論文 97-8-4-03

Performance Evaluation of Hybrid DS/SFH-CDMA Noncoherent MFSK Signal with Channel Coding and MRC Diversity Techniques in Mobile Communication Nakagami Fading Channels

이동통신 Nakagami 페이딩 채널에서 채널코딩과 최대비합성 다이버시티 기법에 의한 Hybrid DS / SFH-CDMA 비동기 MFSK 신호의 성능평가

Heau-Jo Kang* · Norihiko Morinaga**

강 희 조* · Norihiko Morinaga**

요 약

본 논문에서는 Nakagami 페이딩 채널환경에서 하이브리드 DS /SFH-CDMA 비동기 M-ary FSK 시스템의 성능을 분석하여 평가하였다. 다중경로 간섭과 다중접속 간섭을 고려하였고, 스펙트럼 효율은 부호화 하였을 때의 시스템과 부호화 하지 않았을 때의 시스템을 계산하였다. 검파 전 MRC 다이버시티 기법과 인터리브 채널코딩기법(해밍(7, 4), BCH(15, 7), RS(7, 4), (15, 9))을 함께 적용하여 비트에러율의 성능을 개선시켰다. 비동기 하이브리드 시스템의 비트오율은 가우시안 간섭의 근사값을 사용하여 얻었다. 결과들로부터, 페이딩의 영향이 크면 클수록 시스템의 성능이 열화되며, 직접확산 부분의 변조는 다중경로 간섭에, 주파수 호핑 부분의 변조는 다중접속 간섭의 영향에 민감함을 알 수 있었다. 이것들의 결과로부터 채널코딩기법과 검파 전 다이버시티 기법을 함께 사용하므로써 만족할만한 성능을 얻을 수 있었다.

Abstract

This paper presents an analytical evaluation of a hybrid direct-sequence /slow frequency-hopped code division multiple-access (DS /SFH-CDMA) system employing noncoherent M-ary frequency shift keying (MFSK) modulation in a multiple Nakagami fading (m) environment. Multipath interference (MPI) and multi-access interference (MAI) is taken into account and the spectral efficiency is calculated for uncoded as well as channel coding systems. Predetection multipath maximal ratio combining (MRC) diversity in conjunction with interleaved channel coding (Hamming(7, 4) code, BCH (15, 7) code and RS (7, 4), (15, 9) code) is employed for improving the bit error rate (BER) performance. The BER of noncoherent hybrid system is obtained using a Gaussian intereference approximation.

---

* 동신대학교 전기전자공학과(Dept. of Electrical & Electronic Eng., Dongshin Univ.)

** 오사카대학 통신공학과(Dept. of Communications Eng. Graduate School of Engineering, Osaka Univ.)

· 논 문 번 호 : 970211-010

· 수정완료일자 : 1997년 6월 2일

From the results, we know that the bit error rate performance more deteriorates as depth of fading becomes deeper. The DS portion of the modulation combats the multipath interference, whereas the FH portion is a protection against large multi-access interference. It is shown that, for the considered types of a channel coding, the use of a predetection diversity is still essential for obtaining a satisfactory bit error performance.

Ⅰ. Introduction

Code division multiple-access(CDMA) schemes have received considerable attention in the 30years and have been purposed for use in a wide variety of applications. Spread spectrum multiple-access(SSMA) is by far the most popular form of CDMA because, in addition to its multiple-access capabilities, it simultaneously provides other desirable qualities including considerable effectiveness in combating various types of hostile or nonhostile interference. The most commonly used forms of CDMA are direct-sequence SSMA(DS-SSMA), in which a high rate code is used to phase modulate, together with the data signal, the carrier signal: frequency-hopped SSMA (FH-SSMA), in which a high rate code is used to control a frequency synthesized carrier signal into which data are modulated: and hybrid SSMA where a DS / SS modulated signal frequency-hopped according to a specific frequency-hopping pattern[1]~[4].

Frequency-hopped code division multiple-access(FH-CDMA) system can provide frequency diversity by hopping a symbol into multiple frequency slots that are separated by a frequency separation greater than the coherence bandwidth of the channel[5]. FH-CDMA systems are not sensitive to the near far problem. However, operating these systems at an acceptable bit error rate(eg. 10^{-3}), generally yields low spectral efficiency[6].

