行政院國家科學委員會補助專題研究計畫成果報告

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※　**應用** RS **碼之前向改錯系統之研究** (3/3)　※

※　On the study of RS-code-embedded forward error　※

※　correcting systems (3/3)　※

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計畫類別：□**個別型計畫**　　□**整合型計畫**

計畫編號：NSC－89－2213－E－009－183

執行期間： 89 **年** 8 **月** 1 **日至** 90 **年** 7 **月** 31 **日**

計畫主持人：蘇育德　教授

共同主持人：無

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執行單位：交通大學電信工程系 通訊系統實驗室

中　華　民　國 90 **年** 8 **月** 10 **日**

行政院國家科學委員會專題研究計畫成果報告

Preparation of NSC Project Reports

計畫編號：NSC 89-2213-E-009-183
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主持人：交通大學電信系　蘇育德 教授
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I、Abstract

Most investigations on the performance of block codes assume perfect interleaving and memoryless channels that introduce only random errors. Some authors study the effect of finite interleaving size on the decoder performance, using a two-state Gilbert-Elliott (GE) model to characterize the channel effect. However, there are circumstances that the burst-error channel of concern can not be properly described by a two-state GE model. We extend earlier analysis to analyze the performance of block codes in an environment that can be modeled as an arbitrary finite-state Markov chain.

Keywords: Gilbert-Elliott (GE) model, block codes, finite-state Markov chain.

II、Introduction

Interleaving is needed to randomize burst errors and to increase the effectiveness of an error-control code. Most investigators, however, assume perfect interleaving in their analysis. The effect of channel memory on the performance of a decoder is often analyzed by the use of analytic channel models. Kanal and Sastry [1] presented several such models for channel with memory and their applications to error control. Wilhelmsson and Milstein [2] use the Gilbert-Elliott (GE) channel model to evaluate the influence of finite interleaving on the decoded performance of binary BCH codes. Su and Jeng [3] analyzed the impact of imperfect interleaving on RS coded systems in slow frequency-hopped (SFH) jammed channels. A survey of various models for land mobile satellite (LMS) channels can be found in [4]. This purpose of this study is to extend these earlier investigations to the cases when the simple two-state GE model is inappropriate for characterizing the communication channel of concern.

III、Hidden Markov channels

We present two scenarios that can only be described by a four-state Markov model. Consider first a correlated Rayleigh fading channel in which the transmitted signal is corrupted by multiplicative fading distortion, additive white Gaussian noise (AWGN) whose one-sided power spectral density (PSD) is N_0 W/Hz, and a partial band noise jammer (PBNJ) whose probability of presence is μ. Obviously, one needs at least four states to indicate whether a jammer is present (jammed versus unjammed) and if the fading is severe (good versus bad).

Suppose a RS-coded MFSK system uses symbol-wise block interleaving and slow frequency hopping to combat the various adverse channel effects mentioned above. We assume that a hop duration is equal to that of multiple rows of the block interleaver. Hence there will be several hops in one interleaving block of depth m (columns) and span n (rows) and at the interleaver output, symbols of several adjacent rows will be in the same hop. Define $K_I = mn$, H = the number of hops per $K_I\, T_s$ seconds and assume J of H hops are jammed.

The number of jammed symbols in one codeword is JS and the remaining n-JS symbols are free of jamming. Then we can use the hidden Markov model shown in Fig. 1 to evaluate the corresponding decoder performance. The four states that characterizes the channel are (i) unjammed and good (UG), (ii) unjammed and bad (UB), (iii) jammed and good (JG), and (iv) jammed and bad (JB).

The hopping rate and the interleaver structure put constraints on the allowable state transitions of the above model. Depending on whether the first codeword symbol is jammed, the next S-1 consecutive MFSK symbols will be in the same state. The channel reduces to a two-state GE model during this period and will not become a four-state model again until the (S+1)th symbol interval.

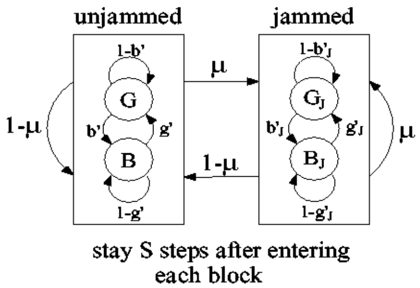

Figure 1. A four-state model for jammed Rayleigh channels.

A PBNJ distributes its total power P_J evenly over a continuous spectrum of W_J Hz. Let W_{SS} be the total hopping bandwidth then $\mu = W_J / W_{SS} \leqq 1$ is the probability that the PBNJ is present in the signal band. Within the jammed band, the transmitted signal is corrupted by an equivalent AWGN whose PSD level N_T is equal to $N_J / \mu + N_0$, where $N_J = P_J / W_{SS}$; otherwise the PSD level is $N_T = N_0$.

