interval of $t=-N_g\sim(N_c-1)$. After the removal of the GI, the received signal is decomposed into N_c frequency components $\{R(k);k=0\sim(N_c-1)\}$ by applying N_c-point FFT. $R(k)$ is expressed as

$$R(k)=\frac{1}{\sqrt{N_c}}\sum_{t=0}^{N_c-1}r(t)\exp\left(-j2\pi k\frac{t}{N_c}\right)=H(k)S(k)+\Pi(k)\ ,(5)$$

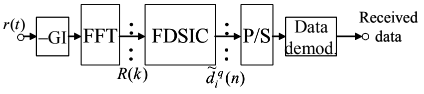
where $S(k)$ is the kth frequency component of $s(t)$ and $H(k)$ and $\Pi(k)$ are the channel gain and the noise component at the kth frequency due to the AWGN, respectively. $S(k)$, $H(k)$ and $\Pi(k)$ are given by

$$\begin{cases}S(k)=\dfrac{1}{\sqrt{N_c}}\displaystyle\sum_{t=0}^{N_c-1}s(t)\exp\left(-j2\pi k\frac{t}{N_c}\right)\\ H(k)=\displaystyle\sum_{l=0}^{L-1}h_l\exp\left(-j2\pi k\frac{\tau_l}{N_c}\right)\\ \Pi(k)=\dfrac{1}{\sqrt{N_c}}\displaystyle\sum_{t=0}^{N_c-1}\eta(t)\exp\left(-j2\pi k\frac{t}{N_c}\right)\end{cases}.\ (6)$$

Then, FDSIC is performed to obtain a sequence of the decision variables. The operation principle of FDSIC is described in Sect. III.



(a) Transmitter



(b) Receiver

Fig. 1 Transmitter/receiver structure for DS- and MC-CDMA.

III. FREQUENCY-DOMAIN SOFT INTERFERENCE CANCELLATION

The structure of FDSIC is illustrated in Fig 2. In the proposed FDSIC, all C data sequences are detected by the conventional MMSE-FDE for multicode CDMA at the initial iteration (i=0). For the i=1st iteration onwards, soft symbol replicas are generated and joint MMSE-FDE and ICI cancellation is carried out in an iterative fashion. This procedure is repeated a sufficient number of times.

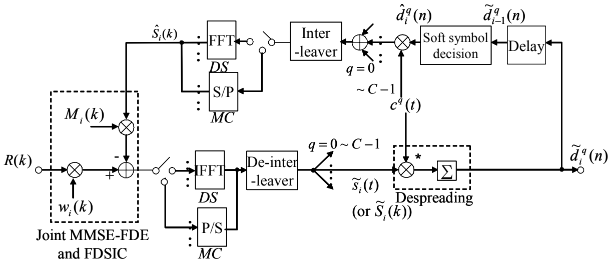


Fig. 2 FDSIC structure for DS- and MC-CDMA.

A. *Soft Symbol Replica Generation*

The decision variable for the nth symbol $d^q(n)$, obtained after the (i–1)th iteration, is denoted by $\tilde{d}^q_{i-1}(n)$. The soft symbol replica $\hat{d}^q_i(n)$ for the qth parallel symbol stream is generated by using $\tilde{d}^q_{i-1}(n)$. The replica generation is as follows.

At first, the LLR $\lambda^q_m(n)$ of the mth bit $b^q_{m,n}$ in the nth symbol $d^q(n)$ (m=0~log$_2M$–1, where M is the modulation level) is computed using the decision variable $\tilde{d}^q_{i-1}(n)$:

