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[1 - 3]

비대칭 격자부호 변조를 쓰는 직접수열 대역확산 다중접속 계통의 분석

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An Analysis of DS/SSMA Systems Using Asymmetric Trellis Coded Modulation

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Abstract - The performance of direct-sequence spread spectrum multiple access (DS/SSMA) systems using trellis coding with asymmetric phase shift keying (PSK) modulation is analyzed. By designing the signal constellation to be asymmetric, we obtain performance gain of DS/SSMA systems over the systems using the traditional symmetric signal constellation. Bit error probability analysis of the proposed system is carried out for some cases. A few examples are given to show the performance gain due to the asymmetry of the signal constellation.

1. INTRODUCTION

In [1] it has been shown that optimally designed rate $n/(n+1)$ trellis codes mapped into the conventional 2^{n+1}−point signal sets can provide a significant coding gain without bandwidth expansion when compared to the uncoded conventional 2^n−point signal sets. Optimization of the signal set design of the modulation was considered in [2]. where a design of the optimum asymmetric MPSK signal constellation in coded additive white Gaussian noise (AWGN) environment was considered.

The DS/SSMA systems using PSK signal constellations were investigated in [3, 4]. In [4], the probability of bit error (pbe) of DS/SSMA system with binary PSK (BPSK) modulation is obtained. In coded AWGN environment, the optimum signal sets are obtained for the trellis coded system with asymmetric MPSK modulation [2]. Since Rayleigh fading is generally present in spread spectrum systems, it is necessary to consider the effect of fading in designing the overall SS systems.

2. SYSTEM MODEL

The model under consideration is similar to that considered in [5]. Let the input to the trellis encoder in Fig. 1 be $b_k(t)a_k(t)$, where $b_k(t)$ is the data signal which consists of rectangular pulses of duration T and takes the values $+1$ and -1 with equal probability, and $a_k(t)$ is the code waveform which is a periodic sequence of rectangular pulses of duration T_c and takes the values $+1$ or -1. For notational convenience, the lth data pulse of $b_k(t)$ and jth code pulse of $a_k(t)$ are denoted as $b_l^{(k)}$ and $a_j^{(k)}$, respectively. Using asymmetric trellis coded modulation (ATCM), one signal in the asymmetric signal sets is chosen as the transmitted signal.

The kth transmitted signal is

$$s_k(t) = Re\{\sqrt{2P}\Phi(t)\exp(j2\pi f_c t + j\theta_k)\}, \quad (1)$$

where $P = E_s/(2T_c)$ is the power in each of the K transmitted signals, $\Phi(t)$ is the shaping waveform with period T_c, f_c is the common carrier frequency, and θ_k is the phase angle selected by the trellis encoder.

The received signal is

$$r(t) = \sum_{u=1}^{U} y_u(t - \tau_u) + n(t), \quad (2)$$

where U is the number of asynchronous simultaneously transmitted signals, τ_u is the time delay, and $n(t)$ is the AWGN with two-sided spectral density $N_0/2$. For a Rician fading channel, $y_u(t)$ is described by

$$y_u(t) = s_u(t) + Re\{\rho_u \exp(j\theta_l^{(u)})\sqrt{2P}\Phi(t)\exp(j\theta_u)\} \quad (3)$$

for $lT \le t < (l+1)T$, where ρ_u is the Rayleigh random variable which represents the attenuation of the signal strength due to the fading, and $\theta_l^{(u)}$ is the phase shift uniformly distributed over $[0, 2\pi]$.

From (2) and (3), the received signal sample at time k can be modeled by

$$r_k = \rho_k x_k + n_k + i_k, \quad (4)$$

where x_k is the sampled transmitted signal, n_k is a sample of a zero mean Gaussian noise process with variance $\sigma^2 = (2E_s/N_0)^{-1}$, and i_k is an interference term by $U-1$ users.

Assuming i_k is a Gaussian random variable, the received signal sample now becomes

$$r_k = \rho_k x_k + \overline{n_k}, \quad (5)$$

where $\overline{n_k} = n_k + i_k$.

