MTJ Performance Analysis of Hybrid DS/SFH Spread-Spectrum System using MSK or QPSK Modulation over Rayleigh Fading Channel

레이리 페이딩 채널상에서 MSK 혹은 QPSK 변조 방식의 하이브리드 DS/SFH 확산 스펙트럼 시스템의 다중톤 재밍 성능 분석

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Abstract

Performance analysis and comparison of the hybrid DS-SFH spread-spectrum (SS) system using coherent MSK and QPSK modulation techniques over Rayleigh fading channel are considered in the presence of MTJ(multi-tone jamming). To analyze the *BER* performance of the hybrid systems with or without the Rake receiver, signal-to-noise plus interference ratio is derived as a function of the average signal-to-noise ratio, the jammer-to-signal ratio and other system parameters. Numerical results show that the performance difference between the two modulation schemes, MSK and QPSK, is negligible for low *JSR*, while it becomes significant with the increase of *JSR*. In multi-path Rayleigh fading channel without Rake receiver, the performances of the two modulation schemes are slightly improved as the DS spreading gain is increased when the total SS bandwidth is fixed. In particular, there is an optimum DS spreading gain for large *JSR*, in which a minimum *BER* is achieved, while only DS spreading gives the best performance for small *JSR*. For hybrid systems with Rake receiver, it is shown that the hybrid system of the MSK modulation scheme provides better anti-jamming performance and larger performance improvement with the increase of multi-path resolution capability of Rake receiver than that of QPSK modulation for all conditions.

Key words : MTJ, DS/SFH Spread-Spectrum System, MSK, QPSK, Rayleigh Channel, and *JSR*

요 약

다중톤 재밍이 있는 경우, 레이리 페이딩 채널상에서 MSK혹은 QPSK 변조 방식을 사용하는 하이브리드 DS/SFH 확산 스펙트럼 시스템의 성능분석과 비교를 연구한다. 신호대 잡음비, 재머전력재 신호전력비(*JSR*) 그리고 기타 시스템 파라미터를 이용하여 신호대 잡음과 간섭비(*SNIR*)를 유도하여 Rake 수신기가 있을 때와 없을 때의 *BER* 성능을 분석한다. 수치 분석 결과, 재머전력재 신호전력비(*JSR*)가 작을 때는 MSK와 QPSK 변조 방식 사이의 성능은 별차이가 없으나, 재머전력재 신호전력비(*JSR*)가 커짐에 따라서 큰 성은의 차이가 나타난다.

Rake 수신기가 없을 때는 DS 처리 이득이 커짐에 따라서 두 변조 방식의 성능이 약간씩 개선된다. 재머전력재 신호전력비(*JSR*)가 작을 때는 DS 처리이득만이 최선의 성능을 좌우하지만, 재머전력재 신호전력비(*JSR*)가 클 때는 *BER*을 최소시키는 최적의 DS처리이득이 있다.

Rake 수신기가 있는 경우에는, 모든 조건에서 MSK변조방식을 사용하는 하이브리드 DS/SFH 확산 스펙트럼 시스템이 QPSK 변조 방식을 사용하는 경우보다 항재밍 성능이 강하고 더 큰 성능 개선이 있음을 보인다.

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Ⅰ. Introduction

It has been known that SS communication systems are very effective under environments of multi-path fading channel, multiple-access interference and intentional jamming. Although DS SS system is effective in multi-path fading channel, power control is needed to overcome the near-far problem. But if this system is used with FH SS system, the problem can be overcome[1]~[4]. However, a hybrid SS system has a difficulty of system implementation.

A great deal of studies on SS system has been accomplished for various modulation techniques[3]~[11]. The previous results have shown that system performance differs according to the modulation techniques. MSK modulation scheme is highly bandwidth-efficient as compared to others, i.e., QPSK or OQPSK[1]. In this paper, MSK modulation scheme is novelly considered and compared with QPSK system over Rayleigh fading channel under the multi-tone jamming.

