FH Pattern Likelihood Ratio Decision Method against CW Jamming or/and Burst Noise

Kenji KOBAYASHI
Nagaoka University of Technology
Department of Electrical Engineering
1603-1 Kamitomioka, Nagaoka-shi, Niigata, 940-2188
Japan
kobay@stn.nagaokaut.ac.jp

Shin’ichi TACHIKAWA
Nagaoka University of Technology
Department of Electrical Engineering
1603-1 Kamitomioka, Nagaoka-shi, Niigata, 940-2188
Japan
tach01@vos.nagoakaut.ac.jp

Abstract— This paper proposes an improvement method of a lump likelihood ratio calculation in detection of frequency hopping pattern. In a conventional lump likelihood calculation, a lump likelihood ratio is calculated from both time-axis and frequency-axis together. However, the conventional calculation is not enough against CW jamming or burst noise because it adopts a probability density function of AWGN and signal gain of a frequency selective fading channel. In this paper, a calculation using a probability density function of CW jamming or/and burst noise is proposed. Then the comparisons with the conventional lump likelihood calculation and the proposed calculation, and its effects are shown.

Keyword: frequency hopping (FH), likelihood ratio, multilevel frequency shift keying (multilevel FSK)

I. INTRODUCTION

Frequency hopping (FH) communication systems have been popularly studied for applications of wireless LAN and power-line data transmission, because of its robustness against near-far problems and frequency diversity effects [1]. Using an inverse fast Fourier transform (IFFT) circuit by digital signal processor (DSP), hardware can be realized easily. When hopping rate (chip rate) is faster than bit rate, it is called “high rate FH system” which has always frequency diversity effect for each data. In this paper, we adopt the high rate FH system.

In a conventional FH receiver, an analog value of frequency slot on frequency domain is kept for each chip, and FH pattern is detected by the figure of analog values. When large fluctuation of signal level for each slot arises independently on the transmission line (e.g., multi-path fading channel and power-line), the FH pattern detection has degraded seriously. If the signal gain (or loss) can be estimated, the performance is not improved because the degradation of signal to noise ratio remains.

However, we can estimate relatively the position of the desired signal tone on time domain even if the fluctuation of signal exists on frequency domain. More accurate estimation can be achieved on frequency domain using the information form the time domain. Further, the accuracy can be improved an iterative algorithm. This method is well know as an iterative likelihood ratio calculation, i.e., turbo decoding [2][3]. To improve the iterative likelihood calculation, a lump likelihood ratio, in which the whole likelihood ratio is calculated from both time-axis and frequency-axis together, is proposed [4]. The lump method can be estimated more accurately and faster than the iterative method. These conventional likelihood calculation methods can be estimated accurately against large fluctuation of signal level for each slot. However, it is not enough against CW jamming or/and burst noise.

In this paper, we focus on a probability density function (PDF) used in likelihood ratio calculation. First, in Sect. 2, FH/multilevel FSK is explained. In Sect. 3, we propose a new calculation method that employs a PDF including amplitude of CW jamming. In Sect. 4, an estimation method of frequency and amplitude of CW jamming is discussed. In Sect. 5 we also proposed a new calculation method that employs a PDF including variance of burst noise. In Sect. 6 an estimation method of chip position and variance in burst noise is discussed. In Sect. 7, a calculation method that employs a PDF including amplitude and variance of both CW jamming and burst noise is proposed. In Sect. 8, the effects of the proposed method are shown and discussed. Finally, in Sect. 9, these results are concluded.

II. FH/MULTILEVEL FSK SYSTEM

Figure 1 shows an example of FH/multilevel FSK signal, which has information levels M=4 and chips in one symbol duration L=3. A matrix of data level is ‘1’, and a hopping pattern is (0, 1, 3) in this case as shown Fig. 1 (a) and (b). They are added by modulo M, i.e., the hopping pattern is shifted by data level as shown in Fig. 1(c). Corresponding to the added pattern, the transmitting tones are formed by a frequency synthesizer or IFFT. Then the number of the transmitting pattern is the information level M. At a receiver, the received pattern matrix is subtracted from the hopping pattern by modulo M. Finally, the data level is decided by the addition of row values. It means a likelihood ratio decision corresponds to M kinds of patterns.
III. LUMP LIKELIHOOD RATIO CALCULATION AGAINST CW JAMMING

