PERFORMANCE OF SATELLITE COMMUNICATION SYSTEM WITH FH-MFSK UNDER VARIOUS JAMMING ENVIRONMENTS

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ABSTRACT

Military satellite communication can be operated with various levels of satellite onboard processing. In this paper, the BER performances of the bent pipe transponder (DRT), dehop only transponder (DOT) and dehop and rehop transponder (DRT) systems with FH-MFSK modulation are compared in the presence of full band, partial-band noise jamming and multi-tone jamming. Further, this paper investigates the BER by changing the data rates, spreading bandwidth and jamming EIRP. The numerical results show that DRT outperforms BPT and DOT, and, DOT is less sensitive to uplink jamming EIRP under full-band jamming strategy than DRT. In the partial band jamming case, the worst case ρ, i.e., a ratio of the spreading bandwidth to the jamming bandwidth is also changed according to the variation of the data rate, and the BER of DRT is more sensitive to different ρ values than DOT. Among various jamming strategies, the performance in MTJ is shown to be the worst.

1. INTRODUCTION

In recent years, the demand to provide global personal communication has resulted in the use of satellite communication system. The use of the commercial satellite communication is originally limited in the case of the military communication, because it has the weakness in the aspect of the survivality and security. In the case of commercial satellite system, the intentional jamming and the eavesdropping can be easily done by the hostile system. Hence, the military satellite system requires various techniques of anti-jamming and low probability of intercept (LPI) to compensate these defects. From these facts, the investigation considering the jamming environment is needed in the satellite communication system.

In the onboard processing techniques, there exist various methods, such as Bent Pipe Transponder (BPT), Dehop and Rehop Transponder (DRT), Dehop only Transponder (DOT) and symbol regenerative processor (SRP), and so on [1],[2]. First, a BPT translates the full FH bandwidth from the uplink to the downlink frequency band and retransmits the received signals including any jamming signal within the bandwidth. The advantage of BPT is in simplicity. In a DRT system, the FH signal is dehopped and filtered through a bandwidth narrower than the hopping bandwidth. Then, the filtered FH signal is rehopped before transmitting through the downlink. The DOT system is similar to DRT. The only different thing is that DOT performs only the dehopping without the rehopping. Finally, in the SRP system, the satellite not only dehops but also demodulates the uplink signal. Generally, it is well known that the SRP is more complex than the DRT.

Among the various jamming strategies, there are well known methods, such as full band jamming (FBJ), partial band jamming (PBJ) and multitone jamming (MTJ) techniques [3],[5]. Generally, the jamming effect is evaluated without considering the practical parameters. As a result, it is difficult to relate those approaches with the case of real situation. And, it is important to estimate the maximum supportable data rate with satisfying the quality of service (QOS). From this purpose, we consider the BER performance with the FH-MFSK modulation scheme according to various data rates. In this paper, we investigate and compare the BER performances of BPT, DOT and DRT systems in the presence of FBJ, PBJ and MTJ jammings by using the link budget analysis. This paper is organized as follows : In Section 2, the link budget analysis and the performance analysis under jamming environment are explained. In Section 3, the methods to obtain total SNR are calculated in the BPT, DOT and DRT systems. The system model and numerical results are explained in Section 4. Finally, the results are summarized and concluded in Section 5.

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2. PERFORMANCE ANALYSIS UNDER JAMMING ENVIRONMENT

2.1. Link Budget Analysis

The received signal power in the satellite is represented as follows [4]:

$$P_{r,sat} = \frac{P_t G_{ts} G_{st} \lambda^2}{(4\pi R_{ts})^2 M_{up}} \tag{1}$$

where P_t is the transmitting power of the terminal, G_{ts} is the transmitting antenna gain from the terminal to the satellite, G_{st} denotes the receiving antenna gain of the satellite to the direction of the terminal and λ is a wavelength of the signal. R_{ts} means the distance between the terminal and the satellite and M_{up} is an uplink margin.