The performance of a hybrid SS system for various modulation techniques was also considered in the presence of multi-tone jamming. In the literature we have studied, there is no paper on the analytical derivation of *BER* equation for DS/SFH SS using MSK modulation over Rayleigh fading channel in the presence of multi-tone jamming. Among the previous results, Zheng and Zhang, and Gangadhar and Gandhi have studied for hybrid SS system using MSK modulation technique in [7] and [8], respectively. However, Zheng and Zhang did not consider fading channel, and Gangadhar and Gandhi did not consider the jamming environment. In this paper, the performance of hybrid SS systems using MSK and QPSK modulation techniques are analyzed over Rayleigh fading channel in the multi-tone jamming environment. Both information and jamming signals are faded. To analyze the performance improvement by diversity in the worst jamming, the system using a Rake receiver is also considered.

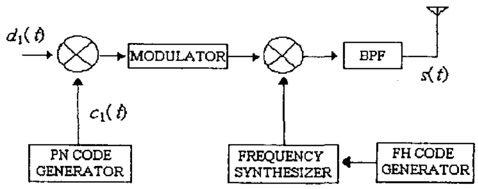

Fig. 1. Transmitter structure(*I* channel).

Ⅱ. Hybrid Spread Spectrum System

In a hybrid DS/SFH SS system, each of K simultaneous users is assigned a code sequence to spread the data sequence by DS spreading gain N and to hop the carrier frequency by FH processing gain N_{FH} within a total SS bandwidth W_{ss}, i.e., the total processing gain is $G=NN_{FH}$.

2-1 Hybrid DS/SFH MSK SS System

In a hybrid DS/SFH MSK SS system, the transmitted signal for kth user is

$$s_k(t)=\sqrt{2P}\{c_{k,I}(t)d_{k,I}(t)\cos[2\pi(f_c+f_{h,k}(t))t+\pi t/T_c+\theta] \\ +c_{k,Q}(t)d_{k,Q}(t)\sin[2\pi(f_c+f_{h,k}(t))t+\pi t/T_c+\theta]\} \quad (1)$$

where f_c is the carrier frequency, P is the transmitted power of the information signal, $d_1(t)$ and $d_2(t)$ of duration T_s are data sequences of I and Q channels, and $c_1(t)$ and $c_2(t)$ of duration T_c are DS spreading seq- uences of I and Q channel. It is assumed that there are N chips in T_s, i.e., $N=T_s/T_c$. The hopping frequency $f_h(t)$ of duration T_h is derived from a set of N_{FH} frequencies equally spaced, i.e., the hopping frequency spacing is equal to the DS spreading bandwidth, W_{DS}, and the number of transmitted data per hop is a positive integer $N_h=T_h/T_s$. θ is the random phase generated from the transmitter and uniformly distributed in $[0,2\pi]$. In this paper, only I channel is considered for simplicity of analysis.

The multi-tone jamming signal takes the form

$$J(t)=\sqrt{2P_J/N_J}\sum_{j=1}^{N_J}\cos(2\pi f_j t+\phi_j) \quad (2)$$

where P_J is the total jamming power, N_J is the number of the jamming tones, i.e., the jammer does equally distribute P_J for N_J jamming tones, f_j is the jth jamming frequency and ϕ_j is the random phase of jth jamming tone signal uniformly distributed in [0, 2π]. It is assumed that jammer does not know the pattern of hopping frequency, but it does place its jamming tone on the center of hopping frequency for the jammed hop slot. In this paper, we consider the multi-path Rayleigh fading channel with impulse response represented as [9]

$$h(t) = \sum_{k=1}^{L} \beta_k \delta(t - t_k) \tag{3}$$

where t_k and β_k are the time delay and the path gain, respectively, and $\delta(t)$ is Dirac delta function. In eq. (3), the path gain β_k has Rayleigh distribution and it is given by [12],[13]

$$p_R(\beta_k) = \frac{2\beta_k}{\Omega_k} e^{-\beta_k^2 / \Omega_k} \tag{4}$$

where Ω_k is the second moment of β_k.

