Determination of Optimal Channel Spacing Based on Spectrums for Spreading Codes in Split Channel BFSK

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Abstract

This paper proposes optimal channel spacing for Split Channel BFSK (Binary Frequency Shift Keying) with direct sequence spread spectrum. To this end, first, the inter-channel interference is observed for various spreading gains and codes through computer simulation. The data rate is 1 MHz and two tone spacing of SC-BFSK is 4 MHz. The receiver filter bandwidth for each tone is 700 kHz. The spreading code is selected between random PN (Pseudo Noise) code or all 1. According to the results, it is confirmed that optimum inter-channel spacing depends on the spreading gains and codes. Specifically, for small spreading gains, all 1 code shows better out-of-band interference characteristics than the PN code while PN code is preferable for large spreading gains. Therefore, neighboring channel spacing should be decided as a function of spreading gain, and a preferable spreading code exists in terms of inter-channel interference mitigation.

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1. Introduction

Multipath fading channel is a channel environment in which many reflected waves exist at the received signals. These channels exhibit frequency-selective characteristics. That is, communication may be difficult because the frequency response of the channel is large at some frequencies but at other frequencies, the frequency response of the channel is small. Various communication techniques have been proposed for stable communication in such fading channels, and one of them is split channel binary frequency shift keying (SC-BFSK).

Unlike conventional BFSK, SC-BFSK is a communication technique that transmits and receives with two frequency tones having a wide spacing (Kim, K. N. et al., 2021, Lee, Gun. Ho. et al., 2020, Ryu, H.G., et al., 2003). The advantage of SC-BFSK is that both tones may not attenuated simultaneously in the frequency selective fading channels, and at least, one of the tones can be received well. Since it is sufficient to receive the transmitted message with only one tone, SC-BFSK is superior to the conventional BFSK in frequency selective fading channels. However, in SC-BFSK, limited frequency resources can be wasted because the transmitter allocates widely separated two tones for transmission (Ibragim, M.A. et al. 2019, Lee, K.P., et al., 2017). In order to solve this problem, an adjacent channel may be allocated between two tones. The frequency efficiency increases as the spacing between adjacent channels becomes smaller. On the other hand, signal to interference plus noise ratio (SINR) may decrease and the communication performance may degrade due to the adjacent channel interference (ACI) (Harvanek, M., et al., 2020, Kim, S.W., et al., 2010, Lan, L., et al., 2011, Yang, X., et al., 2003). However, in previous studies, how to allocate adjacent channels can increase frequency efficiency while reducing interference with each other has not been studied.

In this paper, we propose an optimal adjacent channel allocation interval for SC-BFSK with direct sequence spread spectrum (Ryu, H.G., et al., 2003). First, the spectrum of SC-BFSK is observed through computer simulation. In the simulation, the two-tone spacing is 4 MHz and the transmission rate is set to 1 MHz. After that, a new signal is allocated to an adjacent channel while varying the spreading gain and spreading code. We observe the reception bit error ratio (BER) while varying the frequency interval of the adjacent channel. As a spreading code, a pseudo noise (PN) code and an all 1 code are used. That is, while changing the frequency spacing of adjacent channels, the optimal channel spacing is determined by measuring the reception BER along with the spreading gains and the codes. According to the simulation results, when the spreading gain is 1, the adjacent channel spacings of 1,150 kHz and 2,060 kHz are optimal. For spreading gains of 4 and 16, the optimal spreading code is ALL 1, and the preferable adjacent channel spacings are 1,000 kHz and 2,000 kHz. On the other hand, if the spreading gain is 64, the PN code is a good choice for the spreading code, and 1,000 kHz or 2,000 kHz are adequate for the adjacent channel spacing.

2. System Model

In this paper, we consider the problem of allocating neighboring channel in between two tones of one channel SC-BFSK. If the neighboring channel is allocated in this way, spectral efficiency of SC-BFSK can be improved.

