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Performance of DS-CDMA with Frequency-Domain Equalization over Frequency Selective Rayleigh Fading Channel

Asst. Prof. Maha George Zia ***Bsc. Sameer Akram Dawood***

Al-Mustansiriya University, College of Engineering,

Electrical Engineering Department, 2008

Abstract

To improve the BER performance of DS-CDMA system over a frequency-selective fading channel, the frequency domain equalization (FDE) can be applied, in which one-tap equalization is carried out on each subcarrier component obtained by fast Fourier transform (FFT). In this paper, DS-CDMA system with joint FDE and space antenna diversity combining is analyzed. Then, a channel interleaving method, called chip interleaving is used to improve the performance of DS-CDMA system.

<u>Keywords</u> ***DS-CDMA, frequency domain equalization.***

الخلاصـــــة

لتحسين اداء نظام تقسيم الشفرات متعدد المداخل ذي التتابع المباشر (DS-CDMA) عبر قناة الخفوت الترددية الاختيارية، نستطيع تطبيق تسوية مجال التردد (FDE) ، حيث يتم انجاز عملية التسوية على كل مركبة تردد ثانوية والتي نحصل عليها باستخدام تحويل فورير السريع (FFT). في هذا البحث، سنقوم بتحليل نظام (DS-CDMA) بالاتصال مع تسوية مجال التردد (FDE) وتنوع الهوائيات المكانية. ثم سنستخدم طريقة لبعثرة القناة تدعى بعثرة الشريحة (Chip Interleaving) لتحسين اداء نظام (DS-CDMA).

1. Introduction

In next generation wireless communications systems, a very high-speed data transmission is required under severe fading environments [1]. The wireless channel is composed of many propagation paths with different time delay, producing frequency-selective fading channel [2]. In the frequency-selective fading channel, if an advanced equalization technique is not applied, the bit error rate (BER) performance of single carrier (SC) transmission is significantly degraded due to severe inter-symbol interference (ISI) [3].

Direct sequence code division multiple access (DS-CDMA) can exploit the channel frequency-selectivity by the use of coherent rake receiver that resolves the propagation paths having different time delays and coherently combines them to achieve the path diversity effect. However, in the case of broadband wireless data transmission of more than a few Mbps using DS-CDMA, the transmission performance may significantly degrade due to strong inter-path interference (IPI) even if coherent rake combining is used [4].

Frequency domain equalization (FDE) is an effective technique for improving the single carrier (SC) transmission performance in a frequency selective fading channel [5]. FDE can be applied to DS-CDMA to obtain a good BER performance similar to that of multi carrier code division multiple access (MC-CDMA) [6]. The distinctive point of this technique is the use of Cyclic Prefix (CP), in order to prevent degradation of transmission characteristics caused by multipath interference, which become more apparent during broadband transmission. CP copies multiple data symbols at the end of a frame to the head part of a frame. Moreover, the equalization is performed on a block of data at a time and the operations on this block involve fast Fourier transform (FFT) [7].

Space antenna diversity technique can be used to improve the system performance in a fading channel. Instead of transmitting and receiving the desired signal through one channel, several copies of the desired signal are obtained through different channels [8].

Chip interleaving is a form of channel interleaver that exploits the spreading process in DS-CDMA and thus improves the BER performance in a frequency selective fading channel. Chip interleaver scrambles the chips and transforms the transmission channel into highly time selective or highly memoryless channel [9].

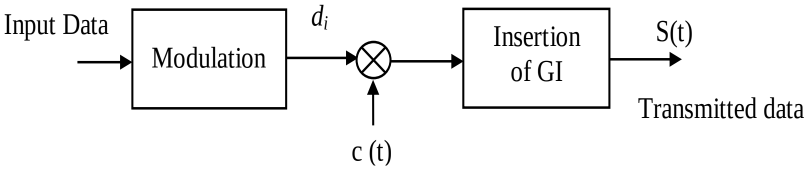
Remainder of this paper is organized as follows. Section 2, presents the transmission system model for a single code DS-CDMA using FDE and antenna diversity combining. Three types of FDE are considered: minimum mean square error (MMSE) equalization, maximal-ratio combining (MRC) equalization, and zero-forcing (ZF) equalization. Moreover, chip interleaver is presented in this section. In section 3, the simulation results for performance of the system in 3-paths frequency selective Rayleigh fading channel are presented. Finally, section 4, presents conclusions.