Regarding the first path as a reference path, Ω_k is assumed to be related to the second moment of the reference path gain Ω_1, and its relation is given by

$$\Omega_k = \Omega_1 e^{-\delta(k-1)} \tag{5}$$

where δ is the decay rate of gain due to the multi-path fading. Equation (5) is referred to as the multi-path intensity profile (MIP)[5].

From eq. (3), the received signal $r(t)$ is given by

$$r(t) = r_s(t) + r_J(t) + n(t) \tag{6}$$

where

$$r_s(t) = \sum_{k=1}^{L} \beta_k s_{MSK}(t - t_k) \tag{7a}$$

$$r_J(t) = \sum_{k=1}^{L} \beta_{k,J} J(t - t_k) \tag{7b}$$

$\beta_{k,J}$ is the kth path gain of jamming signal, and $n(t)$ is additive white Gaussian noise (AWGN) of the two-sided spectral density of $N_0/2$.

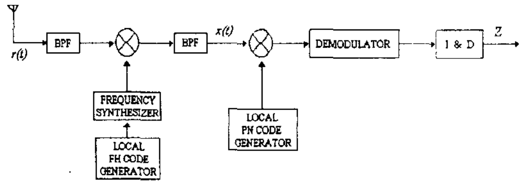

Fig. 2. Receiver structure(I channel).

Consider the first of L paths as a reference, i.e., the receiver is perfectly synchronized to the first path. Then, the dehopping frequency in the receiver is denoted by $f_{h,1}(t)$. Passing through the second BPF after dehopping, the signal $r(t)$ becomes $x(t)$ written by

$$\begin{aligned} x(t) &= BPF\{r(t)\cos[2\pi(f_c + f_{h,1}(t))t + \phi_{h,1}(t)]\} \\ &= x_s(t) + x_J(t) + x_n(t) \end{aligned} \tag{8}$$

where

$$\begin{aligned} x_s(t) = \sqrt{P/2} \sum_{k=1}^{L} \beta_k \delta[f_{h,1}(t), f_{h,k}(t - t_k)] c_1(t - t_k) \\ \times d_1(t - t_k) \cos[\pi t / T_c + \Phi_k(t)] \end{aligned} \tag{9a}$$

$$x_J(t) = \sqrt{P_J / 2N_J} \sum_{k=1}^{L} \beta_{k,J} \cos[2\pi(f_j - f_{h,1}(t) - f_c) + \phi_{k,J} t \tag{9b}$$

$x_n(t)$ is the band-limited version of AWGN. In eq. (9a), $f_{h,k}(t)$ is the hopping frequency of kth path signal and $\delta[u,v]$ is Kronecker function, which is 1 for $u=v$ and 0 for $u \neq v$ (both u and v are real). Assume that the fading is frequency-nonselective, so that the phase estimation can be achieved from the received signal without error. In eq. (9a) and (9b), $\phi_k(t)$ and $\phi_{k,J}(t)$ are constant for symbol duration, T_s, and given by $\phi_k(t) = \theta - 2\pi(f_c + f_{h,1} + (t - t_k))t_k - \pi t_k / T_c - \phi_{h,1}(t)$ and $\phi_{k,J}(t) = \phi_j - 2\pi f_j t_k - \phi_{h,1}(t)$, respectively, where $\phi_{h,1}(t)$ is the phase generated by the frequency dehopper of the receiver. Integrating $x(t)$ for symbol duration T_s gives Z expressed as

$$\begin{aligned} Z &= \int_{nT_s}^{(n+1)T_s} x(t) c_1(t) \cos[\pi t / T_c] dt \\ &= Z_d + Z_J + Z_I + Z_n \end{aligned} \tag{10}$$

where Z_d is the desired signal component received through the reference path(the first path), Z_I is the total ISI (intersymbol interference) component received through $L-1$ paths, Z_J is the jamming component received from L paths, and Z_n is the noise component.