The received jamming power of satellite from the uplink jammer is calculated as

$$P_{J,up} = \frac{(EIRP)_{J,up} G_{sj} \lambda^2}{(4\pi R_{sj})^2 M_{up}} \tag{2}$$

where $(EIRP)_{J,up}$ is a transmitting effective isotropic radiated power (EIRP) of the uplink jammer, G_{sj} is receiving antenna gain of satellite to the direction of uplink jammer and R_{sj} is a distance between the uplink jammer and the satellite. After uplink FH signal passes through the satellite, the received signal power of downlink terminal can be represented as

$$P_{r,ter} = \frac{P_{t,sat}\, G_{st} G_{ts} \lambda^2}{(4\pi R_{ts})^2\, M_{down}} \tag{3}$$

where $P_{t,sat}$ is a transmitting signal power of satellite to the downlink and M_{down} is a downlink margin. The retransmitting uplink jamming power to the downlink terminal is calculated as follows.

$$P_{J,ter} = \frac{P_{J,sat} G_{st} G_{ts} \lambda^2}{(s\pi R_{ts})^2\, M_{down}} \tag{4}$$

where $P_{J,sat}$ is the transmitting jamming power of satellite to the downlink.

Total E_b/N_J in the downlink terminal can be calculated as follows :

$$\left(\frac{E_b}{N_J}\right)_{Tot} = \frac{P_{r,ter}}{P_{J,ter} + P_{J,down}} \cdot \frac{W_s}{R_d} \tag{5}$$

where $P_{J,down}$ is the jamming power received from the downlink jammer, W_s represents the filtering bandwidth of a M-ary FSK system ($\simeq M * 4800$), where the bandwidth is set to a high data rate and R_d denotes the data rate, which varies from 70 to 4800 bps. This can be summarized in Figure 1.

Distance between SAT. and Terminal	40000 km
Uplink Frequency	8 GHz
Downlink Frequency	7 GHz
Uplink Margin	2.9 dB
Downlink Margin	2.2 dB
Data Rate	70 ~ 4800 Hz
Satellite Temperature	900 K
Satellite Receiving Antenna Gain	30 dB
Satellite Transmitting Antenna Gain	30 dB
Satellite Gain	100 dB

Table 1: Link Budget Diagram

2.2. Full Band Jamming (FBJ) Case

The symbol error performance for equally likely non-coherently detected M-ary orthogonal signaling is

$$P_e = \frac{1}{M} \sum_{j=2}^{M} (-1)^j \binom{M}{j} exp\left\{-\frac{E_s}{N_0}\left(\frac{j-1}{j}\right)\right\} \tag{6}$$

where E_s/N_0 represents the symbol energy to noise power spectral dentsity [1],[4]. Equation (6) is represented by $P_b = MP_e/2(M-1)$ as follows :

$$P_b \leq \frac{M}{4} exp\left(-\frac{E_s}{2N_0}\right) \tag{7}$$

In the FBJ environment, the transmitted signal is always jammed by the hostile system while passing through both uplink and downlink. Consequently, after Equation (5) is calculated, the final BER can be obtained by using Equation (7).

2.3. Partial Band Jamming (PBJ) Case

The important variable in the PBJ environment is $\rho = W_J/W_{SS}$, i.e., the ratio of the jamming bandwidth (W_J) to the spreading bandwidth (W_{SS}). In PBJ, the transmitted FH signal can be affected by the jamming signal or not. In this case, we assume that the original jamming power is fixed in the PBJ, which means that the jamming power spectral level increases conversely as the jamming bandwidth decreases. Consequently, if we assume that PBJ and FBJ exist in the uplink and downlink respectively, the final BER can be represented as a combination form of two terms, as follows :

$$P_b \leq \rho P_{b1} + (1-\rho) P_{b2} \tag{8}$$

where P_{b1} and P_{b2} represent the BER when PBJ affects on the transmitted FH signal or not, respectively.