Continuous wave (CW) is a single frequency tone $V_{CW} = A \cos(\omega t + \phi)$, where $A$ is amplitude, $\omega$ is angle frequency, and $\phi$ is phase. In this paper, coherent multilevel FSK system is assumed, for convenience $V_{CW} = A \cos \phi$ on one frequency slot $f_{CW}$ is added as shown in Fig. 2. We propose that a likelihood ratio included amplitude of CW is calculated against a slot added CW jamming. First, in the conventional method [4], a lump likelihood ratio $R(m)$ is given as,

$$A(m) = \ln \frac{\Pr(D_i|R)}{\Pr(D_i|R)} = \ln \frac{\prod_{i=0}^{M} \Pr(D_i|R)}{\prod_{i=0}^{M} \Pr(D_i|R)},$$  

where $\Pr(D_i|R)$ and $\Pr(D_i|R)$ is a probability of transmitting pattern matrix $D_i$ and $D_i$ when the received pattern matrix is $R$. The eq. (3.1) is expanded as,

$$A(m) = \sum_{j=0}^{L-1} \lambda_{ij} + \ln \frac{1}{\sum_{i=0}^{M} \exp \left( \sum_{j=0}^{L-1} \lambda_{ij} \right)},$$

where

$$\lambda_{ij} = \ln \frac{\Pr(R_{ij}|d_{ij}=1)}{\Pr(R_{ij}|d_{ij}=0)} = \frac{1}{2\sigma^2} (2r_j \rho_k - \rho_k^2),$$

and

$$k = (i+j) \mod M,$$

$R_{ij}$ is an element value of received pattern matrix, $d_{ij}$ is an element value of transmitting pattern matrix, $\rho_k$ is signal gain of k-th slot, $h_j$ is a j-th value of hopping pattern and $\sigma^2$ is variance of AWGN. The eq. (3.3) is calculated the likelihood ratio of data by PDF of Gaussian distribution as Fig. 3.

Figure 1. Example of FH/multilevel FSK signal pattern.

Figure 2. Example of multilevel FSK signal pattern added CW jamming.

Figure 3. Likelihood ratio calculation against AWGN.

In an AWGN and CW jamming environment, the PDF is shifted from the distribution of AWGN by $V_{CW}/\rho_k$ where $\rho_k$ is signal gain. In consideration of CW jamming, we propose a new lump likelihood ratio modified from eq. (3.3) as follows,

$$\lambda_{ij} = \ln \frac{\Pr(R_{ij}|d_{ij}=1+V_{CW}/\rho_k)}{\Pr(R_{ij}|d_{ij}=0+V_{CW}/\rho_k)}$$

$$= \ln \left[ \frac{1}{\sqrt{2\pi\sigma^2}} \exp \left( -\frac{R_{ij} - \rho_k \left(1+\frac{V_{CW}}{\rho_k}\right)}{2\sigma^2} \right) \right]$$

$$= \ln \left[ \frac{1}{\sqrt{2\pi\sigma^2}} \exp \left( -\frac{R_{ij} - \rho_k \left(0+\frac{V_{CW}}{\rho_k}\right)}{2\sigma^2} \right) \right]$$

$$= \ln \left[ 1 + 2r_j \rho_k \left(1+\frac{V_{CW}}{\rho_k}\right) \right].$$

When CW frequency $f_{CW}$ and amplitude $V_{CW}$ can be estimated, the value of likelihood ratio is improved by using the eq. (3.5).