Hybrid systems are attractive because they can combine the good features of both DS / SS and FH / SS systems while avoiding some of their short comings. For example a hybrid system can combine the antimultipath effectiveness of DS / SS system with the good antipartial band jamming features of FH / SS system. Hybrid systems may also use shorter signature sequences and hopping patterns, thus reducing the overall acquisition time. A disadvantage of hybrid systems is the increased complexity of their transmitters and receivers Geraniotis analyzed hybrid DS-SFH /SSMA communication systems with noncoherent and coherent reception over additive white Gaussian channels[7],[8]. Wang and Moeneclaey analyzed the BER performance of noncoherent DPSK hybrid DS / SFH-SSMA systems in diversity and coding(BCH, Hamming, Golay) operating multipath Rayleigh and Rician fading channels[9],[10].

In this paper model can describe the Nakagami fading envelope variations of the signal carrier on the mobile receiver moving in urban, suburban and open areas by adequately selecting the number of multipath interference numbers(L) and multiaccess interference numbers(K).

This paper analyzes and compares the bit error rate(BER) performance of noncoherent hybrid direct sequence / slow frequency-hopped code multple-access(DS / SFH-CDMA) systems with diversity and coding for mobile radio multipath Nakagami fading channels. Predetection multipath diversity(maximal ratio combining(MRC)) is used in conjunction with error correction channel coding(Hamming, BCH, RS) and interhop interleaving (whereby each bit of a code word is transmitted during a different hop, to reduce the effect of hits from nonreference users).

The paper is organized as follows. In Section Ⅱ the analysis models (transmitter, Nakagami fading channel and receiver) are described. The average error probability of hybrid systems employing interleaved coding and diversity are derived in Section Ⅲ. This is followed by some numerical results in Section Ⅳ. Finally, conclusions is given in Section Ⅴ.

Ⅱ. Analysis Model

2-1 Transmitter and receiver model

The transmitter for the kth user($1 \leq k \leq K$, where K is the number of active users) consists of five parts: the channel encoder(the use of a block code is assumed), the interleaver, noncoherent encoder, DS modulator (or spreader) and the frequency hopper[7].

For noncoherent FSK modulation, the output of the kth DS modulator $C_k(t)$ is given by:

$$C_k(t)=2\sqrt{2P}\Psi(t)a_k(t)\cos\{2\pi[f_c+b_k(t)\triangle]t+\theta_k(t)\} \quad (1)$$

where $\Psi(t)$; chip waveform,
f_c ; frequency carrier,
P ; transmitted signal power,
$a_k(t)$; code waveform,
$b_k(t)$; data signal,
$\theta_k(t)$; phase angle,
$\triangle$; frequency tone.

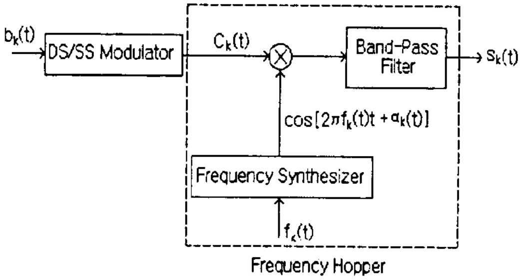


Fig. 1. Transmitter for a hybrid DS-SFH /CDMA systems.

The signal transmitted by the kth user is given by

$$S_k(t)=2\sqrt{2P}\Psi(t)a_k(t)\cos\{2\pi[f_c+f_k(t)+b_k(t)\triangle]t \; \theta_k(t)+\alpha_k(t)\} \quad (2)$$

During a given hop interval, one of M possible signals is transmitted. The M signals are sinusoidal tones of duration T_h, with frequency spacing of $2\triangle$. In order that these tones be orthogonal when aligned in time, $2\triangle T_h$ must be integer; $2\triangle T_h=N$. Taking the spacing between hopping frequencies equals to $2M\triangle$, the minimum spacing between sinusoidal tones transmitted with different hopping frequencies equals $2\triangle$ as well. Multipath and multi-user interference signals are not time aligned with the useful signal.

We assume that the channel between the kth transmitter and the corresponding receiver is a multipath Nakagami slow fading channel. Each path is characterised by three random variables β_{ki}, τ_{ki} and θ_{ki} which are defined as the gain, delay and phase, respectively, of the ith path from the kth user to the receiver. We assume that the number of paths between the

kth transmitter and the receiver equals L for all users and that the gains β_{kl} are independent Nakagami random variables with the parameters. The path delays τ_{kl}, also independent, are allowed to have uniform distribution in $[0, T_h]$, where T_h is the hop duration. That is, we restrict our attention to channels for which the multipath time delay spread is less than the coded bit duration T_h. This, together with the fact that two consecutive hopping frequencies are always different, guarantees that channel does not introduce multipath interference from the same user. Further, we assume, that the path phase θ_{kl} is uniformly distributed in $[0, 2\pi]$. Finally, the channel introduces additive white Gaussian noise $n(t)$, with two side power spectral density $N_0/2$, statistically independent of the multipath. Hence, the received signal is given by