2. DS-CDMA with FDE and Antenna Diversity

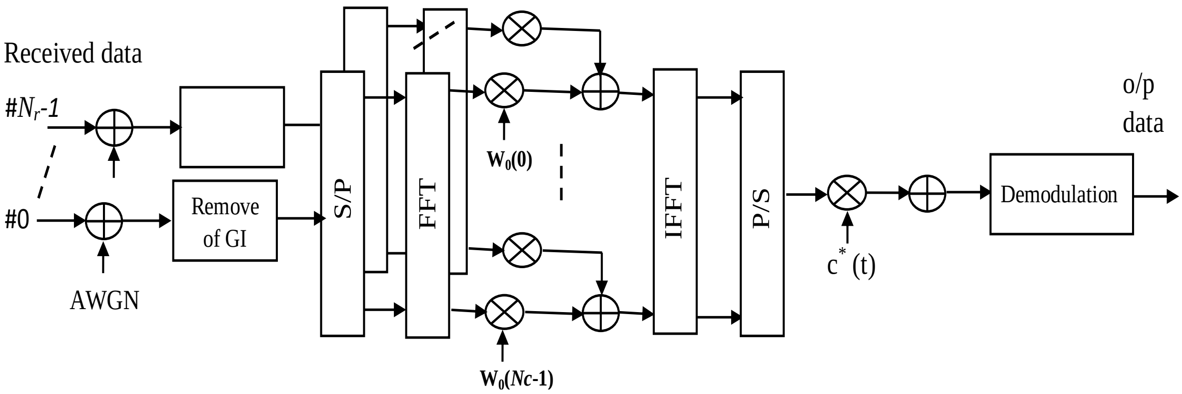
2-1 Transmission System Model

Transmission system model for DS-CDMA using FDE and antenna diversity combining is illustrated in Fig.(1). At the transmitter, the binary data sequence is transformed into data-modulated symbol sequence $\{d(n)\}$ and then spread by multiplying with the spreading sequence $\{c(t)\}$ having spreading factor, *SF*. The resulting chip sequence is divided into a sequence of blocks of N_c chips each and then, the last N_g chips of each block is copied as a cyclic prefix and inserted into the guard interval (GI) at the beginning of each block to form a frame of (N_c+N_g) chips. Figure (2) illustrates the frame structure [4, 10]

The GI-inserted chip sequence is transmitted over a frequency-selective fading channel and is received by N_r diversity antennas at the receiver. After the removal of GI, the received chip sequence on each antenna is decomposed by N_c-point FFT into N_c subcarrier components. Then, joint FDE and antenna diversity combining is carried out. Finally, inverse FFT (IFFT) is applied to obtain the equalized and diversity combined time-domain chip sequence for despreading and data demodulation [4, 10].



(a) Transmitter



(b) Receiver

Fig.(1) Transmission System Model for DS-CDMA with Joint FDE and Antenna Diversity Combining

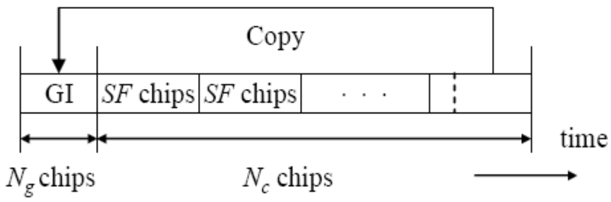


Fig.(2) Frame Structure

2-2 Received Signal

The data symbol sequence $\{d(n);\ n=0\sim(N_c/SF)-1\}$ and the spreading chip sequence $\{c(t);\ t=0\sim N_c-1\}$ of one frame are considered, where N_c and SF are chosen so that the value of (N_c/SF) becomes an integer. The GI-inserted chip sequence $\{s(t);\ t=0\sim N_c-1\}$ can be represented as [4, 10]:

$$s(t)=\sqrt{2E_c/T_c}\ d\left(\lfloor t/SF\rfloor\right)c(t \bmod SF), \qquad t=-N_g\sim N_c-1, \tag{1}$$

where, E_c and T_c denote the chip energy and the chip duration, respectively, and $\lfloor x\rfloor$ represents the largest integer smaller than or equal to x.

