주파수와 타이밍 옵셋에 의한 빠른 주파수 호핑 시스템의 임계값 분석

주증민, 윤여민, 최미흥, *이광억, 김기선
광주과학기술원 정보통신공학과, *국방과학연구소
전화 : 062-970-2285

Threshold level analysis of the FFH-MA system using noncoherent FSK modulation under the presence of frequency and timing offsets

Jeungmin Joo, Yeomin Yoon, Miheung Choe, *Kwangeog Lee, Kiseon Kim
Dept. of Information and Communication, Kwangju institute of Science and Tech.
*Agency for Defense Development
E-mail : gangsang@kjist.ac.kr

Abstract

Under the prsence of the frequency and timing offset, we evaluate the BER performance of the FFH-MA system using noncoherent M-ary FSK modulation in the Rayleigh fading channel. The numerical resuts show that while the frequency and timing offset increases at a given SNR, the BER is severely degraded. The threshold level used in the envelope detector increases with the increase of the frequency and timing offset, and with the proper selection of the threshold level, the BER can be improved under the presence of such offsets.

I. Introduction

Like any other digital communication system, the FFH-MA system suffers from frequency offsets caused by the imperfect estimate of hopping frequencies in the dehopper. Also, the FFH-MA system might estimate imprecisely the symbol epoch and use its inaccurate estimate in the demodulation operation. Hence, it is interesting to analyze the BER performance of the FFH-MA system with the frequency and timing offsets. The frequency and timing offsets in the FFH-MA system using the noncoherent FSK modulation affect the outputs of envelope detectors in such a way that the desired signal's energy is reduced at its own envelope detector, and the reduced amount of the signal's energy infiltrates undesirably into adjacent detectors. Subsequently, the frequency and timing offsets make the correct detection of the desired signal difficult. In the FFH-MA system, the bit error rate (BER) degradation due to such offsets can be relieved by selecting a proper threshold level, and it is possible to improve the BER performance by using the selected threshold level. In this paper, the sensitivity of the FFH-MA system due to the frequency and timing offsets is investigated in terms of the BER, and we investigate the effect of changing threshold levels due to the frequency and timing offsets.

II. System and Channel Model

2.1 Transmitter Model

The binary data sequence of rate R_b is encoded into a sequence of M-ary source symbols of rate

R_s, and then, a block of N_s source symbols is converted into a codeword of N_c Reed-Solomon (RS) coded symbols. A coded symbol, which consists of $\log_2 M$ coded bits, is repeated L times for a coded symbol duration $T_{c,s}$. Then, a sequence of the repeated coded symbols is added to L unique address symbols by using the modulo-M operation, where the address sequence can be represented as $A^s = \{a_1^s, a_2^s, \cdots, a_L^s\}$ with $a_l^s \in \{0, 1, \cdots, M-1\}$ [1]. As a result, it produces a new sequence of length L and each codeword of the new sequence occupies a time slot of duration $T_h = T_{c,s}/L$. The value of each codeword is used for selecting one of the available M orthogonal frequencies. Each modulated codeword by the M-ary FSK modulator is then hopped to one of Q hopping frequencies per T_h, where each user is assigned independently a Markov hopping pattern. The signal transmitted by the kth user for the lth hop duration is given by

$$S_k^{(l)}(t) = Re\{\sqrt{2P}\exp[j(2\pi(f_c + f_k^{(l)})t)]\}, \quad (1)$$

where P and f_c are the transmitted power and carrier frequency, respectively. $f_k^{(l)}$ is composed of a hopping frequency, $h_k^{(l)}$, and a frequency corresponding to one of M-ary FSK signals, $c_k^{(l)}$.

2.2 Channel and Receiver Model

According to the pattern of the hopping sequence of the desired user, the received signal, $r(t)$, is dehopped by the frequency dehopper. When J interferers cause hits after the dehopping operation, the resulting output signal is represented as

$$r_d^{(l)}(t) = \sum_{k=0}^{J} Re\{a_k \exp(j\phi_k)\exp[j(2\pi(c_k^{(l)} + \Delta f)t)]\} + n(t), \quad (2)$$

where Δf denotes the frequency offset due to the imperfect estimate of the hopping frequency. It is assumed that the Δf does not change for $T_{c,s}$, and is less than the minimum frequency spacing among M-ary coded symbols, i.e., $-1/T_h \le \Delta f \le 1/T_h$. The random magnitude, a_k, is Rayleigh distributed, and phase shifts, $\{\phi_k\}$, is uniformly distributed over $[0, 2\pi)$. $n(t)$ denotes the AWGN with two-sided power spectral density of $N_0/2$. The dehopped signal passes through the noncoherent M-ary FSK demodulator, which consists of M envelope detectors. When the received symbol is not known precisely, the receiver could use its own incorrect estimate of the symbol epoch which is offset from the true epoch by ΔT. It is assumed that ΔT is less than the hop duration, i.e., $-T_h \le \Delta T \le T_h$. When a Markov hopping pattern is used and the estimate is delayed by ΔT, the output of the mth envelope detector matched to the mth signal of M-ary FSK signals is represented as

$$R_m^{(l)} = \left| \frac{2}{T_h} \int_{(l-1)T_h + \Delta T}^{lT_h} r_d(t) \exp(j2\pi(\frac{m}{T_h})t) dt \right|, \quad (3)$$