IV. ESTIMATION OF CW

The CW frequency $f_{CW}$ and amplitude $V_{CW}$ are necessary to estimate from the received pattern matrix. In this section, “a voltage distribution estimation method” is explained. In the method, the slot added CW jamming is estimated by a distribution of received signal voltage. Fig. 4 shows an example that distributions of received signal voltage on each frequency slot in multilevel FSK system with M=16 and L=3. On a slot of only AWGN, two normal distributions with variance $\sigma^2$ are formed as Fig. 4(a). The mean of each distribution is “one” or “zero”. They are decided by “signal present” and “signal absent”, respectively. The signal present to signal absent ratio is one to fifteen for M=16. Consider a
The probability of received signal voltage is greater than $\pm 2\sigma$. For convenience, the distribution with mean 1 is ignored, because the probability is fluctuated from a bit energy and less than $1/16$. So that, the probability is about 10.5 percent ($1 - 0.955 \times \frac{15}{16} = 0.105$) in the normal distribution with mean 0. On a slot of AWGN and CW jamming, the distribution is shifted form that of only AWGN by $V_{CW} = \rho \cos \phi$ if $\rho = 1$. Then, a probability of received signal voltage is greater than $\pm 2\sigma$ is between 10.5 and 47 percent when $V_{CW}=0$ and $V_{CW}=\pm 1$, respectively, under the assumption that $A=1$. Thus, the probability of CW jamming is greater than that of AWGN only. The slot added CW jamming can be estimated by the difference of probability. The process of method is described as follow:

1. The probability of received signal voltage is greater than $\pm \sigma$ is measured on each slot in training duration.
2. The slot added CW jamming is estimated that the probability is greater than b.
3. The CW amplitude $V_{CW}$ on the slot is estimated by a square root of average power as follow,
   \[ V_{CW} = \pm \sqrt{\frac{\overline{P_{RXj}} - \overline{P_{TXj}}}{\sigma^2}}, \tag{4.1} \]
   where $\overline{P_{RXj}}$ is an average of received signal power on j-th slot, $\overline{P_{TXj}}$ is an average of transmitting signal power on j-th slot, and plus or minus follows a sign of average of received signal voltage.

![Figure 4. Distributions of received signal voltage on each frequency slot added CW jamming.](image)

V. LUMP LIKELIHOOD RATIO CALCULATION AGAINST BURST NOISE

Burst noise is generated from a switching circuit of an electrical equipment and etc. It is many impulse noises arise in long duration $T_{br}$ as Fig. 5. The burst noise adds on continuous chips in multilevel FSK. However, by using time-interleaver, it is modeled the burst noise adds only the first chip in one symbol for convenience. Where, it is assumed that variance of the burst noise is ten times variance of AWGN, and independent on each slot [5]. Then, the burst noise follows the normal distribution. In consideration of burst noise, the lump likelihood ratio can be obtained from eq. (3.3) as follows,
   \[ \lambda_{ij} = \ln \frac{Pr(R_{ij}|d_{ij}=1)}{Pr(R_{ij}|d_{ij}=0)} \]
   \[ = \frac{1}{2(\sigma_{burst}^2 + \sigma^2)} \left( 2R_{ij}\rho_k - \rho_k^2 \right), \tag{5.1} \]
   where $\sigma_{burst}^2 = 10\sigma^2$.

When a chip added the burst noise $t_{br}$ and variance $\sigma_{burst}^2$ can be estimated, the value of likelihood ratio is improved by using the eq. (5.1).

VI. ESTIMATION OF BURST NOISE

The chip added the burst noise $t_{br}$ and variance $\sigma_{burst}^2$ are necessary to estimate from the received pattern matrix. In this section, “a sampling variance estimation method” is explained. The method uses variance of received pattern matrix. The process of the method is described as follow:

1. A sampling variance is measured on an each chip by the received pattern matrix.
2. By using the variance, the likelihood ratio is calculated on the each chip as follow,
   \[ \lambda_{ij} = \ln \frac{Pr(R_{ij}|d_{ij}=1)}{Pr(R_{ij}|d_{ij}=0)} \]
   \[ = \frac{1}{2\sigma_{samplej}^2} \left( 2R_{ij}\rho_k - \rho_k^2 \right), \tag{6.1} \]
   where $\sigma_{samplej}^2$ is sampling variance of j-th chip.

Even if burst noise is present, absent, or known, the likelihood ratio can be calculated by employing the noise variance on each chip.

