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Bit Error Rate Performance of SFH-Modulation Scheme System under Jamming

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ABSTRACT

The frequency hopping spread spectrum (FH-SS), in which a transmitter changes its carrier frequency according to a certain hopping pattern, is widely used in military network systems since it is highly resistant to deliberate jamming. In this paper, we consider PBNJ(Partial-Band Noise Jamming) and WPBJ(Worst case Partial-Band Noise Jamming) as jamming models, and we evaluate the bit error rate (BER) performances of SFH/NC-MFSK(Non-Coherent M-ary Frequency-Shift Keying), SFH/SDPSK(Symmetric Differential Phase-Shift Keying), and SFH/GMSK(Gaussian filtered Minimum-Shift Keying) modulation schemes under jamming conditions. We then suggest the best transmission method for each condition based on the results. From the results of performance evaluation, we concluded that the most effective jamming occurs when fractional ratio $\rho=1$ for small Eb/NJ, and the small ρ is the best jamming strategy for large Eb/NJ. By using results, the appropriate transmission method by the channel condition of satellite communication maybe determined.

KEYWORDS: frequency hopping, PBNJ, WPBJ, Modulation

1. INTRODUCTION

In tactical communication networks, there are unintended interferences such as partial-band noise jamming (PBNJ) and worst case partial-band noise jamming (WPBJ). In order to mitigate these kinds of detrimental effects, the signal is always termed as a spread spectrum signal. The spread spectrum method considered herein is the frequency hopping spread spectrum (FHSS), in which a transmitter changes its carrier frequency according to a certain hopping pattern. The advantage of FHSS is that the signal sees a different channel and a different set of interfering signals during each hop. By this, we can avoid the problem of failing communication at a particular frequency that is caused by a fade or frequency interferer. There are mainly two kinds of frequency hopping techniques, namely the slow frequency hopping (SFH) and fast frequency hopping (FFH). In the case of SFH, one or more data are transmitted within one hop. The advantage of SFH is that coherent data detection is possible. SFH is a popular technique for wireless LANs. Also, SFH is used in the GSM (Global System for Mobile communication) telephony. In the case of FFH, one data bit is divided over multiple hops, so coherent signal detection is difficult and seldom used. FFH usually outperforms SFH, even with the same processing gain. However, FFH is expensive to implement since it requires very fast frequency synthesizers. In this paper, we analyze the performance of the slow frequency hopping system under jamming, and we compare the bit error rate (BER) performances of NC- MFSK(Non-Coherent M-ary Frequency-Shift Keying), SDPSK(Symmetric Differential Phase-Shift Keying), and GMSK(Gaussian filtered Minimum-Shift Keying) modulation schemes in detail.

2. System Model

In this paper, we propose a system model as shown in Figure 1. The input data is processed through modulating. The contacting radio channel is formed by SFH, where the channel hopping occurred periodically on random basis by the PN(Pseudo random Number) sequence. We assume that the radio channel noise had AWGN (Additive White Gaussian Noise) and jamming during data transmission, and we analysed the performance associated with jamming by using two kinds of models, namely PBNJ(Partial-Band Noise Jamming) and WPBJ(Worst case Partial-Band noise Jamming).