In modeling a correlated fading channel by a two-state Markov chain one has to select a threshold that discriminates whether the channel is in the `good' state when the received envelop is higher than this threshold. However, [2] found that the choice of threshold has little impact on the accuracy of the model. Applying a similar procedure to evaluate the parameters in our hidden Markov model, we have [2]

$$g = \frac{\rho f_D T_s \sqrt{2\pi}}{e^{\rho^2} - 1} \qquad (1)$$
$$b = \rho f_D T_s \sqrt{2\pi}$$

where f_D is the Doppler frequency and T_s is the symbol duration. When a hop is jammed, the average SNR of the received signal $\overline{\gamma}_j$ is equal to $c\overline{\gamma}$, where $c = N_T / N_0$. The transition probabilities then become

$$g_j = \frac{\rho_j f_D T_s \sqrt{2\pi}}{e^{\rho_j^2} - 1} \qquad (2)$$
$$b_j = \rho_j f_D T_s \sqrt{2\pi}$$

where $\rho_j^2 = \gamma_t / \overline{\gamma}_j$.

The second scenario we consider is mobile satellite communication systems. Measurement results reported by Lutz *et al.* [5] indicates that a land mobile satellite signal passes through shadowed and unshadowed sections and the characteristics of the switching process between shadowed and unshadowed sections can be described by a Markov model. Taking the degree of fading into account, we obtain the four-state model for mobile satellite channels of Fig. 2,

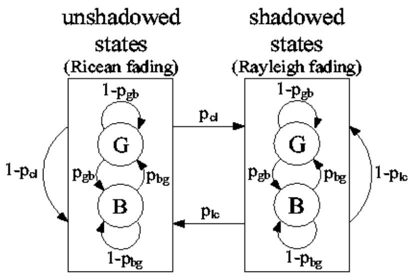

Figure 2. A land mobile satellite channel model.

where p_{cl} and p_{lc} are the transition probabilities, P(unshadowed state → shadowed state) and P(shadowed state → unshadowed state), respectively. These two transition probabilities can be evaluated by using the method in [5]. The transition probabilities between two shadowed or unshadowed states can be evaluated by the same method used for the two-state model [2]. Those for shadowed states (Rayleigh fading) are the same as (1). For unshadowed states (Ricean fading) the transition probabilities are given by

$$p_{bg} = \frac{{}^{\circ}e^{\circ 2} f_D T_s \sqrt{2®}}{(1 - Q_1(\sqrt{2K}, \sqrt{2}\,{}^{\circ}))} \quad (3)$$

$$p_{gb} = \frac{{}^{\circ}e^{\circ 2} f_D T_s \sqrt{2®}}{(Q_1(\sqrt{2K}, \sqrt{2}\,{}^{\circ}))}$$

where $Q_1(a,b)$ is Marcum's Q function.

IV、Codeword error probability analysis

The codeword error probability (CEP), P_w, can be decomposed into a sum of several conditional CEP's. For example, if we define $(n_1, \ldots, n_k)$ as the event that during an n-symbol period, the channel is in state j for n_j times, j=1, 2,…, k, then

$$P_w = \sum_{(n_1,\ldots,n_k)} P_n(n_1,\ldots,n_k) P_w(n_1,\ldots,n_k), \quad (4)$$

where $P_w(n_1,\ldots, n_k)$ is the CEP given that the event $(n_1,\ldots, n_k)$ occurs. Next we present two methods for evaluating $P_n(n_1,\ldots, n_k)$.

Suppose that T = $[p_{ij}]$ is the probability transition matrix of a k-state Markov chain. The first method uses a transfer domain approach. Let Ψ_Z $(z_1,\ldots,z_k)$ be the k-dimensional z-transform of $P_w(n_1,\ldots, n_k)$ and $\Pi_Z = [®_1 z_1, \ldots, ®_k z_k]$ be the initial probability vector of the Markov chain and define the new transition matrix $T_Z = [p_{ij} z_j]$. Then we have

$$Ø_Z(z_1,\ldots, z_k) = \underline{Đ}_z \mathrm{T}_z^{n-1} \underline{1},$$

where $\underline{1}$ = [11…1] and

$$P_n(n_1, \Lambda, n_k) = \frac{1}{n_1! n_2! \Lambda\, n_k!} \frac{\partial Ø_Z(z_1, \Lambda, z_k)}{\partial z_1^{n_1} \Lambda\, \partial z_k^{n_k}}.$$