3. PERFORMANCE ANALYSIS

Using the Bhattacharyya bound [2], we can obtain the upper bound of the chip error probability of the ATCM systems with the generation function method,

$$P_l \le \frac{1}{n}\frac{\partial}{\partial I}T(D,I)|_{I=1}, \quad (6)$$

where T is the transfer function of the TCM scheme, D is the Bhattacharyya distance, and I is a parameter representing that a branch transition occurred by the input data bit 1. For Rayleigh fading, it is known that

$$D = \frac{2N_0}{E_s + 2N_0}. \quad (7)$$

A bound tighter than (6) is given by

$$P_l \le \frac{1}{2n}\text{erfc}\left(\sqrt{\frac{nE_b}{N_0}\frac{d_{free}^2}{4}}\right) D^{-d_{free}^2}\frac{\partial}{\partial I}T(D,I)|_{I=1}, \quad (8)$$

where d_{free} is the free distance [1].

Using (6)-(8), we get the upper bounds of the chip error probability for ATCM schemes. For DS/SSMA systems, we then obtain the upper bound on the bit error probability and optimize the rotation angle of the ATCM scheme.

Example 1: 1/2 rate ATCM scheme

In Fig. 2, we modeled the 4-PSK ATCM signal constellation with rotation angle ϕ. Naturally, if $\phi = \pi/2$, our model is the same as the traditional symmetric signal constellation model. In the case of the 1/2 rate ATCM, the transfer function is

$$T(D,I) = \frac{ID^{4(1+\delta^2)}}{1 - ID^{4(1-\delta^2)}}, \quad (9)$$

where $\delta = \sin(\phi/2)$. Using (6) and (9), the upper bound of the chip error probability is obtained as

$$P_l \le \frac{D^{4(1+\delta^2)}}{[1 - D^{4(1-\delta^2)}]^2}. \quad (10)$$

The optimum value of δ is obtained by differentiating (10),

$$\delta_o^2 = \frac{1}{4}\frac{\log 3}{\log D} + 1. \quad (11)$$

Using (7), (10), and (11), we obtain the upper bound on the chip error probability when $\delta = \delta_o$,

$$P_l \le \frac{9}{4}\left(\frac{2N_0}{E_b + 2N_0}\right)^8. \quad (12)$$

In addition, the tighter upper bound (8) now becomes,

$$P_l \le \frac{9}{8}\text{erfc}\left[\sqrt{\frac{E_b}{N_0}\left[2 - \frac{\{\log_3(\frac{E_b}{N_0}+1)\}^{-1}}{4}\right]}\right]. \quad (13)$$

Using the above results, we can calculate the upper bound on the bit error probability using

$$P_b \le \sum_{i=[\frac{N_c}{2}+1]}^{N_c}\binom{N_c}{i}P_l^i(1-P_l)^{N_c-i}, \quad (14)$$

where N_c is the number of chips. Fig. 3 illustrates the upper bounds for symmetric 1/2 rate TCM ($\phi = \pi/2$) and optimum 1/2 rate ATCM. It is clear that the optimum ATCM would have better performance than the symmetric TCM. When the numbers of users are 1 and 3, the SNR gains are approximately 2dB and 2-4dB, respectively. In addition, as the bit error rate decreases, the SNR gain of the optimum ATCM increases.

Example 2: 2/3 rate ATCM scheme

For the 8-PSK ATCM schemes, we made a signal constellation model in Fig. 4. For the optimum 2/3 rate ATCM scheme, the transfer function is obtained to be

$$T(D,I) = ID^4 + \frac{0.5I(I+1)^2D^2\left(D^{4\delta^2} + D^{4(1-\delta^2)}\right)}{1 - ID^{2(1-2\delta\sqrt{1-\delta^2})} - I^2D^{2(1+2\delta\sqrt{1-\delta^2})}}. \quad (15)$$