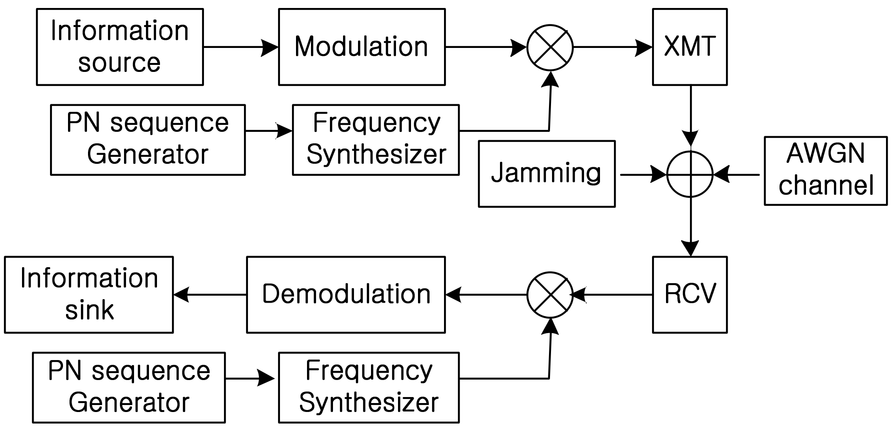

Figure 1. System block diagram

We consider PBNJ and WPNJ as a jamming model. In the case of PBNJ, noise power J is evenly distributed over some frequency bandwidth WJ, which is a subset of the total spread bandwidth WSS. It can be regarded as a Gaussian noise jammer that restricts its total power J to a fraction ρ (0≤ρ≤1) of the full spreading bandwidth WSS as depicted in Figure 2.

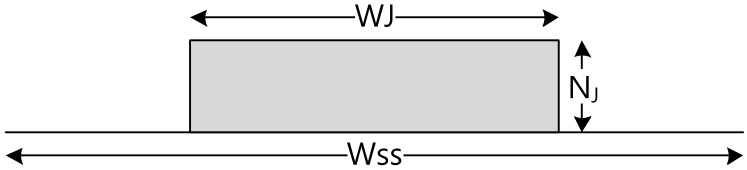

Figure 2. Noise jammer frequency distribution

The fractional ratio ρ is defined as follows.

$$\rho = \frac{W_J}{W_{ss}} \tag{1}$$

Since the jamming power is spread uniformly over W_J, the increased jammer power spectral density is calculated as follows.

$$\frac{J}{\rho W_{ss}} = \frac{N_J}{\rho} \tag{2}$$

where N_J represents the jammer power spectral density of broad band noise jammer calculated as J/W_{SS}. This results in the degraded E_b/N_J level as defined as follows.

$$\frac{E_b}{N_J / \rho} = \frac{\rho E_b}{N_J} \tag{3}$$

In the case of PBNJ, the jamming occurs in a part of the total frequency band, and the transmitted data bit either encounters a jammer with probability ρ or jammer off with probability 1-ρ. Thus, the bit error probability can be calculated as follows (Esli and Delic, 2006).

$$P_b = (1-\rho)\cdot P_1 + \rho \cdot P_2 \cong \rho \cdot P_2 \tag{4}$$

where P_1 represents the bit error probability when the channel has no jammer. Since P_1 would be very small, we approximate P_1 to 0. P_2 represents the bit error probability under jamming, which can be derived by the bit error rate under broad band noise jammer. Since the BER performance under broadband noise jammer is a brute force jammer that does not exploit any knowledge of the anti-jam communication system except its spread bandwidth, BER is the same as under AWGN. Thus, P_2 can be obtained by replacing N_0 under AWGN with N_J/ρ, where N_0 is the spectral density of noise power in AWGN.

Broadband noise jamming (ρ=1) has been proven to always be the most effective for small E_b/N_J condition. Furthermore, there is an optimum value of ρ, ρ*, that can maximize the error probability for any given E_b/N_J, resulting in what is known as the WPBJ scenario. We obtain ρ* theoretically, when the BER formula is derived. However, the theoretical derivations of BER are very complicated for some modulation schemes. In this case, we find ρ* by selecting ρ that causes the worst result in many simulations.

3. Performance under PBNJ and WPBJ

In this section, the performances of various modulation schemes in the slow frequency hopping system are investigated under PBNJ and WPBJ.

3.1 NC-MFSK

The BER of NC-MFSK under PBNJ with fraction ρ can be calculated as follows (Esli and Delic, 2006).

$$P_b = \frac{\rho \cdot 2^{K-1}}{2^K - 1} \sum_{l=1}^{2^K-1} \binom{2^K-1}{l} (-1)^{l+1} \frac{1}{l+1} e^{-lK((E_b \cdot \rho)/N_J)/(l+1)} \tag{5}$$

where $K=\log_2(M)$.