Since the first path is taken as reference, the hopping pattern $f_{h,1}(t)$ and the PN code $c_1(t)$ are known to the receiver. Hence the receiver is synchronized correctly, and the integrator output of the desired signal is

$$Z_d = \sqrt{P/8}\beta_1 T_s d_{1,n} \tag{11}$$

where $d_{1,n}$ is the nth symbol data.

Next, the integrator output by ISI component is

$$Z_I = \sqrt{P/8}\sum_{k=2}^{L}\beta_k \cos(\Phi_k) \times \int_{nT_s}^{(n+1)T_s} c_1(t)c_1(t-t_k)d_1(t-t_k)dt \tag{12}$$

The contribution from multi-tone jamming is obtained as [7]

$$Z_J = \sqrt{2P_J/N_J}\sum_{k=1}^{L}\sum_{i=0}^{N-1}\beta_{k,J}c_{1,i}\frac{\pi T_c}{\pi^2-(2\pi\Delta f T_c)^2} \times (-1)^i \sin[\pi\Delta f T_c(2i+1)+\Phi_{k,J}]\cos(\pi\Delta f T_c) \tag{13}$$

where $c_{1,i}$ is the ith chip of I channel PN sequence and Δf is the frequency difference between the jamming tone frequency and the dehopping center frequency.

2-2 Hybrid DS/SFH QPSK System

From Fig. 1, the transmitted I channel QPSK signal takes the form

$$s_{QPSK}(t) = \sqrt{2P}c_1(t)d_1(t)\cos[2\pi(f_c + f_h(t))t + \theta] \tag{14}$$

where all terms of eq. (14) are the same as the MSK system.

Through the same procedure with previous section, the integrator outputs are written by

$$Z = \int_{nT_s}^{(n+1)T_s} x(t)\cos(2\pi f_c t)dt = Z_d + Z_I + Z_J + Z_n$$

$$Z_d = \sqrt{P/8}\beta_1 T_s d_{1,n} \tag{15}$$

$$Z_I = \sqrt{P/8}\sum_{k=2}^{L}\beta_k \cos(\Phi_k) \times \int_{nT_s}^{(n+1)T_s} c_1(t)c_1(t-t_k)d_1(t-t_k)dt \tag{16}$$

$$Z_J = \sqrt{2P_J/N_J}T_c\sum_{k=1}^{L}\sum_{i=0}^{N-1}\beta_{k,J}c_{1,i}\,\mathrm{sinc}(\Delta f T_c) \times \cos[\pi\Delta f(2i+1)T_c + \Phi_{k,J}] \tag{17}$$

where $\phi_k(t) = \theta - 2\pi(f_c + f_{h,1}(t-t_k))t_k - \phi_{h,1}(t)$, $\phi_{k,J}(t) = \phi_j - 2\pi f_j t_k - \phi_{h,1}(t)$, $sinc(x) = sin(\pi x)/\pi x$ and $\Delta f = f_j - f_{h,1}(t) - f_c$.

Ⅲ. Performance Analysis

3-1 Hybrid DS/SFH MSK System

In this paper, the performance analysis is focused on the worst case multi-tone jamming , i.e., $\Delta f=0$. Using eq. (11), the variance of signal component can be obtained as

$$var\{Z_d\} = \Omega_1 PT_s^2/8 \tag{18}$$

where $\Omega_1 = E\{\beta_1^2\}$ is the second moment of the reference path gain.