$$\lambda^q_m(n)=\ln\left(\frac{p(b^q_{m,n}=1)}{p(b^q_{m,n}=0)}\right)$$
$$\approx\begin{cases}\dfrac{1}{2\hat{\sigma}^2_{i-1}}\left[\left|\tilde{d}^q_{i-1}(n)-\sqrt{\dfrac{2E_s}{T_cSF}}A_{i-1}d^{\min}_{b^q_{m,n}=0}\right|^2-\left|\tilde{d}^q_{i-1}(n)-\sqrt{\dfrac{2E_s}{T_cSF}}A_{i-1}d^{\min}_{b^q_{m,n}=1}\right|^2\right] &, \mathrm{DS-CDMA}\\ \dfrac{1}{2\hat{\sigma}^2_{i-1}(n)}\left[\left|\tilde{d}^q_{i-1}(n)-\sqrt{\dfrac{2E_s}{T_cSF}}A_{i-1}(n)d^{\min}_{b^q_{m,n}=0}\right|^2-\left|\tilde{d}^q_{i-1}(n)-\sqrt{\dfrac{2E_s}{T_cSF}}A_{i-1}(n)d^{\min}_{b^q_{m,n}=1}\right|^2\right] &, \mathrm{MC-CDMA}\end{cases},\ (7)$$

where

$$\begin{cases}A_{i-1}=\dfrac{1}{N_c}\displaystyle\sum_{k=0}^{N_c-1}\hat{H}_{i-1}(k) &, \mathrm{DS-CDMA}\\ A_{i-1}(n)=\dfrac{1}{SF}\displaystyle\sum_{k=nSF}^{(n+1)SF-1}\hat{H}_{i-1}(k) &, \mathrm{MC-CDMA}\end{cases}\quad(8)$$

and $p(b^q_{m,n}=1)$ (or $p(b^q_{m,n}=0)$) is the probability that the bit $b^q_{m,n}=1$ (or 0). In Eq. (7), $d^{\min}_{b^q_{m,n}=0}$ ($d^{\min}_{b^q_{m,n}=1}$) is the most probable symbol whose *m*th bit is 0 (or 1), for which the Euclidean distance from $\tilde{d}^q_{i-1}(n)$ is minimum. $2\hat{\sigma}^2_{i-1}$ (or $2\hat{\sigma}^2_{i-1}(n)$) is the variance of the interference plus noise component and $\hat{H}_{i-1}(k)$ is the equivalent channel gain, given by

$$\begin{cases} 2\hat{\sigma}^2_{i-1}=\dfrac{1}{SF^2}\cdot\dfrac{2E_s}{T_c}\left[\begin{aligned}&\sum_{q'=0}^{C-1}\rho^{q'}_{i-1}\left(\frac{1}{N_c}\sum_{k=0}^{N_c-1}\left|\hat{H}_{i-1}(k)\right|^2-\left|A_{i-1}\right|^2\right)\\ &\qquad+\left(\frac{E_s}{N_0SF}\right)^{-1}\left(\frac{1}{N_c}\sum_{k=0}^{N_c-1}|w_{i-1}(k)|^2\right)\end{aligned}\right] \\ \qquad, \mathrm{DS-CDMA} \\ 2\hat{\sigma}^2_{i-1}(n)=\dfrac{1}{SF^2}\cdot\dfrac{2E_s}{T_c}\left[\begin{aligned}&\sum_{\substack{q'=0\\ \neq q}}^{C-1}\rho^{q'}_{i-1}(n)\left(\frac{1}{SF}\sum_{k=nSF}^{(n+1)SF-1}\left|\hat{H}_{i-1}(k)\right|^2-\left|A_{i-1}(n)\right|^2\right)\\ &\qquad+\left(\frac{E_s}{N_0SF}\right)^{-1}\left(\frac{1}{SF}\sum_{k=nSF}^{(n+1)SF-1}|w_{i-1}(k)|^2\right)\end{aligned}\right] \\ \qquad, \mathrm{MC-CDMA} \end{cases} \tag{9}$$

and

$$\hat{H}_{i-1}(k)=w_{i-1}(k)H(k),\ (10)$$

where $w_{i-1}(k)$ and $\rho^{q'}_{i-1}$ (or $\rho^{q'}_{i-1}(n)$) are the MMSE weight and the residual ICI component, respectively (which are derived in Sect. IV B). The soft decision symbol $\hat{d}^q_i(n)$ can be obtained from