Although the probability that an M-ary transmission is jammed is decreased, we can expect from Equation (5) that the jammed signals suffer a higher conditional error rate when ρ is reduced. Therefore, the net effect may result in the overall degradation of the NC-MFSK performance. In other words, with the decrease of ρ, the performance gets worse when E_b/N_J is larger than a certain value.

We validated the analysis results via simulations. For the simulations, we considered 16symbols/hop environment for a slow frequency hopping system, and we assumed NC-BPSK modulation schemes, in which the bit rate is 256kbps and the hopping rate is 16khops/sec.

Figure 3 shows the theoretical and simulated BER performances of the SFH/NC-BFSK under PBNJ applying various ρ values. As can be seen from the simulation results, the BER performance of SFH/NC-BFSK follows the same theoretical performance as denoted in Equation (5). From Figure 3, we can see that the broadband noise jamming with ρ=1 has the worst jamming effect for small E_b/N_J in the region of 0 to 4 dB. Also, we can observe that the small value of ρ shows the worst effect for large E_b/N_J in the region of 28 to 32 dB.

The BER performances of the SFH/NC-BFSK under WPBJ are calculated as follows. By differentiating Equation (5), ρ* that maximizes P_b can be obtained as follows (Simon *et al*, 1994), (Houston, 1975), (Lee *et al*, 1984).

$$\rho^* = \begin{cases} \dfrac{2}{E_b/N_J}, & E_b/N_J > 2 \\ 1, & E_b/N_J \le 2 \end{cases} \tag{6}$$

This yields the maximum value of P_b as follows.

$$P_b = \begin{cases} \dfrac{e^{-1}}{E_b/N_J}, & E_b/N_J > 2 \\ \dfrac{1}{2} \cdot e^{-(E_b/2N_J)}, & E_b/N_J \le 2 \end{cases} \tag{7}$$

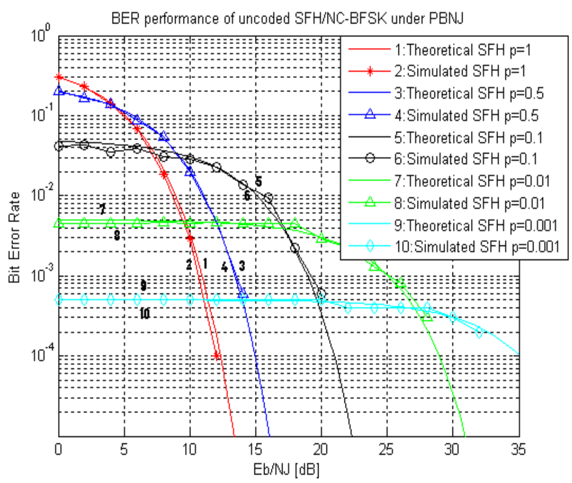

Figure 3. BER performance of SFH/NC-BFSK under PBNJ

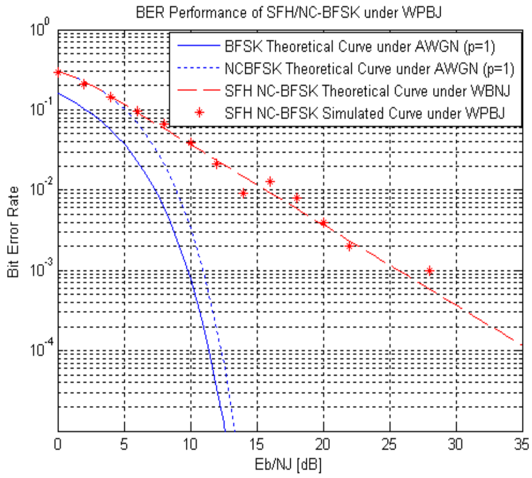

Figure 4. BER performance of SFH/NC-BFSK under WPBJ

Figure 4 shows the theoretical and simulated BER performances of SFH/NC-BFSK under WPBJ. As can be seen from Figure 4, the BER performance of SFH/BFSK under WPBJ is linear and the simulated curve matches well with the theoretical one. Moreover, the performance of SFH/NC-BFSK under WPBJ is much worse than that of AWGN.