The second method utilizes the recursive relation given by

$$Ö_{i,x}(d_1, \mathrm{K}, d_k) = \sum_{y=1}^{k} Ö_{i-1,x}(d_1, \mathrm{K}, d_x - 1, \mathrm{K}, d_k) p_{yx}$$

where $\Phi_{i,x}(d_1,\ldots,d_k)$ is the probability that the process stays in state x at the ith instant of time conditioned on dj = P_r[the process visits the jth state for d_j time during an n-symbol period]. Obviously,

$$Ö_{1,x}(d_1, \mathrm{K}, d_x = 0, \mathrm{K}, d_k) = 0, \quad x = 1,\ldots,k$$

$$Ö_{1,x}(d_1 = 0, \mathrm{K}, d_x = 1, \mathrm{K}, d_k = 0) = ®_x$$

we have,

$$P_n(n_1, \mathrm{K}, n_k) = \sum_{x=1}^{k}\sum_{y=1}^{k} Ö_{n-1,y}(\ldots, n_x - 1, \ldots) p_{yx}.$$

V、Numerical results and conclusions

This section provides some numerical examples of the CEP performance of the two RS-coded systems in channels discussed in Section 2. The first one is the slow frequency-hopped RS-coded MFSK system described in Section 2. The second system uses an M-ary orthogonal signal in conjunction with a RS code for the land mobile satellite (LMS) channel of Fig. 2. We consider errors-only (EO) as well as errors-and-erasures (EE) decoders and assume that both systems employ noncoherent detection. We also assume that the received fading amplitude is constant during a symbol period (nonselective fading). The CEP of these two coded system can be evaluated by using various probabilities derived in the above sections and following procedures similar to those presented in [2] and [3].

The use of an EE decoder necessitates an erasure-insertion method (EIM) that detects the erasure positions. The EIM we used for both systems is Viterbi's ratio threshold test (RTT) [6] that erases a symbol when the ratio between the largest and the second largest outputs, Z_a, Z_b of a noncoherent M-ary detector bank is greater than a threshold ô. In other words, a symbol is erased if Z_b/Z_a > ô. The threshold can be different for different states. We consider single-threshold (1T) and two-threshold (2T) erasure-insertion algorithms only. For the 2T decoder, the same threshold is used for the two jammed or unjammed states or the two shadowed or unshadowed states. Our numerical experiment finds out that using more than two thresholds brings little or no performance improvement.

Fig. 3 compares the CEP performance of the EO, 1T RTT/EE and 2T RTT/EE decoders in the presence of PBNJ when the ratio of the average bit energy to noise power level, $\overline{E_b}/N_J$, is 20 dB. The CEP performance curves are depicted as a function of $\overline{E_b}/N_J$. It is clear that our analytic prediction is very close to that predicted by simulation and, as expected, EE decoders' performance is better than that of EO decoders. At $P_w = 10^{-4}$, the EE decoding gain is greater than 7 dB while the corresponding gain is greater than 4 dB at $P_w = 10^{-3}$.

EO and EE decoder performance of an LMS channel is shown in Fig. 4 when the satellite elevation angle is 13 degrees and the time-share factor of shadowing *A*=0.24 and 0.89, respectively. Again, these curves indicate that our four-state hidden Markov model leads to accurate decoder performance prediction. Moreover, EE decoding brings about a decoding gain (at $P_w = 10^{-3}$) of approximately 1 dB and 2 dB when *A*= 0.89 and 0.24, respectively. Since *A* accounts for the fraction of time the channel stays at Ricean fading states, these coding gains imply that the EE decoding gain tends to be larger in Rayleigh fading.

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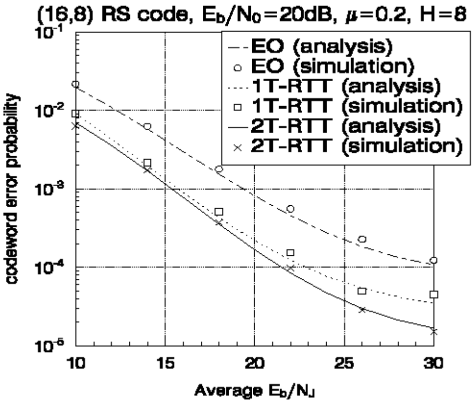

Figure 3. CEP performance of a RS-coded SFH MFSK system in presence of PBNJ and fading.

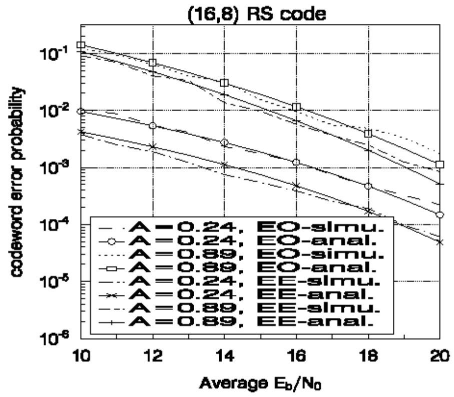

Figure 4. EO and EE RS decoder performance over land mobile satellite channels; *A* = the time-share factor of shadowing.