$$\hat{d}^q_i(n)=\sum_{d\in D}d_{b^q_{m,n}}\prod_{b^q_{m,n}\in d}p(b^q_{m,n}),\ (11)$$

where $d_{b^q_{m,n}}$ is the candidate symbol (that has $b^q_{m,n}$ as the *m*th bit) in the signal space *D*. Since $p(b^q_{m,n}=1)+p(b^q_{m,n}=0)=1$, $p(b^q_{m,n}=1)$ and $p(b^q_{m,n}=0)$ are given by

$$\begin{cases} p(b^q_{m,n}=1)=\dfrac{\exp[\lambda^q_m(n)]}{1+\exp[\lambda^q_m(n)]} \\ p(b^q_{m,n}=0)=\dfrac{1}{1+\exp[\lambda^q_m(n)]} \end{cases}.\ (12)$$

For QPSK data modulation and 16-quadrature amplitude modulation (16QAM), the soft symbol replica $\hat{d}^q_i(n)$ is obtained as follows:

$$\hat{d}^q_i(n)=\begin{cases} \dfrac{1}{\sqrt{2}}\tanh\left(\dfrac{\lambda^q_0(n)}{2}\right)+j\dfrac{1}{\sqrt{2}}\tanh\left(\dfrac{\lambda^q_1(n)}{2}\right) & ,\mathrm{QPSK} \\ \dfrac{1}{\sqrt{10}}\tanh\left(\dfrac{\lambda^q_0(n)}{2}\right)\left\{2+\tanh\left(\dfrac{\lambda^q_1(n)}{2}\right)\right\} & \\ +j\dfrac{1}{\sqrt{10}}\tanh\left(\dfrac{\lambda^q_2(n)}{2}\right)\left\{2+\tanh\left(\dfrac{\lambda^q_3(n)}{2}\right)\right\} & ,\mathrm{16QAM} \end{cases}.\ (13)$$

B. *Joint MMSE-FDE and FDSIC*

$\hat{d}^q_i(n)$ is re-spread to obtain the soft replica $\hat{s}_i(t)$ of the transmitted multicode DS-CDMA signal. Then, $\hat{s}_i(t)$ is decomposed into N_c frequency components $\{\hat{S}_i(k);k=0\sim(N_c-1)\}$ by applying N_c-point FFT. The *k*th frequency component $\hat{S}_i(k)$ is given by

$$\hat{S}_i(k)=\begin{cases} \dfrac{1}{\sqrt{N_c}}\displaystyle\sum_{t=0}^{N_c-1}\hat{s}_i(t)\exp\left(-j2\pi k\frac{t}{N_c}\right) & \\ =\sqrt{\dfrac{2E_s}{T_cSFN_c}}\displaystyle\sum_{t=0}^{N_c-1}\left\{\sum_{q=0}^{C-1}\hat{d}^q_i\left(\left\lfloor\frac{t}{SF}\right\rfloor\right)\cdot c^q(t)\right\}\exp\left(-j2\pi k\frac{t}{N_c}\right) & \\ & ,\mathrm{DS-CDMA} \\ \sqrt{\dfrac{2E_s}{T_cSF}}\displaystyle\sum_{q=0}^{C-1}\hat{d}^q_i\left(\left\lfloor\frac{k}{SF}\right\rfloor\right)\cdot c^q(k) & ,\mathrm{MC-CDMA} \end{cases}.\ (14)$$

Joint MMSE-FDE and ICI cancellation is carried out as

$$\tilde{S}_i(k)=w_i(k)R(k)-M_i(k)\hat{S}_i(k),\ (15)$$

where $M_i(k)$ is the cancellation weight (which will be derived in Sect. IV A) and $\hat{S}_0(k)=0$ for *k*=0~(N_c–1).