VII. LUMP LIKELIHOOD RATIO CALCULATION AGAINST BOTH CW JAMMING AND BURST NOISE

In case of adding both CW jamming and burst noise, a combination of eq. (3.5) and eq. (5.1) can be obtained as,
   \[ \lambda_{ij} = \frac{1}{2(\sigma_{burst}^2 + \sigma^2)} \left( 2R_{ij}\rho_k - \rho_k^2 \right) \left( 1 + 2\frac{V_{CW}}{\rho_k} \right) \tag{7.1} \]
It is necessary to estimate the parameters of CW jamming and burst noise. The voltage distribution estimation method and the sampling variance estimation method are employed to obtain the parameters against CW jamming and burst noise, respectively. However, burst noise interferes the estimation of \( V_{CW} \), while CW jamming interferes the estimation of \( \sigma^2_{\text{burst}} \). So that, an element added both CW jamming and burst noise is not used the estimations. The process of the method is described as follow:

1. Chips added burst noise is estimated on training duration.
2. A slot and amplitude of CW jamming are calculated by a voltage distribution estimation method eliminating the chips added burst noise on training duration.
3. A variance of burst noise is calculated by a sampling variance estimation method eliminating the slots added CW jamming.

VIII. SIMULATIONS

A. Specification

Table 1 shows a common specification for multilevel FSK system to investigate the lump likelihood ratio calculations. In a CW jamming environment, for convenience, CW jamming is added in only the first slot \( f_0 \). The number of training frames to estimate CW jamming is 10. Then, as for \( V_{CW} = \cos \phi \) is random value \((0-2\pi)\) and kept on duration of training and error detecting. Parameters of voltage distribution estimation method are adopted the optimum value \( a=1.5 \) and \( b=0.450 \). In a burst noise environment, burst noise is added in the first chip \( t_0 \) on each slot independently. In CW jamming and burst noise environments, for convenience, CW jamming is added in the first slot \( f_0 \) and burst noise is added in the first chip \( t_0 \). The number of training frames is 10, which is sufficient to estimate parameters of CW jamming.

<table>
<thead>
<tr>
<th>Table 1. SPECIFICATION OF SIMULATION.</th>
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<tr>
<td>System model</td>
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<tr>
<td>Number of frequency slots M</td>
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<tr>
<td>Number of chips L</td>
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<tr>
<td>Hopping pattern</td>
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<tr>
<td>Transmission line</td>
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<td>Carrier detection</td>
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B. Results and discussions

Figures 6 (a), (b) and (c) show BER performances of the proposed method for several environments. In Fig. 6(a) against CW jamming, a conventional curve is employed eq. (3.3), a proposed (estimation) curve is employed eq. (3.5) using the estimated parameters of CW jamming by a voltage distribution estimation method, and a proposed (correct) curve is employed eq. (3.5) using correct parameters of CW jamming. BER of the proposed (estimation) method is superior for that of a conventional method, for example, about
1.5dB of Eb/No can be improved at BER=$10^{-3}$, and it is nearly equal to that of the proposed (correct) method. It means that the estimation method is properly worked.

In Fig. 6(b) against burst noise, the proposed (estimation) curve is employed eq. (5.1) using the estimated parameters of burst noise by a sampling variance estimation method of eq. (6.1). BER of the proposed (estimation) method is much superior to that of a conventional method (improvement of 4.5dB at $10^{-3}$) and nearly equal to that of the proposed (correct) method, similarly.

In Fig. 6(c) against both CW jamming and burst noise, the proposed (estimation 1) is employed a simple combination of the voltage distribution estimation method and the sampling variance estimation method. While the proposed (estimation 2) is employed the modified method eliminating the element added both CW jamming and burst noise in Sect. 7. The proposed (estimation 2) is much superior to that of a conventional one (improvement of 5.5dB at $10^{-3}$), and a little improvement 1.5dB at $10^{-3}$ is obtained compared with the proposed (estimation 1) method. Further, it is little degradation 0.5dB at $10^{-3}$ than that of the proposed (correct) method similar to Fig. 6 (a) and (b).

IX. CONCLUSIONS

In this paper, we have proposed a new lump likelihood ratio calculation method of FH pattern against CW jamming and burst noise. The likelihood ratio has been modified by CW jamming or/and burst noise. The estimation methods for parameters of these jamming and noise have been described. By computer simulations, the improvements of the proposed methods have been shown in comparisons with the conventional method.

For further studies, discussions of the likelihood ratio calculation in a fading environment with CW jamming and burst noise will be necessary.

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