Then, the envelope statistic of $R_m^{(l)}$ has the Rayleigh distribution given by

$$f_{R_m^{(l)}}(R) = \frac{R}{\Omega^2} \exp\left(-\frac{R^2}{2\Omega^2}\right) \quad (4)$$

with

$$\Omega^2 = \sum_{k=0}^{J} P_0 \frac{1 - \cos(2\pi(n_{m,k}^{(l)} + \rho)(1-\lambda))}{2\pi^2(n_{m,k}^{(l)} + \rho)^2} + \frac{N_0}{T_h} \quad (5)$$

where P_0 is the average power of the multipath portion, $\rho = \Delta f T_h$, and $\lambda = \Delta T / T_h$. $n_{m,k}^{(l)}$ is defined by $(n_m^{(l)}/T_h - n_k^{(l)}/T_h)T_h$, where $n_m^{(l)}$ is the frequency index matched to the mth envelope detector and $n_k^{(l)}$ is the frequency index corresponding to a symbol transmitted by the kth user for the lth hop duration.

III. BER Performance Analysis

3.1 Deletion Probability

The deletion probability is defined as the probability that the output of the envelope detector is smaller in magnitude than a given threshold [1]. For the Rayleigh fading, deletion probability is given by

$$P_D = \int_0^{\beta_0\sqrt{N_0/T_h}} f_{R_{m,l}}(R)\,dR = 1-\exp\left(\frac{-\beta_0^2/2}{\sum_{k=0}^{L}\frac{\overline{E_h}}{N_0}\frac{\sin^2(\pi(n_{m,k}^{(l)}+\rho)(1-\lambda))}{\pi^2(n_{m,k}^{(l)}+\rho)^2}+1}\right), \quad (6)$$

where $\beta_0=\beta/\sqrt{N_0/T_h}$ is the actual threshold level β normalized by the rms noise power. This threshold level needs to be selected properly to optimize the BER performance.

3.2 Bit Error Rate

At the receiver the transmitted data is recovered by dehopping the hopping frequency, demodulating the coded M-ary FSK symbol, and performing the modulo-M substraction by the address sequence used in the transmitter. Finally, a decision matrix is used to indicate the presence of the signal [1]. For a given address, A_j^s ($A_j^s \subset A^s$, $j=1,2,\cdots,M^L$), the probability that there are i entries in the mth row of the decision matrix is given by

$$P_{m,A_j}(i) = \frac{1}{i!(L-i)!}\sum_{l_1=1}^{L}\cdots\sum_{l_L=1}^{L}\left\{\prod_{x=1}^{i}(1-D_{m,l_x}) \prod_{y=i+1}^{L}(D_{m,l_y})\right\},\ 0<i<L,\ l_1\neq\cdots\neq l_L \quad (7)$$

where $P_{m,A_j}(0)=\prod_{l=1}^{L}(D_{m,l})$, $P_{m,A_j}(L)=\prod_{l=1}^{L}(1-D_{m,l})$, and $D_{m,l}$ is the deletion probability at the mth row of the decision matrix for the lth hop duration. Note that the address sequence decides which envelope detectors are responsible for the entries placed on the correct row as well as on spurious rows of the decision matrix. Without loss of generality, we assume that the first row of the decision matrix contains entries corresponding to the desired user's data and other rows contain entries for the interferers' data. Then, the probability of the correct coded symbol decision conditioned on a hit pattern $J=(J_1,J_2,\cdots,J_L)$ is given by

$$P_w(J) = \sum_{A_j^s\subset A^s}\left\{\left(\sum_{i=1}^{L}P_{1,A_j^s}(i)\sum_{k=0}^{M-1}\frac{B(k,i)}{1+k}\right) + \frac{1}{M}\prod_{m=1}^{M}P_{m,A_j^s}(0)\right\}P(A_j^s), \quad (8)$$

with

$$B(k,i)=\frac{1}{k!(M-1-k)!}\sum_{m_1=2}^{M}\cdots\sum_{m_{M-1}=2}^{M}\left\{\prod_{x=1}^{k}P_{m_x,A_j^s}(i)\prod_{y=k+1}^{M-1}\left(\sum_{n=0}^{i-1}P_{m_y,A_j^s}(n)\right)\right\},\ 0<k<M-1,\ m_1\neq\cdots\neq m_{M-1}$$

The a priori probability of each address sequence, $P(A_j^s)$, is $1/M^L$ because of the random address sequence operation. The probability that J_l of total $(K-1)$ interferers cause hits for the lth hop duration is given by [3]

$$P_h(J_l)=\binom{K-1}{J_l}\left(\frac{1}{Q}\right)^{J_l}\left(1-\frac{1}{Q}\right)^{K-J_l-1} \quad (9)$$

The unconditional probability, P_w, is given by

$$P_w=\sum_{J_1=0}^{K-1}\cdots\sum_{J_L=0}^{K-1}\left\{P_w(J)\prod_{l=1}^{L}P_h(J_l)\right\} \quad (10)$$

Then, the coded symbol error is given by $P_s=1-P_w$. The BER performance after the RS decoding operation, especially with hard decisions on the received symbols, can be computed analytically as in [4].