C. *Tentative Decision*

N_c-point IFFT is performed on $\{\tilde{S}_i(k);k=0\sim(N_c-1)\}$ to produce the ICI reduced DS-CDMA signal $\tilde{s}_i(t)$. Despreading is carried out to obtain the decision variable $\tilde{d}^q_i(n)$ as

$$\tilde{d}^q_i(n)=\begin{cases} \dfrac{1}{SF}\displaystyle\sum_{t=nSF}^{(n+1)SF-1}\tilde{s}_i(t)\cdot\left\{c^q(t)\right\}^*, \mathrm{DS-CDMA} \\ \dfrac{1}{SF}\displaystyle\sum_{k=nSF}^{(n+1)SF-1}\tilde{S}_i(k)\cdot\left\{c^q(k)\right\}^*, \mathrm{MC-CDMA} \end{cases}.\ (16)$$

A series of the above A~C is repeated a sufficient number of times.

IV. DERIVATION OF CANCELLATION AND EQUALISATION WEIGHTS

A. *Cancellation Weight*

Substitution of Eq. (5) into Eq. (15) gives

$$\tilde{S}_i(k)=\hat{H}_i(k)S(k)-M_i(k)\hat{S}_i(k)+w_i(k)\Pi(k).\ (17)$$

The DS-CDMA signal $\tilde{s}_i(t)$ after joint MMSE-FDE and ICI cancellation and the *k*th frequency component $\tilde{S}_i(k)$ of MC-CDMA signal after joint MMSE-FDE and ICI cancellation are respectively expressed as

$$\begin{cases}\tilde{s}_i(t)=A_i s(t)+\mu_{ICI,i}(t)+\mu_{noise,i}(t), \text{DS}-\text{CDMA}\\ \tilde{S}_i(k)=A_i(\lfloor k/SF\rfloor)S(k)+\mu_{ICI,i}(k)+\mu_{noise,i}(k), \text{MC}-\text{CDMA}\end{cases}, \quad (18)$$

where $\mu_{ICI,i}(t)$ (or $\mu_{ICI,i}(k)$) is the residual ICI component and $\mu_{noise,i}(t)$ (or $\mu_{noise,i}(k)$) is the noise component after joint MMSE-FDE and ICI cancellation. $\mu_{ICI,i}(t)$ and $\mu_{ICI,i}(k)$ are respectively given by

$$\begin{cases}\mu_{ICI,i}(t)=\frac{1}{\sqrt{N_c}}\sum_{k=0}^{N_c-1}\left\{\left(\hat{H}_i(k)-A_i\right)S(k)-M_i(k)\hat{S}_i(k)\right\}\exp\left(j2\pi k\frac{t}{N_c}\right)\\ \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad , \text{DS}-\text{CDMA}\\ \mu_{ICI,i}(k)=\left(\hat{H}_i(k)-A_i(\lfloor k/SF\rfloor)\right)S(k)-M_i(k)\hat{S}_i(k) \quad , \text{MC}-\text{CDMA}\end{cases} \quad . (19)$$

We assume that the signal replica generation in the *i*th iteration is perfect (i.e., $S(k)=\hat{S}_i(k)$). The cancellation weight $M_i(k)$ for $\mu_{ICI,i}(t)=0$ (or $\mu_{ICI,i}(k)=0$) can be obtained as

$$M_i(k)=\begin{cases}\hat{H}_i(k)-A_i & , \text{DS-CDMA}\\ \hat{H}_i(k)-A_i(\lfloor k/SF\rfloor) & , \text{MC-CDMA}\end{cases}. \quad (20)$$

B. Derivation of MMSE-FDE Weight

First, we derive the MMSE-FDE weight for DS-CDMA and then for MC-CDMA.

(1) DS-CDMA

The equalization error $e_i(k)$ at the *i*th iteration is defined as the difference between $\tilde{S}_i(k)$ and the *k*th frequency signal component $A_iS(k)$, which is given by the first term of Eq. (18). Using Eqs. (15) and (20), $e_i(k)$ is given by

$$\begin{aligned}e_i(k)&=\tilde{S}_i(k)-A_iS(k)\\ &=\left(w_i(k)H(k)-A_i\right)\left(S(k)-\hat{S}_i(k)\right)-w_i(k)\Pi(k)\end{aligned}. \quad (21)$$