The propagation channel is assumed to be a frequency-selective fading channel having L discrete paths, each subjected to independent fading, where the time delay of the lth path ($l=0\sim L-1$) is assumed to be τ_l. The chip sequence $\{r_m(t);\ m=0\sim N_r-1,\ t=-N_g\sim N_c-1\}$ received on the mth antenna can be represented as [4, 10]:

$$r_m(t)=\sum_{l=0}^{L-1} h_{m,l}\, s(t-\tau_l)+n_m(t), \tag{2}$$

where, $h_{m,l}$ is the complex path gain of the lth path experienced at the m-th antenna and $n_m(t)$ is the AWGN.

After removal of GI from the received chip sequence $\{r_m(t)\}$, N_c-point FFT is applied to decompose $\{r_m(t);\ t=0\sim N_c-1\}$ into N_c subcarrier components $\{R_m(k);\ k=0\sim N_c-1\}$. The kth subcarrier component $R_m(k)$ can be written as [4, 10]:

$$R_m(k)=\sqrt{2E_c/T_c}\ H_m(k)S(k)+n_m(k), \tag{3}$$

Where, $S(k)$, $H_m(k)$ and $n_m(k)$ are the kth subcarrier components of the transmitted N_c-chip signal sequence $\{s(t);\ t=0\sim N_c-1\}$, the channel gain and noise component due to the AWGN, respectively. They are given by [4, 10]:

$$\begin{cases} S(k) = \sum_{t=o}^{N_c-1} s(t)\exp(-j2\pi k\frac{t}{N_c}) \\ H_m(k) = \sum_{l=o}^{L-1} h_{m,l}\exp(-j2\pi k\frac{\tau_l}{N_c}), \\ n_m(k) = \sum_{t=o}^{N_c-1} n_m(t)\exp(-j2\pi k\frac{t}{N_c}) \end{cases} \quad (4)$$

Then, joint one-tap FDE and antenna diversity combining is carried out to obtain [4, 10]:

$$R\square(k) = \sum_{m=0}^{N_r-1} R_m(k)\, W_m(k), \quad (5)$$

Where $W_m(k)$ is the equalization weight. MMSE equalization, MRC (maximum ratio combining) equalization and ZF equalization are used in this work.

The MRC weight maximizes the signal-to-noise ratio (SNR) at each subcarrier. The MMSE weight is chosen so that the mean square error (MSE) between $S(k)$ and $R\square(k)$ is minimized, while the ZF weight is chosen to get $E[R\square(k)] = S(k)$. They are given by [4, 10]:

$$W_m(k) = \begin{cases} \dfrac{H_m^*(k)}{\sum_{m=0}^{Nr-1}\left|H_m(k)\right|^2 + (E_C/N_o)^{-1}} & \text{, MMSE-FDE} \\ H_m^*(k) & \text{, MRC-FDE} \\ \dfrac{H_m^*(k)}{\sum_{m=0}^{Nr-1}\left|H_m(k)\right|^2} & \text{, ZF-FDE} \end{cases} \quad (6)$$

where, (E_c/N_o) is the average chip energy to-AWGN power spectrum density ratio and * denotes complex conjugation.

N_c-point IFFT is applied to $\{R\square(k);\ k=0\sim N_c-1\}$ to obtain the time-domain chip sequence. Finally, despreading is carried out for succeeding data demodulation.

2-3 Chip Interleaver

Chip interleaver is a channel interleaving method used for DS-CDMA mobile radio. Chip interleaver scrambles the chips associated with a data symbols so that the channel gains experienced by neighboring chips are highly uncorrelated. By doing so, the resultant transmission channel can be transformed into highly time-selective or highly memoryless channel [11].

The proposed chip interleaver interleaves the chip sequence obtained after spreading. Figure (3) illustrates the chip interleaver structure [9]. It is a block interleaver with columns equal to the number of bits to be transmitted and rows equal to *SF*. The chip sequence is written column-wise and read row-wise to be transmitted. At the receiver, the received chip sequence is written and read in the opposite manner in the chip de-interleaver before despreading [4, 11].