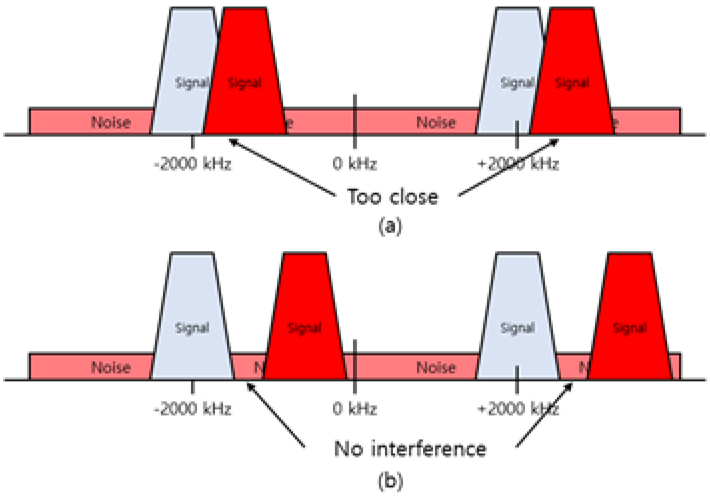


Fig. 1; Example of Spacing Adjacent Channels

Figure 1 shows an example of adjacent channel allocation. As shown in Figure 1-(a), the smaller the distance between the original channel and the neighboring channel, the higher the frequency usage efficiency. On the other hand, as the distance between adjacent channels increases as shown in Figure 1-(b), the influence of interference between the two channels decreases, but the spectral efficiency may decrease. Therefore, finding optimal adjacent channel spacing is important to minimize the adjacent channel interference (ACI) and maximize the spectral efficiency. To this end, in this paper, the reception performance for every frequency interval of the adjacent channel is examined. Through this way, the minimum frequency interval of the neighboring channel can determined while the influence of interference is not significant.

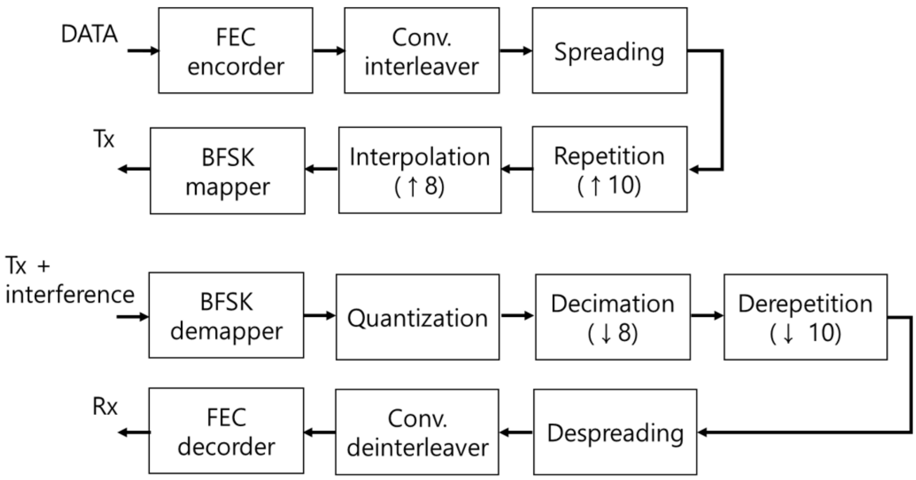


Fig. 2; System Model Structure of SC-BFSK

Figure 2 is the transceiver block diagram of SC-BFSK. First, data to be sent is encoded with R=1/2 using a convolutional code, and then convolutional interleaving is performed to prevent a burst error. The convolution code is used as the forward error correction code (FEC). Then, direct sequence spread spectrum is performed. The reason of the spread spectrum is to obtain excellent reception performance even at a low signal-to-noise ratio (SNR), and through this, the influence of interference can be reduced (Sedaghatnejad, S. et al., 2015). In addition, when SC-BFSK is used for military communication, it is possible to lower the probability of being detected by the enemy. For the spreading code, a PN code may be used as well as all 1 code. If all 1 code is used, spreading is the same as repeatedly transmitting the same signal. The subsequent process is to model the analog processing. The spread signal is repeated 10 times and then, interpolated 8 times. 1 and 0 are converted into signals of different tones spaced apart by 4 MHz and transmitted. This process can be regarded as SC-BFSK modulation. A signal ACI of an adjacent channel is generated through the same process. The two tones frequencies of ACI are spaced apart from the original signal by a certain interval. The original signal and the neighboring signal are added and received. The spectrum of this received signal is shown in Figure 1. The received signal is converted into a digital signal through decimation. Then, despreading is performed using the spreading code, and deinterleaving and FEC decoding are conducted in turn. The BER is measured by comparing the data received through this process with the transmitted data.

3. Spectrum Analysis and Adjacent Channel Spacing Determination

3.1. Transmit Signal and Channel Environment

3.2.