IV. Numerical Results

Figure 1 shows the change of normalized threshold level corresponding to each frequency offset in the given system parameters ($M=4$, $Q=55$, $L=3$, coding rate $=1/3$). A numerical search algorithm is employed for specific values of the SNR to obtain normalized threshold values optimizing the BER performance. Figure 1 shows that, with the presence of the frequency offset, the normalized threshold level for the large SNR of more than about 20dB is quite high compared to the case of the perfect frequency synchronization. This implies that, as the SNR increases, the amount that the desired user's signal loses its own energy due to the frequency becomes larger than the amount that interferers' signals are robbed of their own energy by the desired envelope detector, because most energy interferers' signals lose is absorbed into unwanted envelope detectors.

Figure 2 shows the change of normalized threshold level corresponding to each timing offset. The inclination is similiar to the case of Figure 1.

In Figure 3, the BER (solid lines) when optimum threshold levels is used is compared to that (dotted lines) when the the threshold level used for the perfect frequency synchronization system is selected in itself. From this figure, we can observe that the proper selection of the threshold level can give the improvement of the BER performance under the presence of frequency and timing offsets.

V. Conclusion

As the frequency and timing offset increases, the BER degradation of the FFH-MA system becomes larger. When such offsets increase, the threshold level used in the envelope detector should be increased for improving the BER performance. In other words, with the proper selection of the threshold level, the BER can be improved under the presence of such offsets.

Reference

[1] D. Goodman, P. Henry, and V. Prabhu, "Frequency-hopped multilevel FSK for mobile radio," Bell. Syst. Tech. J., Sept. 1980.

[2] S. Hinedi, M. Simon, and D. Raphaeli, "The performance of noncoherent orthogonal M-FSK in the presence of timing and frequency errors," IEEE Trans. Commun., Feb./Mar./Apr. 1995.

[3] C. Hung and Y. Su, "Diversity combining consideration for incoherent frequency hopping multiple access systems," IEEE J. Select. Areas Commun., Feb. 1995.

[4] R. Khalona, "Optimum Reed-Solomon codes for M-ary FSK modulation with hard decision decoding in Rician-fading channels," IEEE Trans. Commun., Apr. 1996.

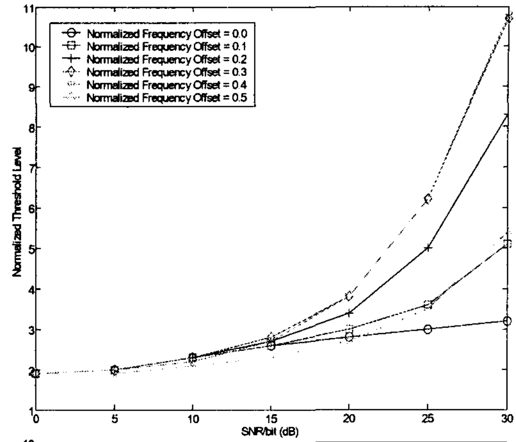

Figure 1. Normalized threshold level versus SNR for given frequency offsets

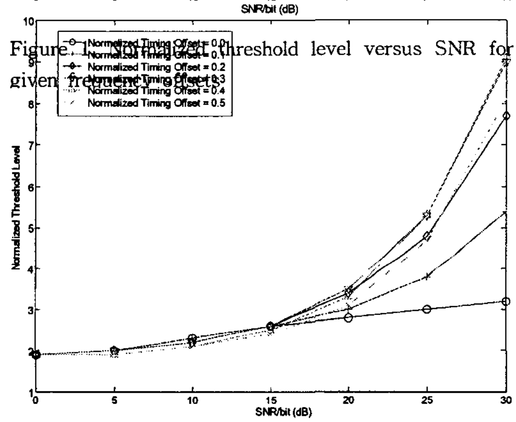

Figure 2. Normalized threshold level versus SNR for given timing offsets

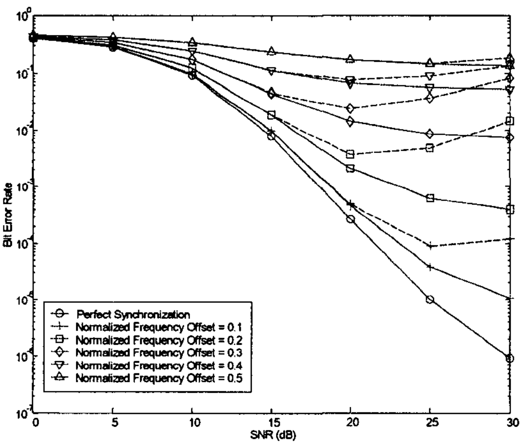

Figure 3. Improvement of BER performance with using the optimum threshold levels und the presence of frequency offsets