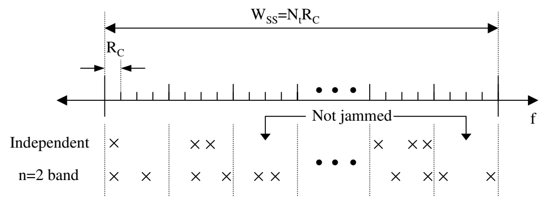

Figure 1: Multitone jamming stategies: independent MTJ and n band MTJ (4-ary band)

2.4. Multi-tone Jamming (MTJ) Case

In the case of MTJ, there exist popular two schemes, such as independent MTJ and band MTJ [5]. Let's consider that the jammer divides its total received power J into Q distinct, equal power, random phase CW tones. These are distributed over the spreading bandwidth W_{SS} as shown in Figure 1, where each jamming tone coincides exactly in frequency with one of the N_t available FH slots, with at most one tone per slot. The independent MTJ distributes the tones pseudorandomly over all N_t FH frequencies. Whereas, The n band MTJ places n jamming tones in each jammed M-ary band. In this paper, we concentrate on the n band MTJ, because it affects more the system than the independent MTJ. Generally, the performance is improved as the n of band MTJ increases. Hence, n=1 is fixed in order to consider the worst case of BER performance. The detailed BER is well known in [5].

3. PERFORMANCES OF BPT, DOT AND DRT SYSTEMS

3.1. Bent Pipe Transponder (BPT) Case

The purpose of this analysis is to calculate the end-to-end performance of the satellite system for various combinations of uplink and downlink jammer signals. Let W_u and W_d be spreading bandwidths andJ_u and J_d be the total jamming powers in the uplink and downlink, respectively. If we assume that the jamming signal is a bandlimited white Gaussian noise, the power spectral densities is $N_u = J_u/W_u$ and $N_d = J_d/W_d$ in uplink and downlink, respectively. And, let the satellite receiver noise density and ground receiver noise density be KT_u and KT_d, where K is Boltzmann's constant and T_u and T_d represent the terminal temperature in uplink and downlink, respectively. Each of uplink and downlink noise densities is represented, respectively, as follows :

$$N_{ou} = KT_u + J_u/W_u\,,\ N_{od} = KT_d + J_d/W_d \qquad (9)$$

If we assume that C_u and C_d denote the received power at the input to the receiver in the uplink and downlink, respectively, the total SNR is given by

$$\begin{aligned}\left(\frac{S}{N}\right)_T &= \frac{C_d\left(\frac{C_u}{C_u+N}\right)}{C_d\left(\frac{N}{C_u+N}\right)+N_{od}W_u} \\ &= \left[\left(\frac{C_u}{N_{ou}W_u}\right)^{-1}+\left(\frac{C_d}{N_{od}W_u}\right)^{-1}\right. \\ &\quad\left.+\left(\frac{C_u}{N_{ou}W_u}\right)^{-1}\left(\frac{C_d}{N_{od}W_u}\right)^{-1}\right]^{-1} \qquad (10)\end{aligned}$$

Equation (10) can be simplified as

$$\left(\frac{S}{N}\right)_T = X_T = \frac{X_uX_d}{X_u+X_d+1} \qquad (11)$$

where $X_u = C_u/(N_{ou}W_u)$ and $X_d = C_d/(N_{od}W_u)$.

3.2. Dehop-Rehop Transponder (DRT) and Dehop Only Transponder (DOT) Cases

Total SNR forms of DRT and DOT are very similar to that of BPT. Unlike the BPT, only the uplink jamming power included in the filter bandwidth of satellite is retransmitted to the downlink terminal.

$$\begin{aligned}\left(\frac{S}{N}\right)_T &= \frac{C_d\left(\frac{C_u}{C_u+N}\right)}{C_d\left(\frac{N}{C_u+N}\right)+N_{od}W_s} \\ &= \frac{X_uX_d}{X_u+X_d+1} \qquad (12)\end{aligned}$$

where $X_u = C_u/(N_{ou}W_s)$ and $X_d = C_d/(N_{od}W_s)$.