If the period of the PN sequence $c_1(t)$ is considerably large, then the sequence may be modelled as random binary sequence, where each chip in the sequence is independently determined. Thus the integral in eq. (12) is a random variable with zero-mean and conditional variance of $2T_s^2/3N$ conditioned on the PN sequence [4],[5]. Therefore, the variance of Z_I can be written as

$$var\{Z_I\} = \frac{PT_s^2}{24N}\Omega_k\sum_{k=2}^{L}e^{-\delta(k-1)} \tag{19}$$

where $\Omega_k = E\{\beta_k^2\}$.

In the case of the worst-case multi-tone jamming, the variance of Z_J is

$$var\{Z_J\} = \frac{P_J N T_c^2}{N_J\pi^2}\sum_{k=1}^{L}\Omega_{k,J}e^{-\delta(k-1)} \tag{20}$$

where $\Omega_{k,J} = E\{\beta_{k,J}^2\}$. Then, the total signal-to-noise plus interference power ratio λ_{jam} can be written as

$$\lambda_{jam}=\left[\frac{1}{2N}\sum_{k=2}^{L}e^{-\delta(k-1)}+\frac{8JSR}{\pi^2 NN_J}\sum_{k=1}^{L}\gamma_k e^{-\delta(k-1)}+\frac{1}{2\lambda_b}\right]^{-1} \quad (21)$$

where $\lambda_b=\Omega_l E_b/N_0$ is the average received *SNR* per bit and $\gamma_k=\Omega_{k,J}/\Omega_l$ is the second moment ratio of jammer and signal.

Next, consider the Rayleigh fading channel effect on the *BER* performance. For fixed β_l in eq. (4), the conditional error probability is given by [1],[2],[12]

$$P_e=Q\left(\sqrt{z}\right) \quad (22)$$

whereand $Q(x)=\int_x^\infty e^{-t^2/2}dt/\sqrt{2\pi}$ z is the average signal to noise plus interference ratio given by eq. (21).

Since β_l is a Rayleigh-distributed random variable, β_l^2 has chi-square density function with two-degree of freedom. Therefore, a random variable z in eq. (22) is chi-square distributed. Then the probability density function of z is given by [12]

$$p(z)=\frac{1}{\lambda}e^{-z/\lambda}, \quad z\geq 0 \quad (23)$$

Consequently, the average error probability takes the form

$$P_e=\int_0^\infty Q\left(\sqrt{z}\right)p(z)dz \quad (24)$$

After integrating, the above equation becomes [1,2]

$$P_e=\frac{1}{2}\left(1-\sqrt{\frac{\lambda}{2+\lambda}}\right) \quad (25)$$

Then λ in eq. (25) is substituted into λ_{jam} of eq. (21). To discriminate the jamming and the non-jamming case, let us denote that $P_{e,jam}$ and λ_{jam} are the jamming case, and that $P_{e,no}$ and λ_{no} are the non-jamming case, respectively. From the above results, the total error probability of hybrid DS/SFH MSK system is

$$P_b=\rho P_{e,jam}+(1-\rho)P_{e,no} \quad (26)$$

where $\rho=N_J/NFH$.

3-2 Hybrid DS/SFH QPSK System

Through similar derivation, under the worst case multi-tone jamming the total signal-to-interference power ratio for QPSK can be written as

$$\lambda_{jam}=\left[\frac{1}{2N}\sum_{k=2}^{L}e^{-\delta(k-1)}+\frac{2JSR}{NN_J}\sum_{k=1}^{L}\gamma_k e^{-\delta(k-1)}+\frac{1}{2\lambda_b}\right]^{-1} \quad (27)$$

and the total error probability is the same as eq. (26), except that only λ_{jam} is different from eq. (21).