$$r(t)=\sqrt{2P}\sum_{k=1}^{K}\sum_{l=1}^{L}\beta_{kl}\Psi(t-\tau_{kl})a_k(t-\tau_{kl})\cdot\cos\{2\pi[f_c+f_k(t-\tau_{kl})+b_k(t-\tau_{kl})\triangle]t+\psi_{kl}(t)\}+n(t) \qquad (3)$$

where, $\psi_{kl}(t)=\alpha_k(t-\tau_{kl})-2\pi[f_c+f_k(t-\tau_{kl})+b_k(t-\tau_{kl})\triangle]\tau_{kl}-\theta_{kl}$.

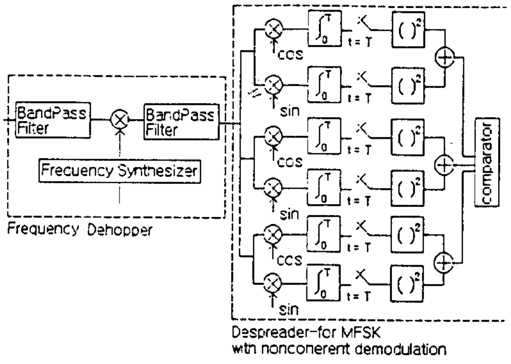


Fig. 2. Receiver for a hybrid DS-SFH/CDMA system employing MFSK modulation.

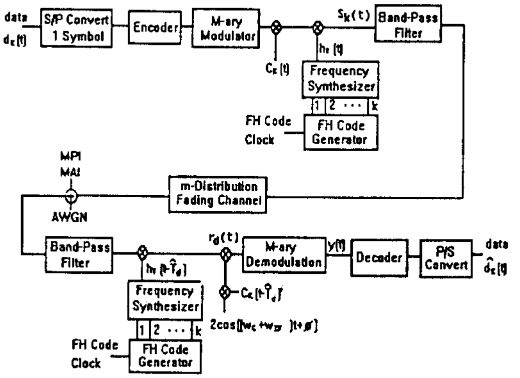


Fig. 3. Block diagrams of hybrid DS/SFH transmitter, channel and receiver.

The receiver, shown in Figure 2, consists of a frequency-dehopper, an MFSK demodulator (consisting of a bank of M matched filters and square law envelope detectors Figure 3, a combing circuit, a hard decision device, a Reed Solomon (RS) decoder and Parallel to Serial (P/S) convertor. Figure 3 shows the configuration of the hybrid DS/SFH.

The received signal $r(t)$ enters a bandpass filter which removes out of band noise. The mixer of the dehopper performs the appropriate for frequency translation, according to hopping sequence $f_i(t)$ of user i, which is arbitrarily chosen as the reference user. We assume that the hopping pattern of the receiver is synchronized with the hopping pattern of the signal associated with the jth path of user i. The dehopper introduces a phase $d_i(t)$, which is the constant over a hopping interval; $d_j^{(i)}$, stands for the constant phase during the Jth hop. The bandpass filter which follows the mixer removes high frequency terms.

The resulting dehopper output signal is given by

$$r_d(t)=\sqrt{2P}\sum_{k=1}^{K}\sum_{l=1}^{L}\beta_{kl}\,\delta[f_k(t-\tau_{kl}),f_i(t-\tau_{ij})]$$
$$\Psi(t-\tau_{kl})\;a_k(t-\tau_{kl})\cdot\cos\{2\pi[f_c+b_k(t-\tau_{kl})\triangle]t+\psi_{kl}(t)\}+\hat{n}(t) \tag{4}$$

where $\hat{n}(t)$ can be treated as additive white Gaussian noise with two side power spectral density $N_0/2$. The phase waveform $\psi_{kl}(t)$ is defined $\psi_{kl}(t)=\psi_{kl}-d_i(t)$, and the Kronecker function $\delta(\cdot,\cdot)$is defined by $\delta(u, v)=1$ for $u=v$ and $\delta(u, v)=0$ for $u\neq v$ Note that the dehopper suppresses, at any instant t, all path signals whose hopping frequency at in stant t differs from $f_i(t-\tau_{ij})$. Evidently, the reference path signal is not suppressed; the other path signals from the reference user are suppressed only during a part of a hop, depending on the relative delay of the considered path with respect to the reference path. Path signals from users different from the reference user contribute to the dehopper output only during those time intervals for which their frequencies accidentally equal the frequency of the reference path signal. The M square-law detector outputs are sampled at the instants $\lambda T_s+\tau_{ij}+uT_h(u=1, 2,\cdots, U;\lambda=1, 2, \cdots)$; this yields the M random variables $\{|Z_{\lambda}^{(u)}(\lambda)|^2\}$ for $l=\pm1, \pm3,\cdots, \pm(M-1)$, where

$$Z_{1}^{(u)}(\lambda)=\int_{\lambda T_s+\tau_{ij}+uT_k}^{(\lambda T_s+\tau_{ij}+(u+1)}\{2r_d(t)\Psi(t)$$
$$\exp[j2\pi(f_c+\lambda\triangle)t]\}dt \tag{5}$$