Using (6) and (15), we obtain the upper bound on the chip error probability for the 2/3 rate ATCM as

$$P_c \leq 0.5D^4 + \frac{D^2\left(D^{4\delta^2} + D^{4(1-\delta^2)}\right)\left(2 - D^{2\left(1-2\delta\sqrt{1-\delta^2}\right)}\right)}{\left\{1 - D^{2\left(1-2\delta\sqrt{1-\delta^2}\right)} - D^{2\left(1+2\delta\sqrt{1-\delta^2}\right)}\right\}^2}. \quad (16)$$

Minimizing (16) with respect to ϕ does not lead to a closed-form expression for the optimum rotation angle. Thus we minimized (16) by numerical analysis. The results are tabulated in Tables 1 and 2 when the numbers of users are 1 and 3, respectively. Substituting the values in Tables 1 and 2 into (16) results in the upper bound on the bit error probability, which is shown in Fig. 5.

Table 1

The optimum δ and ϕ_o versus E_b/N_0 for the optimum 2/3 rate ATCM when the number of user is 1

E_b/N_0	δ	ϕ_o (rad)	E_b/N_0	δ	ϕ_o (rad)
6	0.1414	0.2851	7	0.2408	0.4864
8	0.3163	0.6437	9	0.3700	0.7580
10	0.4102	0.8453	11	0.4416	0.9148
12	0.4630	0.9628	13	0.4876	1.0187
14	0.5051	1.0590	15	0.5198	1.0932

Table 2

The optimum δ and ϕ_o versus E_b/N_0 for the optimum 2/3 rate ATCM when the number of user is 3

E_b/N_0	δ	ϕ (rad)	E_b/N_0	δ	ϕ (rad)
6	0.0654	0.1309	7	0.0881	0.1764
8	0.1301	0.2609	9	0.1882	0.3787
10	0.2399	0.4845	11	0.2791	0.5657
12	0.3084	0.6270	13	0.3306	0.6739
14	0.3476	0.7100	15	0.3609	0.7384

4. CONCLUDING REMARKS

In this paper, we obtained the upper bound of the DS/SSMA system performance using ATCM signal constellation. For the optimum 1/2 and 2/3 rate ATCM schemes, we obtained the optimum rotation angles minimizing the upper bound of the chip error probability.

The closed-form optimum upper bound of the chip error probability for the optimum 1/2 rate ATCM scheme was obtained.

For the optimum 2/3 rate ATCM scheme, we obtained the optimum rotation angles by numerical analysis. Using the optimum rotation angles, we obtained the upper bound for the optimum 2/3 rate ATCM scheme.

Based on the results we may conclude that the optimum ATCM scheme would have better performance than the symmetric TCM scheme. In addition, if the number of users is small and the SNR is high, the optimum ATCM scheme is expected to have more SNR gain over the traditional symmetric scheme.

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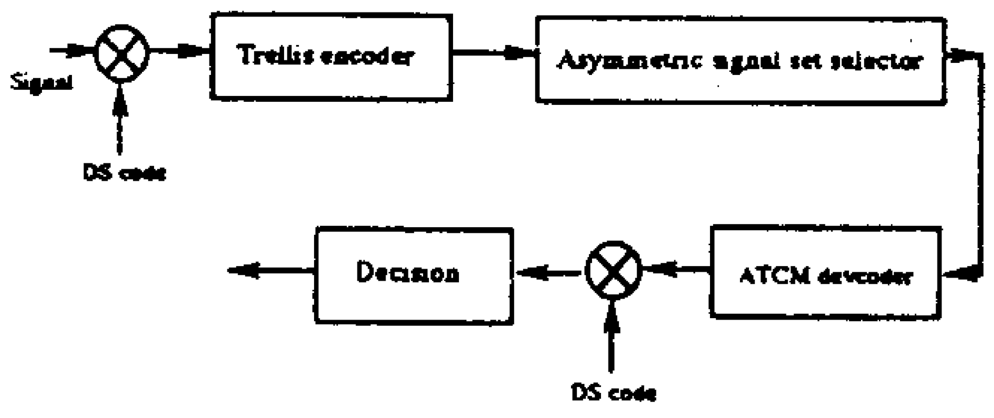