In the DOT system, X_u and X_d in total SNR form are given by

$$\begin{aligned}X_u &= \frac{C_u}{N_{ou}W_s} = \frac{C_u}{KT_uW_s + J_uW_s/W_u} \\ &= \frac{C_u}{KT_uW_s + J_u/P_{gain}} \qquad (13)\end{aligned}$$

and $X_d = C_d/(N_{od}W_s)$ where $P_{gain} = W_s/W_u$. In the DRT system, only X_d is changed as compared with the DOT.

$$X_d = \frac{C_d}{KT_dW_s + J_d/P_{gain}} \qquad (14)$$

4. SYSTEM MODEL AND NUMERICAL RESULTS

In order to investigate BER performances of BPT, DOT and DRT systems in the presence of FBJ, PBJ

Distance between SAT. and Terminal	40000 km
Uplink Frequency	8.4 GHz
Downlink Frequency	7.75 GHz
Uplink Margin	2.9 dB
Downlink Margin	2.2 dB
Data Rate	70 ~ 4800 Hz
Satellite Temperature	900 K
Satellite Receiving Antenna Gain	31 dB
Satellite Transmitting Antenna Gain	31 dB
Satellite Gain	100 dB

Table 2: General Assumptions

Terminal EIRP (dBW)	Terminal 1	Terminal 2
Receiving Antenna Gain (dB)	60	70
Transmitting Antenna Gain (dB)	43	40
Terminal Temperature (K)	40	400

Table 3: Ground Terminal Assumptions

and MTJ, the analysis model is based on the Table 2. The type of Terminal is summarized in Table 3 and the transmitter and receiver are referred to Terminals 1 and 2, respectively.

Figure 2 represents the BER variation of DRT system for different data rates when FBJ noise exists in both uplink and downlink. In this case, if the spreading bandwidth and downlink C/I increase, the BER is also improved. Though the downlink C/I gradually increases beyond about 20 dB, the BER curve is saturated to certain bound. This phenomenon is originated from the fact total BER is determined by only the uplink jamming when downlink C/I is very large. Figures 3 and 4 represent the BER comparison of BPT, DOT and DRT systems when the value of downlink C/I and the uplink EIRP are varied, respectively. In Figure 3, BPT is inadequate to support any data rate when the system model is established from Tables 2 and 3. DOT is more sensitive to the variation of $(C/I)_{down}$ than DRT. In the case of DOT, if $(C/I)_{down}$ changes from 40 to 30 dB, then the data rate decreases from 2500 to 500 bps, which is about a reduction of 80%. This is due to the fact that the effect of downlink jamming becomes weak because the DRT is rehopping the filtered signal in the satellite before transmitting to the downlink terminal. Whereas, in the case of variation of uplink jamming EIRP, DRT is relatively sensitive to that than DOT from Figure 4. In this case, when the uplink EIRP is relatively large, the performance of DOT is similar to that of DRT. Figure 5 represents the BER performances of DOT and DRT under PBN in

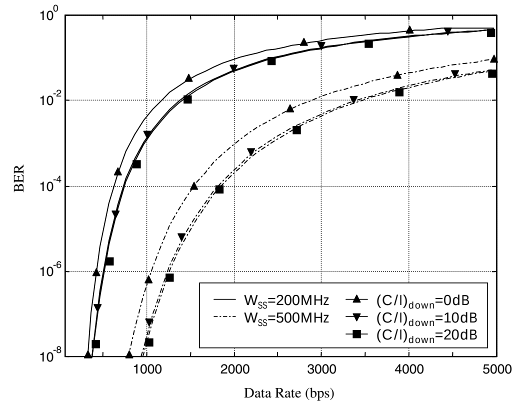

Figure 2: BER performance variation vs. data rate of the DRT system under the FBJ of uplink and downlink (uplink jamming EIRP=110dBW)

uplink and FBN in downlink when all variables except ρ value are fixed. In Figure 5, we can find that DRT is more sensitive to the ρ value than DOT. Finally, Figure 6 shows the BER performance of DRT when n=1 band MTJ exists in uplink. Among various jamming strategies, the environment of band MTJ is the worst case. In addition, performance improvement of MTJ with the bandwidth expansion is the smallest in the investigated jamming circumstances.