The receiver bases its hard decision about the coded symbol $b_i^{(\lambda)}$ on the M combined random variables $\{|Z_{\lambda}^{(u)}(\lambda)|^2\}$ for $l=\pm1, \pm3,\cdots, \pm(M-1)$, where $|Z_{\lambda}(\lambda)|^2=\sum_{u=1}^{U}|Z_{\lambda}^{(u)}(\lambda)|^2$ by selecting the largest $|Z_{\lambda}(\lambda)|^2$, and declaring that the symbol with the corresponding value of λ has been transmitted.

2-2 Channel model

In this paper, we consider the mobile communication channel which is characterized by AWGN, MAI, MPI and Nakagami fading. As a fading model, we consider the frequency non-selective Nakagami fading which provides more flexibility in matching experimental data than Rayleigh, lognormal, or Rician distribution[11]. It has the advantage of including the Rayleigh and the one sided Gaussian distributions as a special cases. Also according to the reference[12], there is a close fit between the Nakagami distribution and the Rician distribution when the following parameter relationship holds:

$$K_r=\frac{\sqrt{(m^2-m)}}{m-\sqrt{(m^2-m)}},\quad m\geq1, \tag{6}$$

where K_r ; direct to diffuse signal power ratio,

m ; fading index $(m\geq\frac{1}{2})$.

In Nakagami fading channel the probability density function $(p.\ d.\ f)$ of $\gamma_k(k=1, 2, 3,\cdots,L)$ is given by[13]

$$p_{\alpha^2}(\gamma_k)=\frac{m_k^{m_k}\,\gamma_k^{m_k}-1}{\Gamma(m_k)\,\overline{\gamma_k}^{\,m_k}}\exp\left(-\frac{m_k\gamma_k}{\overline{\gamma_k}}\right), \tag{7}$$

where $\Gamma(\cdot)$; gamma function,

γ_k ; instantaneous SNR$(=\alpha^2\frac{E_b}{N_0})$,

$\overline{\gamma_k}$; average SNR,

α ; Nakagami random variable.

Ⅲ. System performance

To evaluate the error probabilities of the systems under consideration, we first need to provide a detailed description of the outputs of the various matched filter receivers. The various components of the interference must be identified and characterized. Although for hybrid DS/SFH-CDMA systems these components resemble the corresponding entities of the DS/CDMA systems described in[7], there are also essential differences which make their accurate description necessary.

For hybrid systems with MFSK modulation we can use the description of the various components of the M branches of the demodulator of Fig. 3 are given

$$Z_l^{(u)}(\lambda)=F_l(\lambda)+N_l(\lambda)+\sum_{l=1,l\neq 1}^{L} I_{il} + \sum_{k=1,k\neq 1}^{K}\sum_{l=1}^{L} I_{kl} \tag{8}$$

Let us consider the right-hand side of (8) in more detail.

$F_l(\lambda)$ is a complex-valued useful signal term which is due to the specular component and the fading component of the lth path signal from the reference user.

$$F_l(\lambda)=\sqrt{2P}\,\beta_{il}T_h\delta(\lambda,\ b_i^{(\lambda)})\exp[lV_1] \tag{9}$$

where V_1 is a phase angle, uniformly distributed in $(0,\ 2\pi)$. The real and imaginary parts of the useful term are uncorrelated and have the same variance equal to $2P\rho_0T_h^2$.

$N_l(\lambda)$ is a complex-valued Gaussian noise term. Its real and imaginary parts of the useful term are uncorrelated and have the same variance equal to N_0T_h.

$I_{il'}(l'\neq l)$ is a complex-valued multipath interference term, which is due to the $L-1$ other path signals of the reference user. The contributions from different paths are uncorrelated.

$I_{kl'}(k\neq i)$ as a complex-valued multi-access interference term, which is due to the path signal from the $K-1$ nonreference user.