Figure 1. A block diagram of the transmitting system

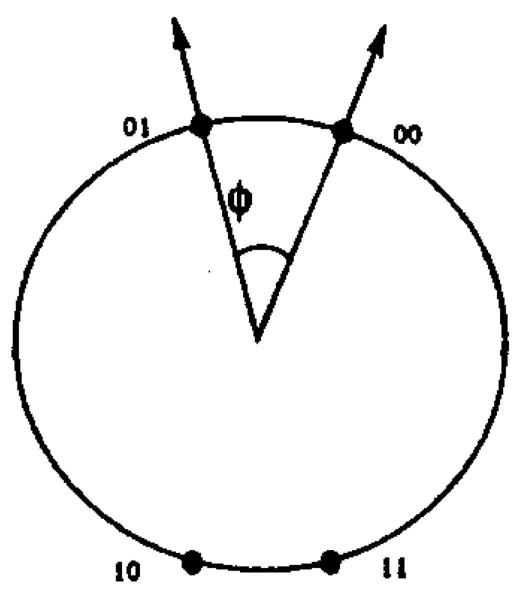

Figure 2. Asymmetric 4PSK signal set

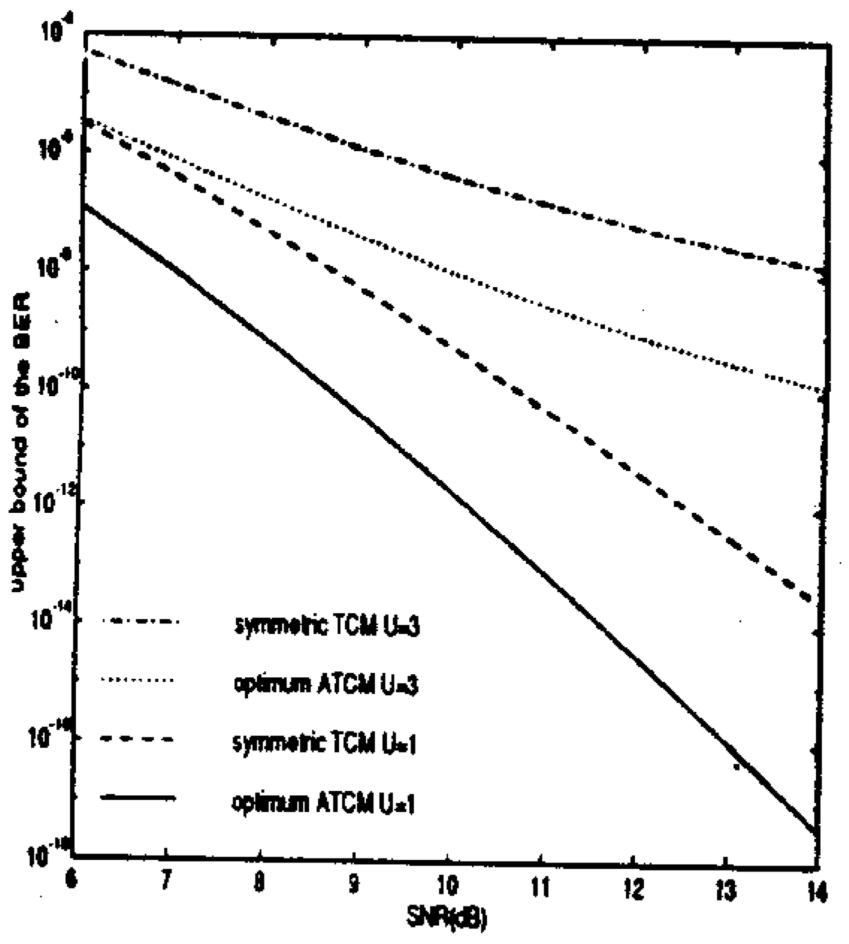

Fig. 3. The upper bounds of the probability of bit error versus SNR in Rayleigh fading channel for the optimum 1/2 rate ATCM and symmetric TCM.