5. CONCLUDING REMARKS

In this paper, we investigated the BER performances of BPT, DOT and DRT systems in the presence of full band jamming (FBJ), partial band jamming (PBJ) and multi-tone jamming (MTJ) and compared these systems for different uplink jamming EIRP, downlink C/I and spread bandwidth. Among those, the BER performance of DRT system outperforms those of DOT and BPT. In the case of FBJ, though the downlink C/I gradually increases, the BER curve is saturated to a certain bound. The DRT system is more sensitive to uplink jamming signal than DOT. Whereas, the DOT is more affected by the downlink C/I. In this case, when the uplink EIRP is relatively large, the performance of DOT is similar to that of DRT. In the case of PBJ, the DRT is more dependent on ρ than the DOT. In MTJ, the performance is the worst and the expansion of bandwidth does not give the advantage effectively on the BER performance as compared with other cases.

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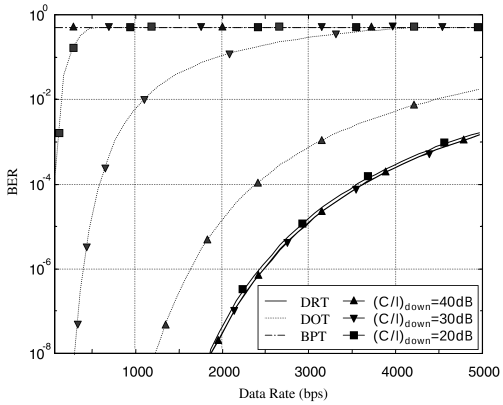

Figure 3: BER performance comparisons of BPT, DOT and DRT under FBN in uplink and downlink ($W_{ss} = 100MHz$, uplink jamming EIRP=100 dBW)

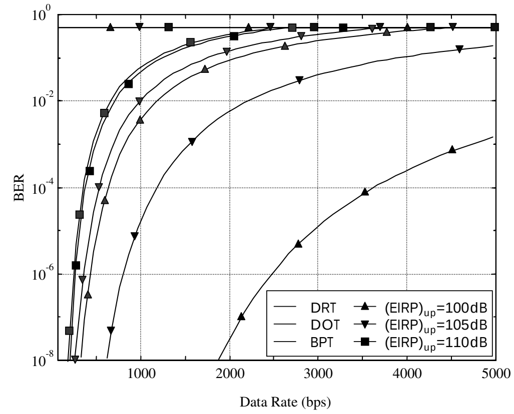

Figure 4: BER performance comparisons of BPT, DOT and DRT under FBN in uplink and downlink ($W_{ss} = 100MHz$, $(C/I)_{down} = 30dB$)

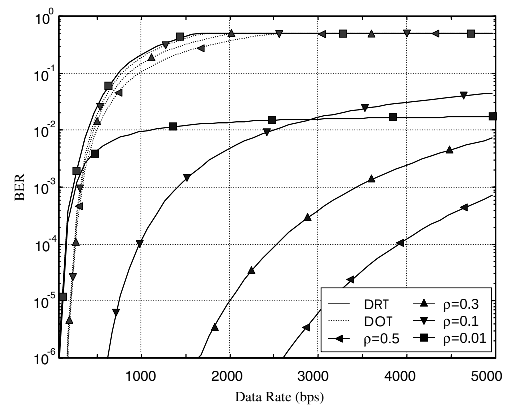

Figure 5: BER performance comparisons of DOT and DRT under PBN in uplink and FBN in downlink ($W_{ss} = 200MHz$, uplink jamming EIRP=100 dBW, $(C/I)_{down} = 30dB$)

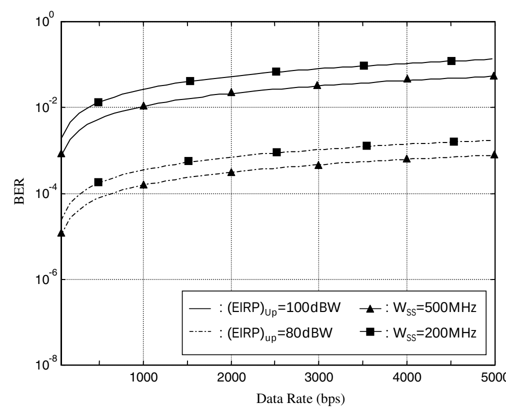

Figure 6: BER performance of DRT under n=1 band MTJ in uplink and FBN in downlink ($(C/I)_{down} = 30dB$)

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