3-3 Hybrid DS/SFH System with a Coherent Rake Receiver

In this subsection, we consider the effect of a Rake receiver on the system performance in the worst case multi-tone jamming over multi-path Rayleigh fading channel. It is assumed that this receiver is a coherent Rake receiver and capable of resolving L_r-path out of L-multi-path. Also, the Rake receiver is assumed to have perfect estimates for the fading chanenel. To demonstrate the performance improvement by diversity in a hybrid DS/SFH system with a Rake receiver, it is assumed that a condition $L_r\leq L$ is always satisfied. Also, for the simplicity of analysis, we consider only a Rayleigh fading channel with uniform MIP, i.e., $\delta=0$.

Using the result of [5], the average error probability for Rayleigh fading channel with $\delta=0$ is given by

$$P_e=\frac{1}{2}\left[1-\mu\sum_{k=0}^{L_r-1}\binom{2k}{k}\left(\frac{1-\mu^2}{4}\right)^k\right], \quad \mu=\sqrt{\frac{\lambda}{2+\lambda}} \quad (28)$$

where λ is the average signal to noise plus interference ratio given as eq. (21) or eq. (27). In a Rayleigh faidng channel without Rake receiver, i.e., $L_r=1$, eq. (28) is reduced to eq.(25). Then, the total average bit error probability is given by eq. (26).

Ⅳ. Numerical Results and Discussions

In this section, we evaluate the system performance for different values of DS spreading gain, N, and the number of FH slots, N_{FH}, when the total processing gain is 30 dB (NN_{FH}=30 dB). Also, we investigate the performance difference between the two hybrid DS/ SFH systems using MSK and QPSK modulation sche- mes with or without the Rake receiver. Fig. 3 shows the *BER* versus *N* for hybrid systems with MSK and QPSK modulation schemes. It is shown that MSK modulation scheme always outperforms QPSK one and the performance diffe- rence between the two modulation schemes becomes larger with increase of *JSR*. When *JSR* is large or average *SNR* is small, the overall *BER* performance is almost constant for all DS spreading gains, irrespective of the modulation scheme. It is because that although the effect of the jamming power in a jammed slot can be reduced by DS spreading gain, the effect of multi-tone jamming in the overall spread-spectrum bandwidth becomes larger with de- crease of the number of FH slots since the total spreading bandwidth is fixed.

Fig. 4 plots the effect of the number of jamming tones, N_J, on the *BER* performances of the two hybrid systems for the average *SNR*. It is observed that the performance difference between the two hybrid systems becomes larger as both average *SNR* and *JSR* are increased. It means that the system performance is more deteriorated as the jamming power is distributed to more jamming tones, when

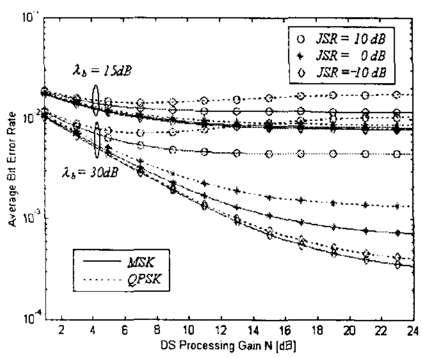

Fig. 3. *BER* versus DS spreading gain for the two hybrid systems when δ=3, γ_k=1, L=4, L_r=1 and N_J=4.

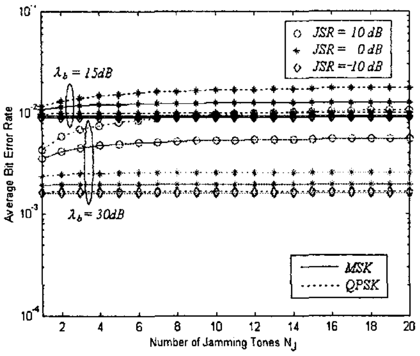

Fig. 4. The effect of the number of jamming tones, N_J, on the *BER* when N=10 dB, δ = 3, γ_k=1, L=4, and L_r=1.