Since $\Pi(k)$ is a zero-mean complex-valued Gaussian noise having variance $2N_0/T_c$, the mean square error (MSE) is given, using Eqs. (5), (6), and (14), by

$$E\left[|e_i(k)|^2\right]=\frac{2E_s}{SFT_c}\sum_{q'=0}^{C-1}\rho_i^{q'}\left|w_i(k)H(k)-A_i\right|^2+\frac{2N_0}{T_c}\left|w_i(k)\right|^2, \quad (22)$$

where

$$\rho_i^{q'}=\begin{cases}1 & , i=0\\ \frac{1}{N}\sum_{n=0}^{N-1}\left\{\left|\bar{d}_i^{q'}(n)\right|^2-\left|\hat{d}_i^{q'}(n)\right|^2\right\} & , i\geq 1\end{cases} \quad (23)$$

with $\bar{d}_i^{q'}(n)$ being the hard decision result obtained from $\tilde{d}_{i-1}^{q'}(n)$.

The set of MMSE-FDE weights $\{w_i(k);k=0\sim(N_c\text{ - }1)\}$ is the one that satisfies $\partial E[|e_i(k)|^2]/\partial w_i(k)=0$ for all *k*. Eq. (22) becomes

$$\frac{\partial E[|e_i(k)|^2]}{\partial w_i(k)}=w_i(k)\sum_{q'=0}^{C-1}\rho_i^{q'}\left|H(k)\right|^2+w_i(k)\left(\frac{E_s}{SFN_0}\right)^{-1}-\sum_{q'=0}^{C-1}\rho_i^{q'}A_iH^*(k)$$

$$. \quad (24)$$

We get the following MMSE-FDE weight:

$$w_i(k)=\frac{H^*(k)}{\left|H(k)\right|^2+\left(\frac{E_s}{SFN_0}\sum_{q'=0}^{C-1}\rho_i^{q'}\right)^{-1}}, \quad (25)$$

where $w_0(k)$ is equal to the conventional MMSE-FDE weight.

(2) MC-CDMA

In a similar manner to DS-CDMA, we get the MMSE-FDE weight for MC-CDMA as

$$w_i(k)=\frac{H^*(k)}{\left|H(k)\right|^2+\left(\frac{E_s}{SFN_0}\sum_{q'=0}^{C-1}\rho_i^{q'}(\lfloor k/SF\rfloor)\right)^{-1}}, \quad (26)$$

where

$$\rho_i^{q'}(n)=\begin{cases}1 & , i=0\\ \left\{\left|\bar{d}_i^{q'}(n)\right|^2-\left|\hat{d}_i^{q'}(n)\right|^2\right\} & , i\geq 1\end{cases}. \quad (27)$$

Similar to DS-CDMA case, $w_0(k)$ is equal to the conventional MMSE-FDE weight.

V. SIMULATION RESULTS

Table 1 shows the computer simulation condition. A chip-spaced 16-path (L=16) frequency-selective block Rayleigh fading channel having uniform power delay profile are assumed. We assume an FFT block size of N_c=256 chips, a GI length of N_g=32 chips. We assume ideal channel estimation.

Fig. 3 plots the average BER performance of FDSIC as a function of the average received signal energy per bit-to-the AWGN power spectrum density ratio E_b/N_0 (=$(1/\log_2M)SF(1+N_g/N_c)(E_s/(SFN_0))$) for $SF=C=256$. For comparison, the lower bound BER performance [4] is also plotted. Without ICI cancellation (i=0), the BER performance is severely degraded. However, it can be seen that the proposed FDSIC can significantly improve the BER performance; almost the same BER performance can be achieved for DS- and MC-CDMA. Since the transmitted symbol is spread over entire frequency band in both DS- and MC-CDMA, the same frequency diversity effect can be achieved and therefore, the BER performance is almost the same for both CDMA. For QPSK modulation, even at the i=2nd iteration, the E_b/N_0 reduction from the no ICI cancellation case is as much as 4.7 dB for BER=10^{-3} and the BER performance gets close to the theoretical lower bound by about 1.1 dB. For 16QAM, the Euclidean distance between different symbols becomes shorter and hence, decision errors due to the residual ICI are more likely than for QPSK. However, FDSIC is very effective to improve the BER performance even for 16QAM. An E_b/N_0 reduction of as much as 7.2 dB can be achieved for BER=10^{-3} in both DS- and MC-CDMA.