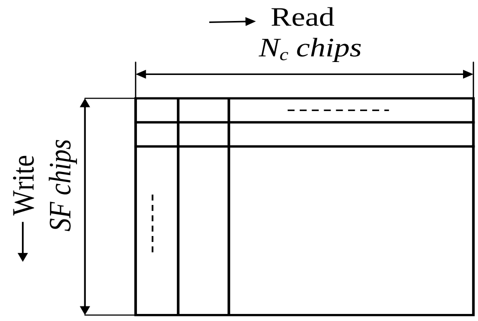


Fig.(3) Chip Interleaver Structure

3. Computer Simulation

3-1 Simulation Condition

The parameters that have been used in simulation are listed in Table (1). This system is software implemented with MATLAB 7.0 technical programming language.

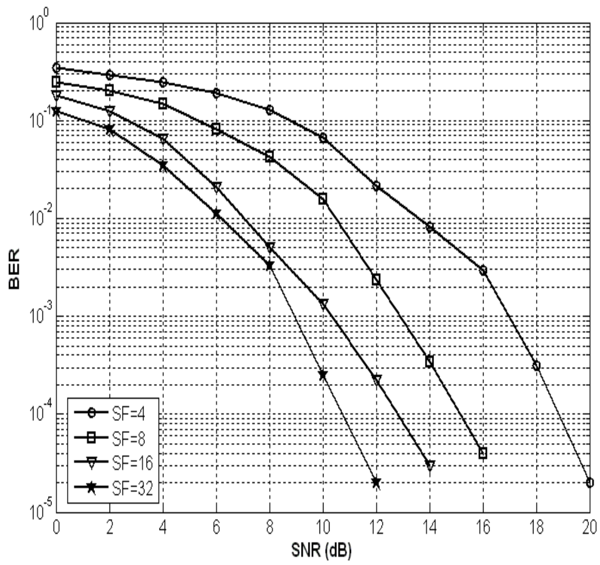
Table (1)

PARAMETER	VALUE
Data rate	3MHz
No. of transmitted bits	100000
Modulation type	QPSK
Spreading code type	Walsh code
Spreading Factor	*SF*=4, 8, 16, 32
No. of FFT points	N_c =256
Cyclic prefix interval	N_g=32 (chips)
fading channel model	Rayleigh fading channel (Jakes model)
Doppler Frequency	f_d=10 Hz
No. of channel paths	L=3
No. of receiver antennas	N_r=1, 2, 4
Frequency-Domain Equalization Types	MMSE-FDE, MRC-FDE, ZF-FDE
SNR	(0,2,…,22) dB

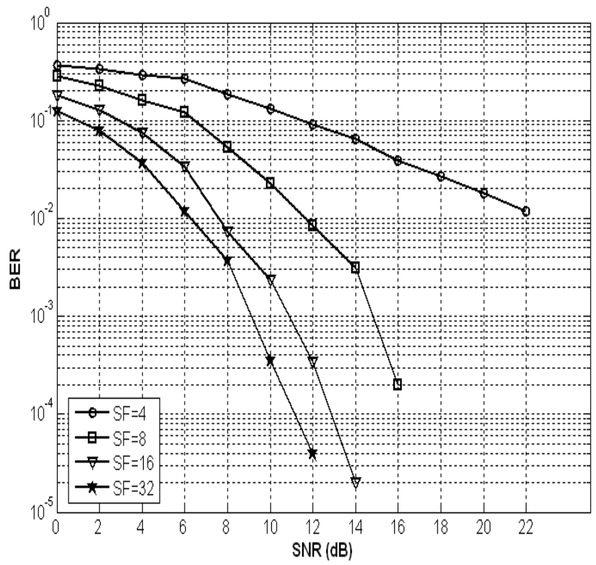
3-2 Comparison of MMSE, MRC and ZF Equalizations

The BER performances versus SNR of DS-CDMA system using different values of spreading factor (*SF*), state that these are without antenna diversity with joint MMSE-FDE, MRC-FDE, and ZF-FDE in three paths Rayleigh fading channel are illustrated in Figs.4(a), 4(b), and 4(c), respectively.