The random variable k_h takes the values 0, 1,⋯, $K-1$, with

$$P_h(k_h)=\binom{K-1}{k_h}\ P_h^{k_h}\,(1-P_h)^{K-1-k_h},\qquad 0\le k_h<K \tag{10}$$

Frequency hits occur when signals from other users hop into the desired users frequency slots during the interval $[nT,\ (n+1)T]$. Two kinds of frequency hits are considered, full hits and partial hits. A full hit from an interfering user occurs when the signal is present in the desired user's frequency slot during the entire symbol duration. A partial hit occurs when the interfering signal is present for only part of the symbol duration.

For asynchronous hybrid DS/FH spread spectrum systems, and a nonselective random memoryless fading channel, a full hit from the kth user occurs during the nth data symbol if $f_i(t-\tau_k)=f_i(t)$. for all values of t in the interval $[nT,\ (n+1)T]$. In this case, the probability of a full hit is given by

$$P_f=[1-N_b(1-q^{-1})]q^{-1} \tag{11}$$

where N_b is the number of symbols transmitted during a dwell time. A partial hit from the kth user for a nonselective fading channel occurs when (8) is satisfied for some but not all values of t in the interval $[nT, (n+1)T]$. The probability of this event is

$$P_p = 2N_b^{-1}(1-q^{-1})q^{-1} \tag{12}$$

Thus the probability of a hit is given by $P_h = P_f + P_p$.

In the case of synchronous hybrid DS/FH spread spectrum systems operating in a nonselective random memoryless fading channel, the interfering users can only cause full hits with probability

$$P_h = q^{-1} \tag{13}$$

where q denotes the number of available hopping frequencies.

The above result for the multi-access interference assumes that all paths signals of a hitting user cause full hits, and neglects the effects that occur when the considered reference user bit is only partially hit. By considering upper and lower bounds it has been shown in[9], [10] that these effects are negligibly small, because full hits are much more probable than partial hits in the case of SFH (*i. e.*, $N_b \gg 1$).

The average bit error probability, P_e at the hard decision ouput is then given by

$$P_e = \sum_{k_h=0}^{K-1} P_b(k_h)\, P_h(k_h) \tag{14}$$

where $P_h(k_h)$ is given by (10) and $P_b(k_h)$ is the bit error probability after decoding, conditioned on the number of interfering nonreference users.

When the interhop interleaving technique is used, each bit of a code word is transmitted during different hop. Therefore, all bits of the code word are hit independently by nonreference users. The resulting bit error rate (BER) after hard decision decoding is approximately given by[9]

$$P_b(k_h) = \left[\frac{1}{n} \sum_{i=t+1}^{n} i \binom{n}{i} P_e^i(k_h) \right. \\ \left. (1-P_e(k_h))^{n-i}\right] \tag{15}$$

where n is the number is bits in a code word and t denotes the errors that the code can correct. In our discussion, the considered black codes are Hamming (7, 4) code, the BCH (15, 7) code and the RS (7, 4), (15, 7) code. Following Barrow, we find the symbol error probability for Nakagami m-fading by averaging the nonfading symbol error probability over the underling fading random variable. Barrow considered the binary case only, but in the following we generalize to MFSK. Here the symbol error probability is given by

$$P_M = \int_0^{\infty} \sum_{i=1}^{M-1} \binom{M-1}{i} \frac{(-1)^{i+1}}{i+1} \\ \cdot \exp\left(\frac{-i}{i+1} \frac{E_s \alpha^2}{N_o}\right) p_\alpha^2(\gamma_k)\, d\gamma_k \tag{16}$$

where $P_b = \dfrac{M}{2(M-1)} P_M$ and $E_b = \dfrac{E_s}{\log_2 M}$ we find the MFSK bit error probability

$$P_{bm}(k_h) = \frac{M}{2(M-1)} \sum_{i=1}^{M-1} \binom{M-1}{i}$$

$$\frac{(-1)^{i+1}}{i+1} \cdot \left| \frac{m}{m+\frac{i\overline{\gamma_b}}{i+1}} \right|^{m} \quad (17)$$

where

$$\overline{\gamma_b}=\left\{\left(\frac{\overline{2E_b}\log_2 M}{N_0}\right)^{-1}+\frac{2[k_h L\gamma+(L-1)]}{(3N\log_2 M)}\right\}^{-1}$$

3-1 MRC diversity techniques

The γ at the output of L branches MRC diversity is given by[13]

$$\gamma=\sum_{k=1}^{L}\gamma_k.$$

If we assume the fading as well as noise of each branch is to be statistically independent and the ratio m_k/γ_k is the same for all branches, then the p. d. f of the composite γ is

$$p_{Lb}(\gamma)=\frac{\gamma^{mLb-1}}{\Gamma(mLb)}\left(\frac{m}{\overline{\gamma}}\right)^{mLb}\exp\left(-\frac{m\gamma}{\overline{\gamma}}\right) \quad (18)$$