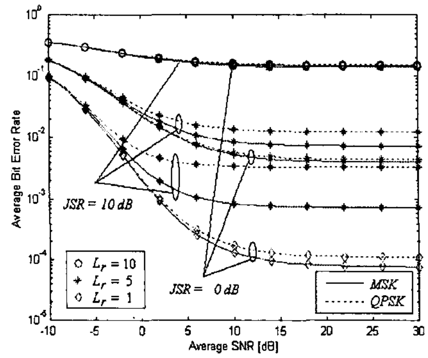

Fig. 5. *BER* versus average *SNR* according to L_r when N=10 dB, L=10, δ=0, γ_k=1 and N_J = 8.

JSR are relatively large. Furthermore, it becomes more significant in the case using a hybrid system with QPSK modulation scheme when both *JSR* and average *SNR* are large. Therefore, the communicator should allocate the small number of hopping slots as possible in a given spread spectrum bandwidth, in particular for high *JSR* and average *SNR*. In other words, it is more efficient to use only DS spreading than hybrid spread spectrum system for large *JSR*. To show the performance improvement by a Rake receiver in multi-path Rayleigh fading channel, Fig. 5 plots the average *BER* as functions of *N*, *JSR* and L_r. It is apparent that *BER* performances of both hybrid systems are significantly improved as the number of resolvable paths, L_r, is increased and show an error floor although all multi-path is resolved by the Rake receiver, that is, L_r=L. We also observe that the performance difference between the two hybrid systems becomes large, in particular for high *JSR*, i.e., *JSR*=10 dB as the multi-path resolution capability of the Rake receiver is increased. However, for a small *JSR* the two hybrid systems show almost the same *BER* performance, independent of other system parameters such as the number of resolved paths or average *SNR*. Consider the case that Rake receiver can resolve all multi-path. It is plotted in Fig. 6. As shown, if the Rake receiver can resolve all multi-path, i.e., L=L_r, the performance improvement becomes larger as the number of multi-path, L, is increased. In Fig. 5 and 6, it is also shown the hybrid system with MSK modulation scheme outperforms that of QPSK one, irrespective of the number of resolved paths, except for non-diversity reception, L_r=1, in the worst case multi-tone jamming environment with high *JSR*. Also, the amount of improved performance becomes larger in a hybrid MSK system with increase of L_r.

In Table 1, it is summarized that the worst case number of jamming tones, in which the multi-tone jammer causes the largest *BER* for each hybrid system, according to *JSR* and the number of resolved paths under given conditions. It is observed that *BER* is constant for all N_J independent *JSR* when L_r=1,

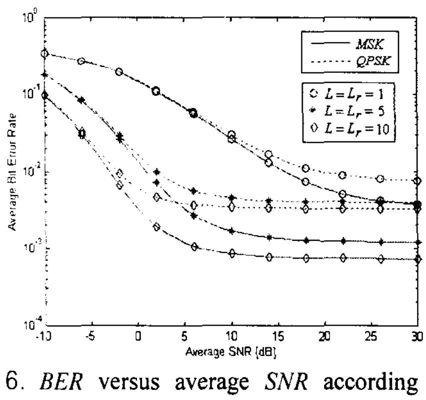

Fig. 6. *BER* versus average *SNR* according to L and L_r when N=10 dB, L=10, δ=0, γ_k=1 and N_J =8.

Table 1. Worst case N_J corresponding to L_r and *JSR* for each hybrid system when N=10 dB, L=10, δ=0, γ_k=1 and λ_b= 30 dB.