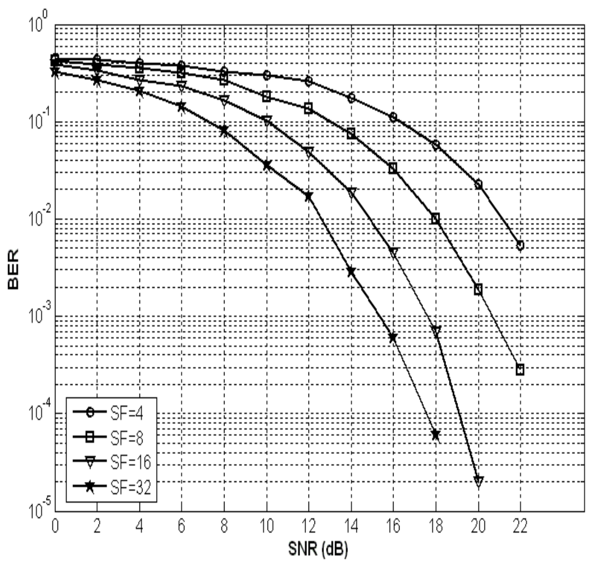
The BER performance is improved when *SF* is increased for all types of FDE. The MMSE equalization always achieves better BER performance as compared to MRC and ZF equalization. The MRC equalization achieves poor performance (BER floor) for *SF*=4, due to the larger ISI produced by the enhanced frequency-selectivity, but when *SF*=8, 16, and 32, the MRC equalization achieves almost the same BER performance as MMSE equalization since the ISI can be sufficiently suppressed during the despreading process. The ZF equalization achieves good performance at high *SF* and at high SNR values only, because the ZF equalization removes all ISI, but can lead to noise enhancement.



(*a*) DS-CDMA with MMSE-FDE



(b) DS-CDMA with MRC-FDE



(c) DS-CDMA with ZF-FDE

Fig.(4) Simulated BER Performances of DS-CDMA Using MMSE, MRC and ZF Equalizations. No Antenna Diversity (Nr=1).

3-3 Error Rate Performance of DS-CDMA with FDE and Fading Rate as a Parameter:

The BER performance versus SNR of DS-CDMA system using *SF*=16 and fading rate (f_d*T_{blk}, where, f_d is the Doppler shift, and $T_{blk}=(N_c+N_g)T_c$) as a parameter, with joint MMSE-FDE, MRC-FDE, and ZF-FDE in three paths Rayleigh fading channel is illustrated in Fig.(5).

In this work, block fading is assumed, where the path gains stay constant over one frame duration. For *SF*=16 and f_d*T_{blk}=1.2e-4, the BER performance is better than f_d*T_{blk}=2.4e-3, because when f_d=200 Hz (fast fading), the path gains of the channel do not stay constant during one frame duration. The MMSE equalization still achieves better BER performance as compared with MRC and ZF equalizations.

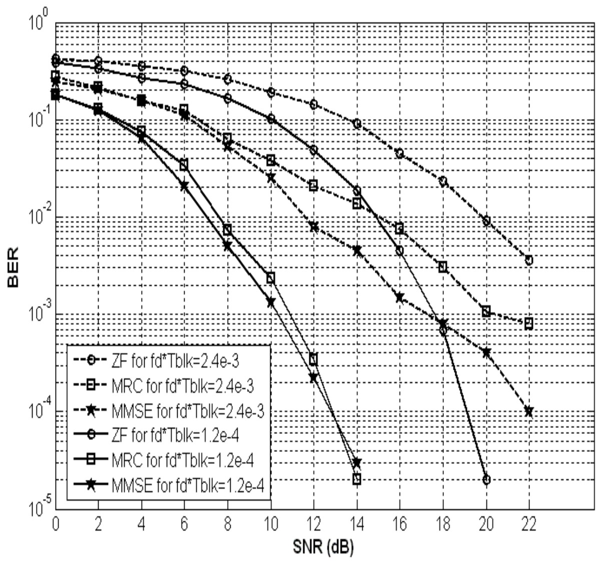


Fig.(5) BER Performance of DS-CDMA with Frequency Domain Equalizers and Fading Rate as a Parameter (fd=10 & 200 Hz)

Since the MMSE equalization always achieves better BER performance. Hence, in the following results, only MMSE equalization is used.

3-4 The Effect of Chip Interleaver on the Performance of DS-CDMA with MMSE-FDE:

Figure (6) shows the BER performance versus SNR of DS-CDMA system using chip interleaver with MMSE-FDE in three paths Rayleigh fading channel, for *SF*=4 and 8. With chip interleaving, the BER performance improves as *SF* increases, when *SF*=4 (8), about 0.8dB (1dB) improvement is seen in the SNR required for a BER=10^{-4}.

