Performance Characteristics of QPSK and MSK DS/FH Hybrid CDMA Systems in Rayleigh Fading

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ABSTRACT: Hybrid code division multiple access (CDMA) scheme utilizes advantages of both direct sequence spread spectrum (DS/SS) and frequency hopped spread spectrum (FH/SS) systems, while overcoming some of their shortcomings. To enhance performance of this hybrid system, an efficient modulation scheme must be used that can perform favorably in a fading environment. We have compared the bit error rate (BER) performance of two spectrally efficient schemes namely, quadrature phase shift keying (QPSK) and minimum phase shift keying (MSK), when used in a hybrid system, over a Rayleigh fading channel. Simulation results show that hybrid MSK indeed is a better scheme in a multi-user (CDMA) environment in that, it achieves lower BER than hybrid QPSK. The comparison has been extended by including a predetection diversity reception scheme.

I. INTRODUCTION

Spread spectrum CDMA scheme has in the recent years generated a lot of excitement in the mobile radio communication industry. It has been shown that CDMA offers a tremendous increase in capacity and performance in a mobile radio environment, when compared to existing digital technologies such as time division multiple access (TDMA). Both DS/SS and FH/SS have been studied in the past and performance comparisons have been made [1-3]. Hybrid DS/FH systems have also been considered and their performance have been evaluated [4-7]. Hybrid SS systems are attractive since they combine antimultipath effectiveness of DS/SS with antipartial-band-jamming and anti-near/far effectiveness of FH/SS system. Hybrid systems may also use shorter signature sequences and hopping patterns thus reducing the overall acquisition time. Increased implementation complexity is often the main disadvantage of a hybrid SS system.

The choice of a specific modulation scheme is an important design consideration in SS systems. Factors such as improved bandwidth efficiency, better performance in a multi-user environment, etc. often dictate this choice. The binary phase shift keying (BPSK) scheme is often used in DS/FH SS systems due to its optimal BER performance. QPSK and MSK schemes are also employed, to increase data rate. However, in QPSK the occasional fall of the signal amplitude to zero increases the out-of-band interference, which can be deleterious especially in a multi-user environment. On the other hand, in MSK the sinusoidal weighting of the pulses, coupled by staggering of in-phase and the quadrature components keeps the signal envelope constant, thereby preventing it from going to zero [8]. This inherent advantage of the MSK scheme can be utilized to improve performance of a hybrid CDMA system. Also, MSK is a more compact scheme in that, 99% of the total power is present in a smaller bandwidth (1.17/T versus 8/T for QPSK with T being the bit period), which suggests that in wide-band channels, MSK may be spectrally more efficient than QPSK[9].

In this paper, we have compared BER performance of the above two spectrally efficient modulation schemes for varying number of users. Predetection diversity has been used to further improve the BER. The commonly used Rayleigh fading model is assumed for the channel. We have used hopping rates much slower than the data rate so that coherent demodulation is feasible. In addition, synchronous hybrid model with deterministic signature sequences have been considered.

The paper is organized as follows. Section II describes the transmitter, channel and receiver models of both the QPSK and the MSK hybrid systems. Simulation results are given in Section III, followed by brief concluding remarks in Section IV.

II. SYSTEM MODEL

We assume K users to be transmitting simultaneously. Transmitted signal $s_k(t)$ of the kth user is then given by

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$$s_k(t) = \sqrt{2P} b_{2k-1}(t)\Psi(t)c_{2k-1}(t)\sin\{2\pi[f_c + f_k(t)]t + \theta_k(t) + \alpha_k(t)\} + \sqrt{2P} b_{2k}(t)\Psi(t)c_{2k}(t) \cos\{2\pi[f_c + f_k(t)]t + \theta_k(t) + \alpha_k(t)\} \quad (1)$$

where P is the transmitted power, $b_{2k-1}(t)$ and $b_{2k}(t)$ are rectangular data sequences of duration T. In the case of MSK, the transmitted signal will have sinusoidal pulse weighting, and is given by