The average error probability of noncoherent M-ary FSK signal over the Nakagami fading channel with MRC diversity reception is

$$P_e(k_h)=\int_0^\infty P_M \cdot p_{L_b}(\gamma)d\gamma=\sum_{j=1}^{M-1}(-1)^{j+1} \quad (19)$$
$$\cdot\binom{M-1}{j}\frac{1}{j+1}\left(1+\frac{\overline{\gamma_b j}}{m(j+1)}\right)^{-mL_b}$$

where

$$\overline{\gamma_b}=\left\{\left(\frac{\overline{2E_b}\log_2 M}{N_0}\right)^{-1}+\frac{2[k_h L\gamma+(L-1)]}{3N\log_2 M}\right\}^{-1}$$

, L_b is diversity branch number.

Ⅳ. Numerical Results and Discussions

In this section, we present numerical results about the BER of hybrid DS /SFH-CDMA system employing noncoherent M-ary frequency shift keying (MFSK) modulation in a multiple Nakagami fading channel with diversity and coding. Multipath interference number (L) and multi-access interference number (K) is taken into account and the spectral efficiency is calculated for uncoded as well as channel coding systems. Predetection multipath maximal ratio combining diversity in conjunction with interleaved channel coding (Hamming(7, 4) code, BCH(15, 7) code and RS(7, 4), (15, 9) code) is employed for improving the bit error rate (BER) performance.

Fig. 4 illustrates the error performance in Nakagami fading channel. m=0.5 half Gaus-

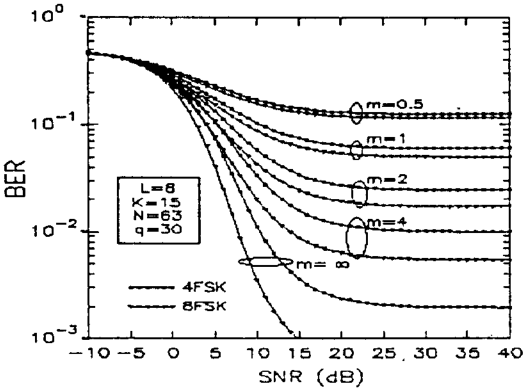


Fig. 4. BER of hybrid DS /SFH 4, 8FSK signal with the variation of m (K=15, L=8, N=63, q=30).

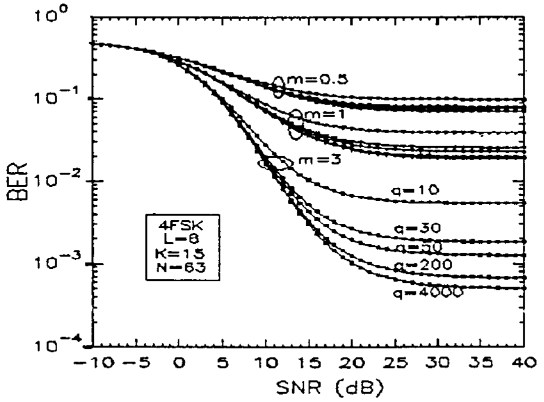


Fig. 5. BER of hybrid DS/SFH 4FSK signal with the variation of a number of frequency hopping in Nakagami fading (K=15, L=8, N=63).

sian fading, *m*=1 Rayleigh fading. As *m* increases, the depth of fading becomes shallower. As shown in the figure not adopting any improvement techniques, we could not obtain a reliable performance even in high SNR region.

Shown in Fig. 5 for different values of *q*, the number of available hopping frequencies. Increasing *q* reduces the effect of multi-access interference, because of the decreasing probability of a hit. When *q* is much larger than the number of users (*K*), the BER at high SNR is dominated by the multipath interference while the multi-access interference is negligible. At low SNR, the BER is essentially independent of *q* because additive noise is the dominating disturbance.

Fig. 6 shown the uncoded BER in the case of PN sequence, for various *N* of codelength. It is clearly seen that increasing the PN code number considerably reduces the BER.

Fig. 7 shown the uncoded BER in the case of MRC, for various (Lb) of diversity. It is clearly seen that increasing the order of diversity considerably reduces the BER.