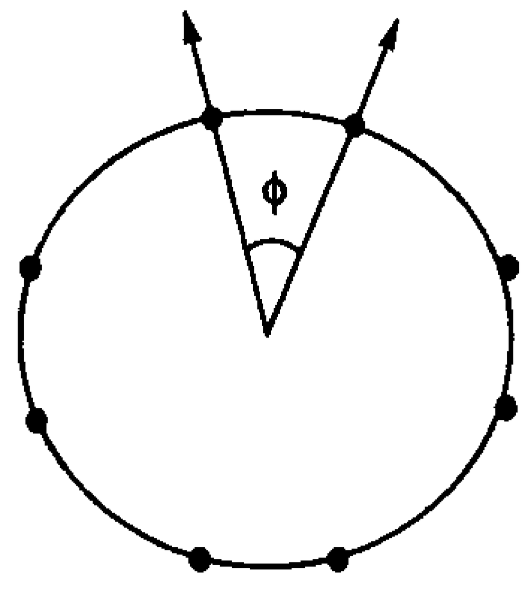

Figure 4. Asymmetric 8PSK signal set

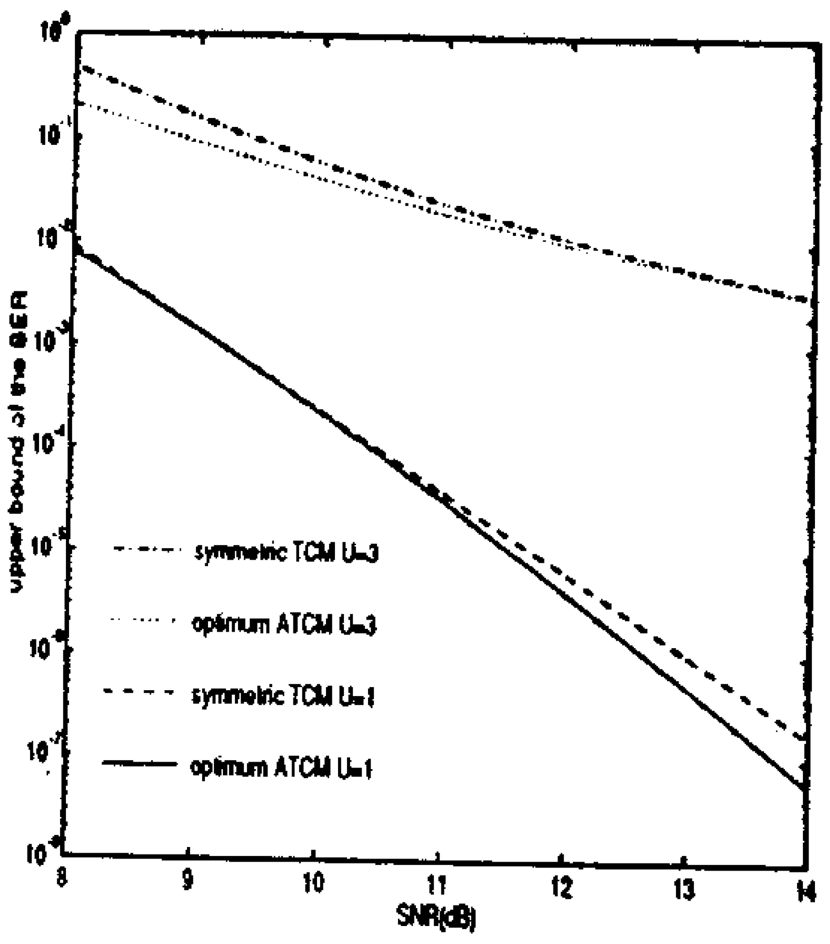

Fig. 5. The upper bounds of the probability of bit error versus SNR in Rayleigh fading channel for the optimum 2/3 rate ATCM and symmetric TCM.