$$s_k(t) = \sqrt{2P} b_{2k-1}(t)\Psi(t)c_{2k-1}(t)\sin(\frac{\pi t}{T})\sin\{2\pi[f_c + f_k(t)]t + \theta_k(t) + \alpha_k(t)\} + \sqrt{2P} b_{2k}(t)\Psi(t)c_{2k}(t)\cos(\frac{\pi t}{T}) \cos\{2\pi[f_c + f_k(t)]t + \theta_k(t) + \alpha_k(t)\} \quad (2)$$

c_{2k} and c_{2k-1} are the code waveforms of the inphase and the quadrature components respectively, and f_c is the carrier frequency, $f_k(t)$ is the kth hopping pattern, derived from a sequence $f_j^{\,k}$ of frequencies from a set $S = \{\nu_1, \nu_2, \nu_3, \ldots \nu_q\}$ of q frequencies (possibly non-equispaced) having a minimum spacing of Δ'. It is assumed that these frequencies are ordered such that $\nu_n < \nu_{n+1}$ for each n, $1 \le n \le q$. Then, $f_k(t) = f_j^{\,k}$ for $jT_h \le t \le (j+1)T_h$ where T_h is the dwell time. It is assumed that $\Delta' >> 2T_c^{-1} = 2NT^{-1}$ where T_c is the chip period, and that the number of data bits transmitted per hop $N_b = \frac{T_h}{T}$ is a positive integer greater than 1. The requirement on N_b is necessary so as to facilitate coherent detection. θ_k and α_k are the phases introduced by the kth modulator spreader and hopper, respectively. $\Psi(t)$ is the shaping waveform. The data bits are modulated by either QPSK or MSK scheme and then shaped by the shaping waveform. The inphase and the quadrature components are then spread by the signature codes c_{2k} and c_{2k-1}, respectively. The spread signal is then frequency hopped by the kth user's frequency hop pattern.

The signal is assumed to take three paths, of which one of them is the direct path. The delays along the paths are randomly chosen to be within the bit period T. The three path model can be written as [10]

$$s_r(t) = s(t) + \alpha s(t-\tau_1) + \beta s(t-\tau_0) \quad (3)$$

where α and β are Rayleigh path gains, τ_1 and τ_0 are time delays along the two paths. The gains, delays and the phases associated with each of the three paths are assumed to be statistically independent. The gains are Rayleigh distributed and the path delays are uniformly distributed in $[0,T]$. The random phase associated with each path is uniformly distributed in $[0,2\pi]$.

The received signal is the sum of the signals from K users transmitting simultaneously with each user's signal taking three paths. The signal at the receiver of the kth user is given by

$$r(t) = \sum_{k=1}^{K} s(t) * h_k(t) + n(t) \quad (4)$$

where $h_k(t)$ is the impulse response of the Rayleigh fading channel and $n(t)$ is the additive white Gaussian noise with power density $N_0/2$.

The receiver of a hybrid system consists of a bandpass filter that removes the out-of-band noise components, a dehopper that performs the appropriate frequency translation followed by a despreader and a conventional data demodulator. The QPSK system, due to its large phase transitions has more of the out-of-band noise when compared to the MSK system. The continuos waveform nature of MSK prevents large occurrences of out-of-band noise components, thus reducing mutual interference. The filtered signal is then dehopped by the kth user's hopping pattern. It is assumed that the hopping pattern of the receiver is synchronized with the hopping pattern of the signal associated with jth path of the kth reference user. The dehopper introduces a phase $\beta_k(t)$ that is analogous to the phase $\alpha_k(t)$ introduced by the hopper at the transmitter, and is constant during a single hop interval. The dehopper is followed by a bandpass filter that removes the high frequency components. The output of the filter is given by

$$r_k(t) = \sum_{l=1}^{3} \sqrt{\frac{1}{2}P}\,\delta[f_k(t-\tau_l), f_i(t)]\{b_{2k-1}(t-\tau_l)\Psi(t-\tau_l) c_{2k-1}(t-\tau_l)\sin\{2\pi[f_c + f_k(t-\tau_l)]t + \phi_k\} + \sqrt{\frac{1}{2}P} b_{2k}(t-\tau_l)\Psi(t-\tau_l)c_{2k}(t-\tau_l) \cos\{2\pi[f_c + f_k(t-\tau_l)]t + \phi_k\} + \hat{n}(t) \quad (5)$$

where $\hat{n}(t)$ is the bandlimited version of the zero mean double sided Gaussian stationary process $n(t)$ and

$$\phi_k = \theta_k - 2\pi[f_c + f_k(t-\tau_l)]\tau_l + \alpha_k(t-\tau_l) - \beta_k(t) \quad (6)$$