In Fig. 8, the BER's corresponding to the coding and *m*=1 is shown for with MRC diversity respectively. Also, noncoding and nondiversity BER's are plotted in order to allow for comparison. It is obvious from Fig. 8, that using in order to obtain a satisfactory BER

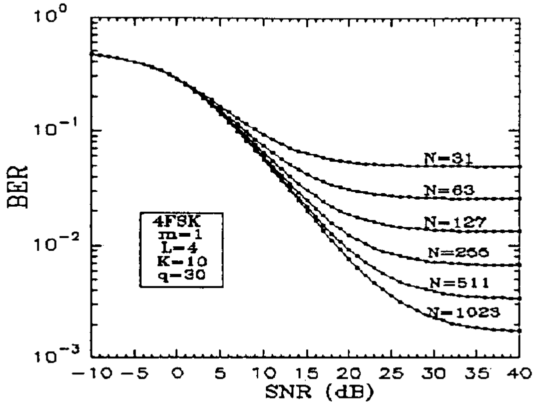


Fig. 6. BER of hybrid DS/SFH 4 FSK signal with the variation of *N* (K=10, L=4, q=30, m=1).

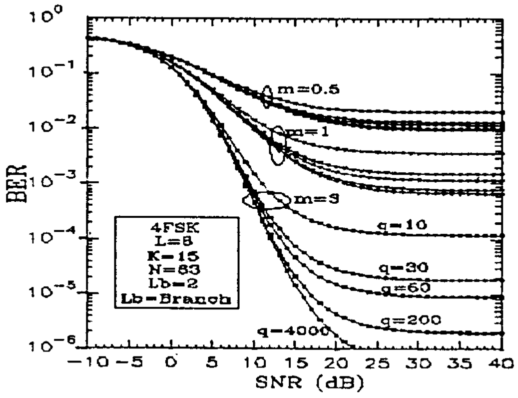


Fig. 7. BER of hybrid DS/SFH 4FSK signal adopting diversity (K=15, L=8, N=63, q=50).

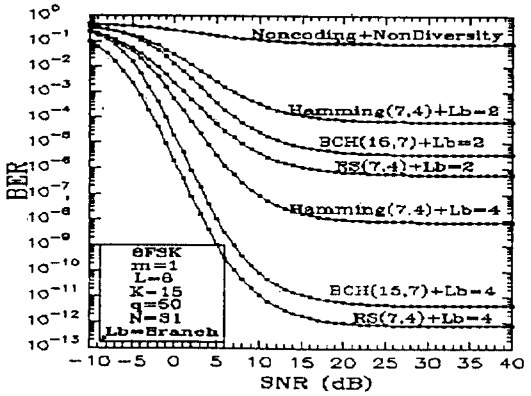


Fig. 8. BER of hybrid DS/SFH 8FSK signal adopting Hamming, BCH and RS code plus diversity (K=15, L=8, N=31, q=50, m=1).

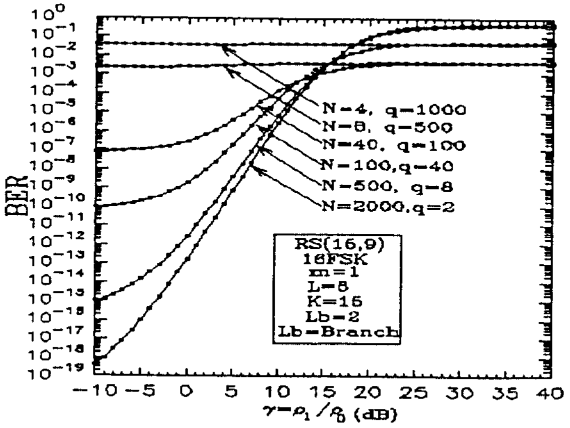


Fig. 9. BER of hybrid DS/SFH CDMA systems adopting RS code plus diversity in different interference powers (K=15, L=8, Lb=2, m=1).

performance, diversity and coding should be combined.

The asymptotic $E_b/N_0=20$(dB) the average bit error probabilities MRC diversity combined with RS(15, 9) coding is shown in Fig. 9, as a function of the nonreference user average path power ratio $\gamma=\rho_1/\rho_0$. We have considered various combinations of numbers of hopping frequencies (q) and PN sequence periods (N), yielding the same transmission bandwidth (constant value of qN).

V. Conclusion

The BER performance of noncoherent DS/SFH CDMA with predetection multipath diversity and interleaved coding for mobile communication multipath Nagakami fading channels has been evaluated. System performance is affected by the multipath fading and multi-access interferences.

It is known that system performance can be improved by process gain (N, q), MRC diversity, error correcting, and MRC diversity plus error correcting codes.