Table 1 Simulation condition.

Transmitter	Modulation	QPSK, 16QAM
	FFT block length	N_c=256 chips
	GI length	N_g=32 chips
	Spreading factor	SF=256
	Number of codes	C=256
Channel	Fading	Frequency-selective block Rayleigh fading
	Number of paths	L=16
	Power delay profile	Uniform
Receiver	Frequency-domain equalization	MMSE
	Channel estimation	Ideal

VI. CONCLUSION

In this paper, we proposed frequency-domain soft interference cancellation (FDSIC) for multicode DS- and MC-CDMA signal transmissions in a frequency-selective channel. Joint MMSE-FDE and ICI cancellation is carried out in an iterative fashion. The MMSE-FDE and cancellation weights were derived taking into account the residual ICI. Both weights are updated in each iteration. The BER performance with the proposed FDSIC in a frequency-selective Rayleigh fading was evaluated by computer simulation. It was found that, when SF=C=256 and QPSK (16QAM) data modulation, the E_b/N_0 reduction from the no cancellation case is as much as about 4.7 (7.2) dB for achieving BER=10^{-3} and the performance approaches the theoretical lower bound by about 1.1 (2.4) dB. Joint MMSE-FDE and ICI cancellation can be applied to improve the transmission performance of the high speed downlink of a CDMA mobile communication system.

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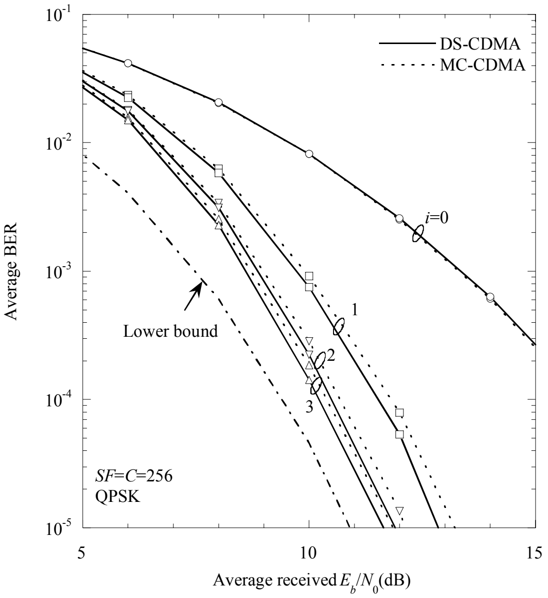
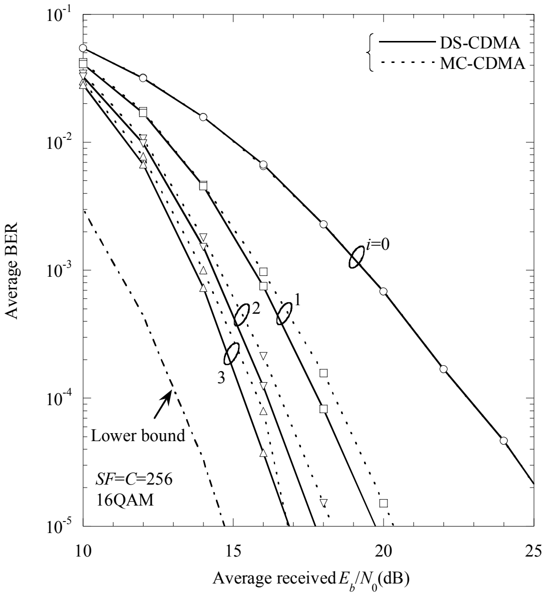


(a) QPSK



(b) 16QAM

Fig. 3 BER performance of joint MMSE-FDE and FDSIC.