The filtered output is then demodulated by a conventional demodulator. Inphase and quadrature phases at the demodulator output during the time interval $[\lambda T, (\lambda+1)T]$, where $\lambda = j_i N_b + n_i$, i.e. for the n_ith data bit and the j_ith hop, are given by

$$Z_{2i} = \int_{\lambda T}^{(\lambda+1)T} r(t)\Psi(t)c_{2i}(t)\cos(2\pi f_c t)\, dt \qquad (7)$$

and

$$Z_{2i-1} = \int_{\lambda T}^{(\lambda+1)T} r(t)\Psi(t)c_{2i-1}(t)\sin(2\pi f_c t)\, dt \qquad (8)$$

respectively.

III SIMULATION RESULTS

A frequency hit may either be full or partial. A full hit occurs when an interfering signal is present in the kth user's signal during the entire symbol duration. In a fading channel, a full hit from interferer can occur during the nth data symbol duration if

$$f_k(t-\tau_l) = f_{\text{int}}(t) \qquad (9)$$

A partial hit occurs when the interfering signal is present only for a portion of the kth user's symbol duration. In a synchronous hybrid system, only full hits can occur and they do so with a probability

$$P_f = q^{-l} \qquad (10)$$

The use of Equal Gain Combining (EGC) diversity involves the use of M random variables where M is the order of the diversity scheme. The decision variable is the average of the M random variables [5].

Both QPSK and MSK DS/FH hybrid schemes were simulated. The same number of hopping frequencies, q = 100 were used in both cases. Hadamard codes of length 127 were used as deterministic signature sequences. The number of symbols transmitted per hop was $N_b = 10$. Fig. 1 shows the performance of the QPSK hybrid system. For voice transmission, a BER of 10^{-3} or less is considered tolerable. It is seen that the performance degrades fairly quickly as the number of users increase. The MSK hybrid scheme on the other hand is seen to perform slightly better under similar channel conditions (Fig. 2). This may be attributed to its smooth pulse shape as well as its compactness.

Fig. 3 shows the performance improvement in a QPSK hybrid system upon the use of diversity of order 3 i.e., with three receiving branches. For small number of users, the BER reduction is more pronounced. However, for large