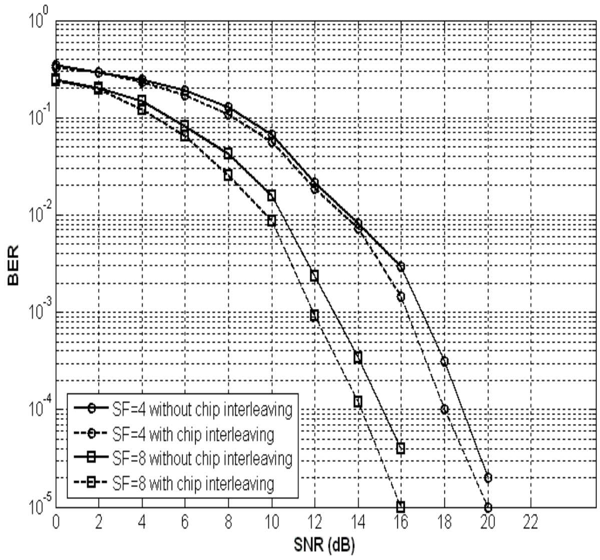


Fig.(6) BER Performance of DS-CDMA with MMSE-FDE and Chip Interleaving in 3-Paths Rayleigh Fading Channel (fd=10 Hz)

3-5 Error Rate Performance of DS-CDMA with MMSE-FDE and Space Antenna Diversity:

Figure (7) shows the BER performance versus SNR of DS-CDMA system with MMSE-FDE and space antenna diversity (N_r=1, 2, and 4) in three paths Rayleigh fading channel for *SF*=4. It can be clearly seen that the use of antenna diversity combining is always beneficial, where as the number of branches (N_r) is increased, the BER decreases.

It can be seen from Fig. (7), that when BER=10^{-4}, there is about 2.3dB and 3.8dB improvement for N_r=2 and N_r=4, respectively.

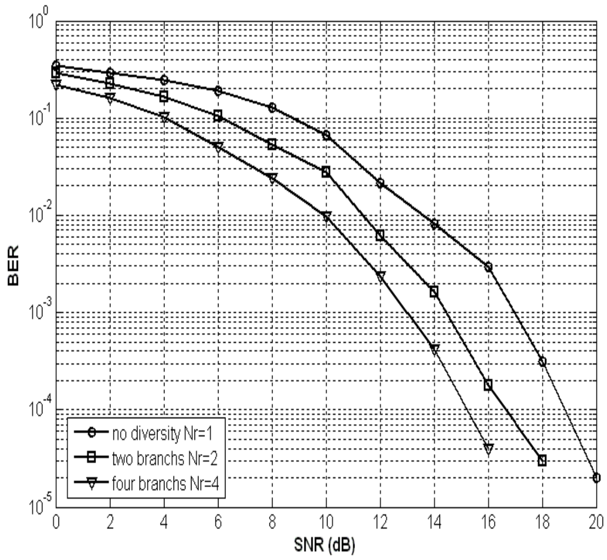


Fig.(7) BER Performance of DS-CDMA with MMSE-FDE and Space Antenna Diversity in 3-Paths Rayleigh Fading Channel (fd=10 Hz)

4 . Conclusions

In this paper, frequency-domain equalization was presented for single code DS-CDMA and the achievable BER performance in a 3-paths frequency-selective Rayleigh fading channel was evaluated by computer simulation (Matlab Language). The BER performance using MMSE, MRC and ZF equalization were compared to find that the MMSE equalization gives the best BER performance. Also, it was found that as the spreading factor increases, the equalization schemes improve the BER performance since the ISI produced by the frequency-selectivity can be effectively suppressed during the despreading process.

Chip interleaver was introduced to exploit the time selectivity of the channel in a DS-CDMA system with MMSE-FDE. It was shown by computer simulations that the chip interleaving improved the BER performance as *SF* is increased. Also space antenna diversity was presented in this paper to improve the BER performance of DS-CDMA with MMSE-FDE. It was shown that the use of antenna diversity is powerful to improve the BER performance, where as the number of branches is increased, the BER performance decreases and the complexity of the system becomes expensive.

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