3.2 SDPSK

In the case of SDPSK under PBNJ, the bit error rate of SFH/SDPSK under PBNJ is calculated as follows (Eakin, 2005).

$$P_b = \frac{\rho}{2} \cdot e^{-\rho(E_b / N_j)} \tag{8}$$

We validated the analysis results via simulations. For the simulations, we considered the same environment as than in Section 3.1.

Figure 5 shows the theoretical and simulated BER performances of the SFH/SDPSK under PBNJ applying various ρ values. From this figure, we can observe a tendency similar to that shown in case of the SFH/NC-BFSK under PBNJ. The large value of ρ has the worst jamming effect for small E_b/N_J, and the small value of ρ shows the worst effect for large E_b/N_J.

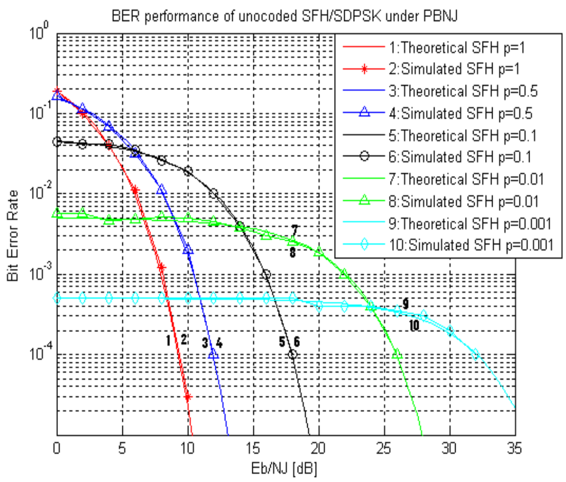

Figure 5. BER performance of SFH/SDPSK under PBNJ

The BER performances of the uncoded SFH/SDPSK under WPBJ are calculated as follows. By differentiating Equation (8) with respect to ρ, ρ* that maximizes P_b can be obtained as follows.

$$\rho^* = \frac{1}{(E_b / N_J)} \tag{9}$$

This yields the maximum value of P_b as follows.

$$P_b = \begin{cases} \frac{1}{2}\exp(-E_b / N_J), & E_b / N_J < 2 \\ \frac{1}{2e(E_b / N_J)}, & E_b / N_J \le 2 \end{cases} \tag{10}$$

Figure 6 shows the theoretical and simulated BER performances of SFH/SDPSK under WPBJ. As can be seen from Figure 6, the BER performance of SFH/SDPSK under WPBJ is linear, and the simulated curve matches well with the theoretical one. Moreover, the performance of SFH/SDPSK under WPBJ is much worse than that of AWGN.

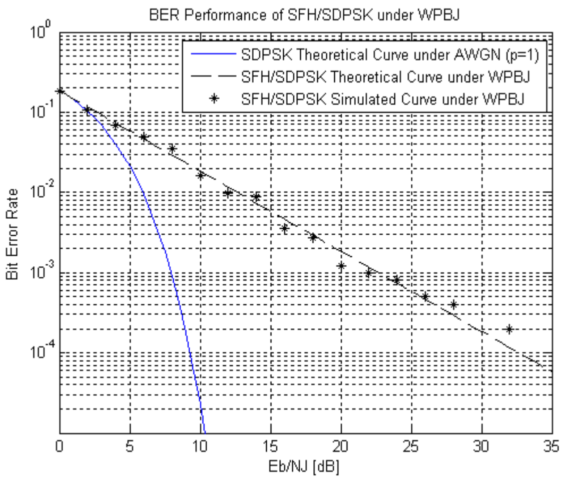

Figure 6. BER performance of SFH/SDPSK under WPBJ

3.3 SFH/GMSK

In the case of GMSK using one bit differential detection (1-bit DD), it is complicated to derive the theoretical BER formula for SFH/GMSK under PBNJ, and thus we only performed the simulations. For the simulations, we considered the same environment as that in Section 3.1.