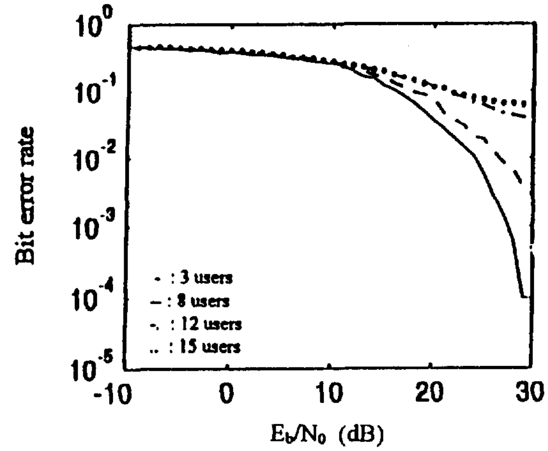

Fig. 1 Performance of QPSK hybrid system

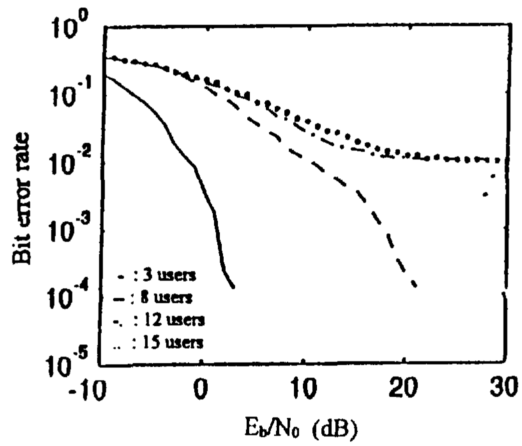

Fig. 2 Performance of MSK hybrid system

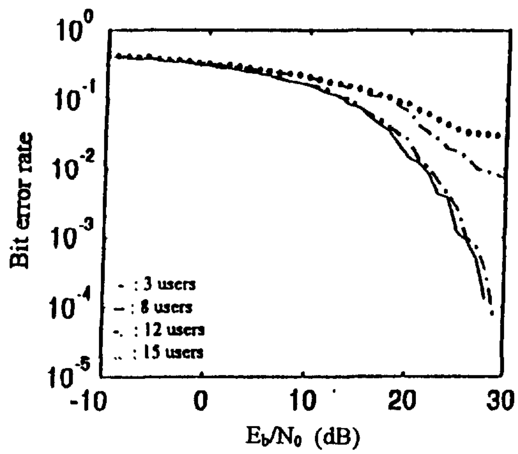

Fig. 3 Performance of the QPSK hybrid system with diversity

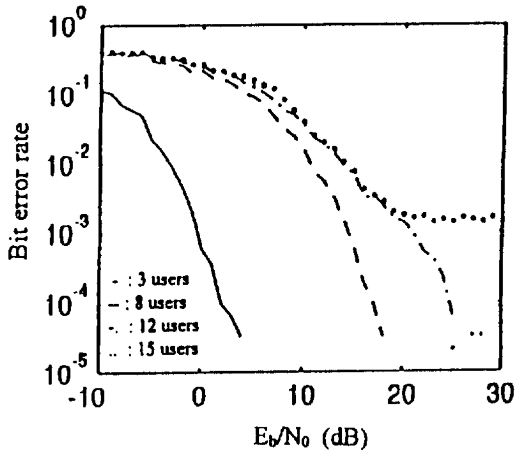

Fig. 4 Performance of the MSK hybrid system with diversity

number of users, the improvement is only marginal.

Fig. 4 shows the performance of the MSK hybrid system with the inclusion of predetection diversity. There is a vast improvement in performance even for large number of users.

IV CONCLUSIONS

Performance comparison of two DS/FH hybrid spread spectrum CDMA systems has been presented in a Rayleigh fading environment. It is seen that BER performance of a hybrid CDMA system can be improved while achieving increased bandwidth efficiency, by choosing an appropriate keying scheme. The capacity of the hybrid scheme may further be enhanced by using powerful error correcting codes (although, this will reduce the bit rate to an extent), and by choosing better hopping patterns.

REFERENCES

[1] M. B. Pursley, et. al., " Error probability for direct sequence spread spectrum multiple - access communications - Part I: Upper and lower bounds, " *IEEE Trans. Commun.*, vol. COM - 30, pp. 975 - 984, May 1982.

[2] J. S. Lehnert and M.B. Pursley, "Error probabilities for binary direct - sequence spread spectrum communication with random signature sequences, " *IEEE Trans. Commun.* vol. COM-35, pp. 87-98, Jan. 1987.

[3] E.A Geraniotis and M.B. Pursley, "Error probabilities for slow frequency hopped spread spectrum multiple-access communications over fading channels," *IEEE Trans. Commun.*, vol. COM-30, pp. 996-1009, 1982.

[4] L. Sadiq and A. H. Aghvami," Performance of an asynchronous hybrid spread spectrum system in the presence of interference, Rician fading and AWGN', IEEE Proceedings-I, vol. 138, No. 2, April 1991.

[5] J. Wang and M. Moeneclaey," Hybrid DS/SFH spread spectrum multiple access with predetection diversity and coding for indoor radio,' *IEEE Journal on selected areas of communications*, pp. 705-713, May 1992.

[6] A. Evaggelos Geraniotis, " Coherent hybrid DS-SFH spread spectrum multiple-access communications," *IEEE Journal on selected areas in communications*, pp. 695-705, September 1985.

[7] A. Evaggelos Geraniotis, " Noncoherent hybrid DS - SFH spread spectrum multiple - access communication," *IEEE Trans. on Communications*, vol. COM-34, No. 9, pp. 862-872, September 1986.

[8] S. Pasupathy, " Minimum shift keying: A spectrally efficient modulation, " *IEEE Communications Magazine*, pp. 14-22, July 1979.

[9] S. Haykin, *Communication Systems*, John Wiley & Sons Inc., 1983.

[10] Michel C. Jeruchim, et. al., *Simulation of Communication Systems*, Plenum Press, New York, 1992.