From our results, we know that the error performance more deteriorates as depth of fading becomes deeper. In Rayleigh fading environment ($m=1$), increasing of the the number of frequency hopping (q) reduces the effect of multi-access interference, because it decreases the probability a hit. When q is much larger than the number of user (K), the probability of error in high E_b/N_0 region is dominated by the multipath interference while the multi-access interference is negligible. Hybrid system with MRC diversity plus interleaved coding for mobile communication multipath Nakagami fading channels, and show that hybrid CDMA system can have the appropriate performance even though there is a near far problem.

Acknowledgment

The authors would like to thank Morinaga Laboratory, Osaka University for his valuable discussion. This study was supported by KOSEF (Korea Science and Engineering Foundation).

Reference

[1] R. C. Dixon, *Spread spectrum systems*, Willy Interscience, 1976.

[2] M. K. Simon, et al., *Spread spectrum communication*, vol. Ⅱ, 1985.

[3] R. E. Ziemer and R. S. Peterson, *Digital communications and spread spectrum systems*, New York: Macmillan, 1985.

[4] G. R. Cooper and C. D. McGillem, *Modern communication and spread spectrum*, New York: McGraw-Hill, 1986.

[5] J. G. Proakis, *Digital communications*, McGraw-Hill, 1989.

[6] T. T. Ha, *Digital Satellite communications*, New York: McGraw-Hill, 1986.

[7] E. A. Geraniotis, "Noncoherent hybrid DS-SFH spread spectrum multiple-access communications," *IEEE Trans. Commun.*, vol. COM-34, no. 9, pp. 862-872, Sep. 1986.

[8] E. A. Geraniotis, "Coherent hybrid DS-SFH spread spectrum multiple-access communications," *IEEE J. Select. Areas Commun.*, vol. SAC-3, no. 5 pp. 695-705, Sep. 1985.

[9] J. Wang and M. Moeneclaey, "Hybrid DS/SFH spread spectrum multiple access with predetection diversity and coding for indoor radio," *IEEE J. Select. Areas Commun.*, vol. 10, no. 4, pp. 705-713, May 1992.

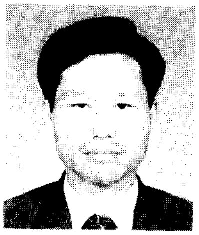
[10] J. Wang and M. Moeneclaey, "Hybrid DS/SFH SSMA with predetection diversity and coding over indoor radio miltipath Rician fading channels," *IEEE Trans. Commun.*, vol. 40, no. 10, pp. 1654-1662, Oct. 1992.

[11] E. Al-Hussaini and A. Al-Bassiouni, "Performance of MRC diversity systems for the detection of signals with Nakagami fading," *IEEE Trans. on Commun.*, vol. COM-33, no. 12, pp. 1315-1319, Dec. 1985.

[12] P. J Crepeau, "Uncoded and coded performance of MFSK and DPSK in Nakagami fading channels," *IEEE Trans. on Commun.*, vol. 40, no. 3, pp. 487-493, March 1992.

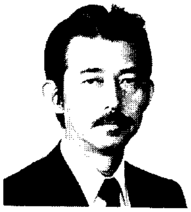
[13] T. Namekawa, S. Okui, *Communications Spectrum systems(in Japenese)*, Morikita Publishing Co., 1990.

강 희 조



was born in Youngdong, Korea in 1961. He received the B.S. degree in electronics engineering from Wonkwang University, Chonbook, Korea, in 1986, and M. E. degree in electronics engineering from Soongsil University, Seoul, Korea, in 1988, and Ph. D. degree in electronics engineering from Hankuk Aviation University, Kyonggido, Korea, in 1994, respectively. From 1994 to 1995 he was at the ETRI of Satellite Network Communication, as a visiting researcher. During 1996 to 1997, he was at the University of Oaska, Japan, Post-Doc. He is currently an Associate Professor in the Department of the Electrical & Electronic Engineering at Dongshin University, working in the area of radio, mobile, spread spectrum, and satellite communication systems and EMC. Dr. Kang is a member of the IEEE and the IEICE.

Norihiko Morinaga



received the B.E. degree in electrical engineering from Shizuoka University, Shizuoka, Japan, in 1963, and M.E. and Ph. D. degrees from Osaka University, Osaka, Japan, in 1965 and 1968, respectively. He is currently a Professor at the Department of the Communications Engineering, Osaka University, working in the area of radio, mobile, satellite, and optical communication systems and EMC. He is an Edition-in-Chief of IEICE Trans. B, a guest researcher of CRL, Ministry of Posts and Telecommunications, and National Space Development Agency. He received a Telecom Natural Science Award, 1993, Telecom System Technology Award, 1995, and 1995 Award for best paper, IEICE. Dr. Morinaga is a senior member of the IEEE, a member of the IEICE and the Institute of Television Engineers of Japan.