MSK	L_r=1	L_r = 5	L_r = 10
JSR=0 dB	–	–	N_J = 1
JSR=10 dB	–	N_J = 4	N_J = 2
QPSK	L_r=1	L_r = 5	L_r = 10
JSR=0 dB	–	–	N_J = 1
JSR=10 dB	–	N_J ≥ 6	N_J = 4

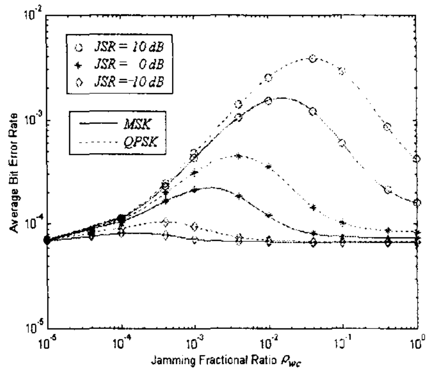

Fig. 7. *BER* versus jamming fractional ratio, ρ when λ_b=30 dB, N=10 dB, L=L_r=10, δ=0, γ_k=1.

while there is a value of the worst case N_J as L_r is increased. Based on these results, Fig. 7 illustrates the worst case jamming fractional ratio, ρ_{wc}, for different *JSR*s. When *JSR* is small, both hybrid systems show nearly constant *BER* performances for all jamming fractional ratios and have almost the same ρ_{wc}. But they have different ρ_{wc} and the performance difference between them becomes more significant with increase of *JSR*.

V. Conclusion

In this paper, we investigated the performances of hybrid DS/SFH spread spectrum systems using MSK and QPSK modulation schemes under the worst-case multi-tone jamming environment and compared for several system parameters over multi-path Rayleigh fading channel.

For hybrid systems without a Rake receiver, *BER* is very sensitive to *JSR* when the average *SNR* is large. In particular, there is an optimum DS spreading gain for large *JSR*, in which a minimum *BER* is achieved, while only DS spreading gives the best performance for small *JSR*. Therefore, for large *JSR* the communicator should allocate more hopping slots within a given spread spectrum bandwidth to reduce the jamming fractional ratio. A Rake receiver can provide better performance than non-diversity reception, independent of *JSR*, but there is an error floor due to the multi-tone jamming. Also, it is shown that a hybrid system with MSK modulation scheme has better anti-jamming performance against the worst-case multi-tone jamming and provides larger performance improvement than that with QPSK modulation scheme for all conditions. It means that in the worst-case multi-tone jamming environment we should shape the chip waveform with a half-sine waveform rather than a rectangular one.

References

[1] R. E. Ziemer and W. H. Tranter, *Principles of Communications*, John Wiley, 1995.

[2] R. E. Ziemer, R. L. Peterson, and D. E. Borth, *Introduction to Spread Spectrum Communications*. Prentice Hall, 1995.

[3] 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, Sept. 1985.

[4] S. K. Park and J. T. Kim, "Hybrid DS/SFH Spread-Spectrum Multiple-Access Communications over Nonselective Fading Channels", *IEEE VTC*, vol. 1, pp. 70-72, 1994.

[5] T. Eng and L. B. Milstein, "Coherent DS-CDMA performance in Nakagami multi-path fading," *IEEE Trans. on Commun.*, vol. 43, no. 2/3/4, pp. 1134-1143, Feb.-March-April 1995.

[6] C. B. Park and J. H. Lee, "Probability of Error for a Hybrid DS/SFH Spread-Spectrum System over a Rician Fading Channel in the Presence of Multiple-Tone Jamming", *IEEE ISSSTA '92*, pp. 123-126, Nov.-Dec. 1992.

[7] H. Zheng and N. Zhang, "Performance Analysis of Hybrid DS-SFH/MSK Spread-Spectrum System under Multione Jamming", *IEEE MILCOM' 99*, 1999.

[8] R. M. Gangadhar and P. P. Gandhi, "Performance Characteristic of QPSK and MSK DS/FH Hybrid CDMA Systems in Rayleigh Fading", *Signals, Systems and Computers 1994 Conference Record of the Twenty-Eightth Asilomar Conference*, vol. 1, pp. 446-449, 1994.

[9] Z. Tan and I.F. Blake, "Performance Analysis of Noncoherent DS-SFH Spread Spectrum Multiple Access for Indoor Wireless Communications", *IEEE MILCOM '92*, vol. 3, pp. 851-855, 1992.

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