Figure 7 shows the BER performance of SFH/GMSK using 1-bit differential detection under PBNJ for BT=0.5. From Figure 7, it can be seen that for small E_b/N_J, the most effective jamming occurs when ρ=1, and for large E_b/N_J, the small ρ is the best jamming strategy.

In the case of WPBJ, it is not possible to directly obtain the maximization value of P_b by mathematical derivation since the derivation of a mathematical formula for the BERs of GMSK is not obtainable. However, it can be approximately achieved via simulation. We apply various values of ρ to get the bit error rates for the fixed value of E_b/N_J, and we then choose ρ that shows the worst performance.

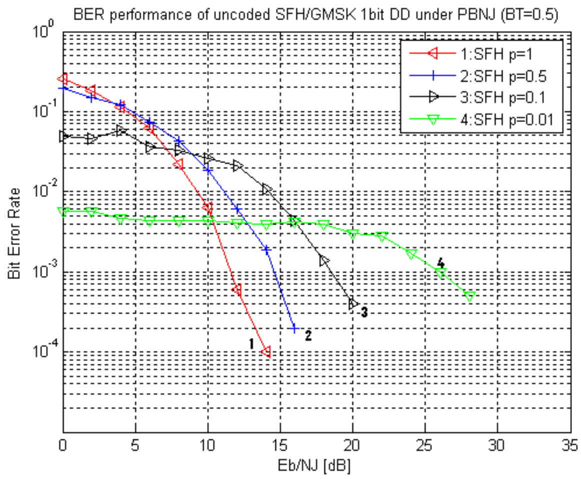

Figure 7. BER performance of uncoded SFH/GMSK using 1-bit DD under PBNJ (BT=0.5)

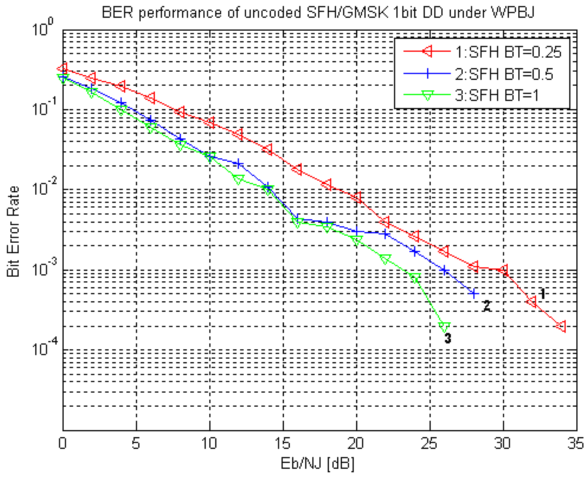

Figure 8. BER performance of SFH/GMSK under WPBJ

Figure 8 shows the BER performance of GMSK under WPBJ for BT=0.25, 0.5 and 1. As can be seen from Figure 8, the BER performances are approximately straight lines for all BT products like in the case of NC-BFSK and SDPSK, and the smaller BT product shows worse performance.

3. CONCLUSIONS

In this paper, the performances of NC-MFSK, SDPSK, and GMSK in the slow frequency hopping system have been evaluated under PBNJ and WPBJ. The study herein was focused on assessing the bit error probability of the concerned modulation schemes under AWGN, PBNJ, and WPBJ. Under various scenarios, the theoretical and simulated results have been presented. The performances are compared mainly for environments under AWGN, PBNJ, and WPBJ. From the results, we concluded that the most effective jamming occurs when ρ=1 for small Eb/NJ, and the small ρ is the best jamming strategy for large Eb/NJ. By using the above result, the appropriate transmission method by the radio channel condition of satellite communication maybe determined. The simulator suggested in this study would be helpful to design the system model.

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