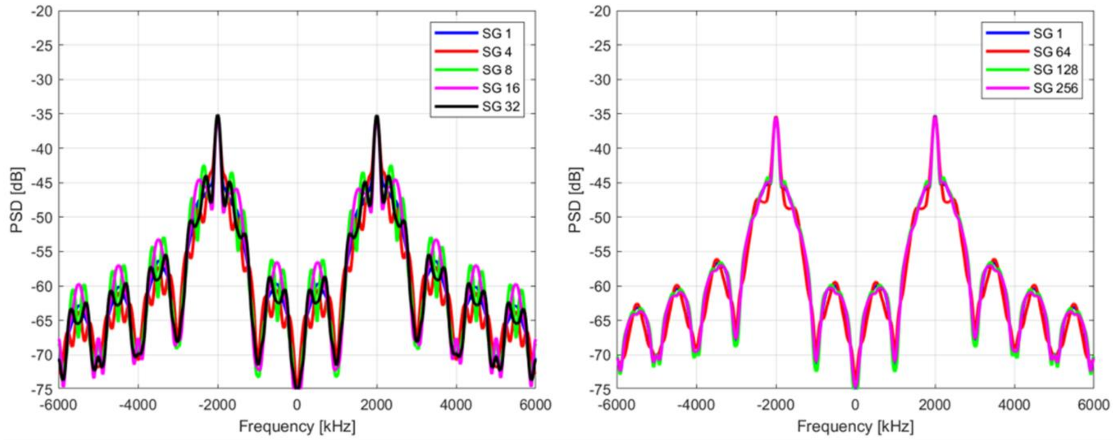
Table 1. Transmission Signal and Channel Environment

transmission signal	1Mbps
Code rate	1/2
channel environment	AWGN
tone spacing	4MHz
spreading gain	1, 4, 16, 64

Table 1 shows the types of signals and the channel environments used to examine the performance according to the adjacent channel spacing. The channel coding rate is 1/2, and the data rate of the channel encoder output is 1 Mbps (thus, the user data rate is 0.5 Mbps). The channel environment is additive white Gaussian noise (AWGN). The two-tone spacing of SC-BFSK is 4 MHz, and the spreading gains are 1, 4, 16, and 64. The length of the receiver band pass filter for each tone is 121 taps whose transition band is 400 kHz, and the pass bandwidth is 700 kHz. The purpose of this filter is to remove any noise or interference other than the tone signal.

3.3. Spectrums for various Spreading Codes

In this section, the transmit spectrum is observed while varying the spreading gains to 1, 4, 8, 16, 32, 64, 128, and 256.



(a) Spectrum of spread gain 1, 4, 8, 16, 32 (b) Spectrum of spread gain 1, 64, 128, 256

Fig. 3; Spectrum by Spreading Gain

Figure 3 shows the spectrum for each spreading gain when the PN code is used as the spreading code. Figure 3(a) shows the spectrum when the spreading gains are 1, 4, 8, 16, and 32, and Figure 3(b) shows the spectrum when spreading gains are 1, 64, 128, and 256. A PN code has random characteristics, that is, a code sequence looks like random. However, when the spreading gain is too low, the PN code exhibits regular rather than random. This regularity appears as a distortion in the spectrum especially at the out-of-band. Irregular codes have the best spectral characteristics, and when the irregularity is the highest, the same spectrum as that of the spreading gain 1 appears. Spectral distortion causes the ACI at low spreading gains. Next, the optimal spreading code and adjacent channel spacing are determined by comparing reception performance for each adjacent channel spacing and different spreading codes.

3.4. Performance by Spreading Code

In order to observe the performance for adjacent channel interval and the spreading code, we compare and simulate three random PN codes and an 'all 1' code. Spreading using the all 1 code is equivalent to repeating as many as the spreading gain, and this case is denoted as 'ALL 1'. The spreading gain is varied among 1, 4, 16, and 64.

Table 2. SNRs and SIRs for Simulation

Spreading gain	SNR [dB]	SIR [dB]
1	9	-10
4	4	-20
16	-1	-20
64	-4	-25

Table 2 shows simulation parameters for examining the performance of adjacent channels for spreading gains. For a spreading gain of 1, SNR = 9 dB and SIR (Signal to Interference Ratio) = -10 dB, for a spreading gain of 4, SNR = 4 dB, and SIR = -20 dB, and for a spreading gain of 16, SNR = -1 dB, and SIR = -20 dB. For a spreading gain of 64, SNR = -4 dB and SIR = -25 dB. The adjacent channel spacing is varied in the range of 100 kHz to 4,000 kHz with 50 kHz step.

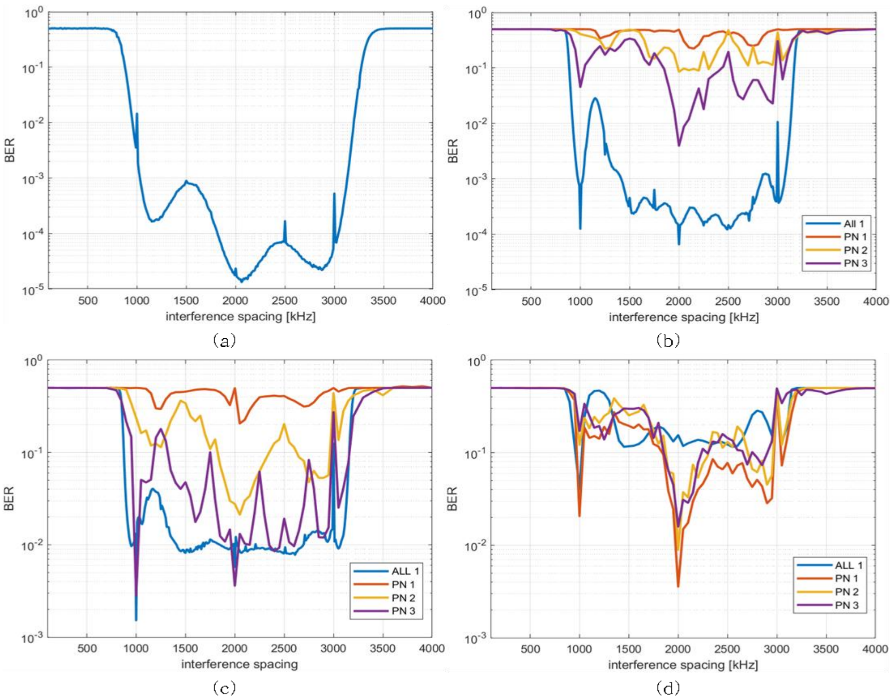


Fig. 4; BER Performance for Adjacent Channel Spacing with (a) Spreading Gain 1, (b) Spreading Gain 4, (c) Spreading Gain 16, and (d) Spreading Gain 64

Figure 4(a) ~ 4(d) show the performances for adjacent channel spacing when the spreading gain is 1, 4, 16, and 64, respectively. As mentioned earlier, the spreading codes are 3 types of PN codes and ALL 1 code. The x-axis of the graph is the adjacent channel spacing (kHz), and the y-axis is the BER. In the figure, blue is the BER performance when the spreading code ALL 1, and orange, yellow, and purple are the BER performance when PN 1, PN 2, and PN 3 are used, respectively. When the spreading gain is 1, the optimal adjacent channel spacing for the best BER is 2,060 kHz. Also, it can be seen that the BER is lowered at 1,150 kHz spacing. If frequency efficiency is important, 1,150 kHz is a good choice, and if BER performance is important, 2,060 kHz is the best choice. When the spreading gains are 4 and 16, it can be seen that the BER performance is much degraded when the PN codes are used. The overall BER is large. Those results indicate that PN code is not preferable at low spreading gains. However, when the spreading code ALL 1 is used, it can be seen that the BER is relatively low when the adjacent channel spacing is 1,000 kHz and 2,000 kHz. When the spreading gains are 4 and 16, it is recommended to use ALL 1 as the spreading code. In addition, it is advantageous to use 1,000 kHz if frequency efficiency is important and 2,000 kHz if BER performance is important. When the spreading gain is 64, the PN code is a suitable choice because the BER performance is superior to that of ALL 1 code. In addition, the performance variation for the PN codes is not large. Hence, it is recommended to use the PN code for the spreading gain of 64, and the desirable channel spacings are 1,000 kHz and 2,000 kHz.

4. Conclusion

In this paper, when the transmission rate is 1 MHz and the spacing between two tones is 4 MHz in SC-BFSK, adjacent channel spacings and spreading codes were found through computer simulation. According to the results, when the spreading gains are 1, 4, and 16, using ALL 1 had better BER performance than using the PN code. On the other hand, when the spreading gain is 64, it is excellent to use the PN code. It was confirmed that the optimal adjacent channel spacings for spreading gains are different for spreading gains. For a spreading gain of 1, 1,150 kHz or 2,060 kHz were good values, but for a spreading gain of 4 or more, 1,000 kHz or 2,000 kHz were good values. If the suggested spreading code and adjacent channel spacing are used, the performance degradation caused by ACI can be minimized while using the frequency resource efficiently in SC-BFSK. When the transmission rate and the tone interval are different than this paper, it will be helpful to determine a good spreading code and adjacent channel interval using the results of this paper.

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