Realization of Simplified Diversity Combining Algorithms for Fast Frequency Hopping System

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Abstract. In the fast frequency hopping system, the diversity combining technique of the receiver can effectively restrain the partial band interference, and it is the key to improve the anti-jamming capability. For the computation and complexity of the maximum likelihood diversity combining algorithm, we allow the reduction of the SNR to a smaller level, then we can use the sum of squares to simplify the approximation. The several maximum likelihood diversity combining algorithms are compared and analyzed. It gives the realization process of the simplified diversity combining algorithm, the complexity of the algorithm is greatly reduced, and it is easier to implement on hardware.

Introduction

In the fast frequency hopping (FFH) system, due to a symbol in a plurality of frequency hopping frequency to send, hopping with the function of frequency diversity, the receiving end can through proper diversity combining techniques enhance the system's anti-jamming ability. But in the partial band jamming, the performance of the fast frequency hopping system will decrease. The partial band jamming can be effectively suppressed if the full use of the frequency diversity in the fast frequency hopping system can be effectively suppressed by the receiver diversity combining technique. Therefore, it is a key to improve the anti-jamming ability of the fast frequency hopping system.

In the fast frequency hopping system using hops/bit L (L>1), most of the sending end uses the MFSK modulation mode, the receiver uses the non coherent envelope demodulation [1, 2]. After the diversity of the decision variables can be obtained by a number of envelope values, this mapping function is a diversity combining algorithm, it can be a linear process, but also can be a non-linear process.

Simplified Maximum Likelihood Diversity Combining Algorithms

In the FFH/MFSK system, in a large number of diversity combining, we consider the maximum likelihood combined with [3,4] for the best diversity combining if the diversity number is L. In the fast frequency hopping system, in order to achieve diversity, a symbol is required to repeat the transmission L times, reducing the probability of partial band interference. In the receiver, detection frequency diversity, a symbol of all jump frequency envelope detection output sampling value can be through the maximum likelihood method with together, the implementation of anti interference of frequency diversity combining in Figure 1.

Figure 1. L hop/bit MFSK/FFH ML Receivers.
We assume that the side information includes the power ratio of the signal to the noise, the noise variance and so on. Assuming that the background thermal noise power spectral density is the bilateral band $N_0/2$, $E_s/N_0 = 13.35dB$.

In the channel interference model, the main parameters of PBN $\gamma$ and $N_j/2$, bilateral band power spectrum density is $N_j/(2\gamma)$. The whole interference power is distributed evenly on the part of the spread spectrum bandwidth $\gamma$. There are two non correlation matched filters in the system. A non correlation matched filter consists of a matched filter and an envelope detector. The matched filter outputs for the $i$th symbol of the first symbol is $X_{ik} = 2X_{ik}\sqrt{E_c}$, and $i = 0,1,2\ldots,M-1$, $k = 1,2\ldots,L$. Assume that PBN interference is applied to $j$th of the code chip $L$, here $0 \leq j \leq L$. Assuming that the previous $j$ code is affected by PBN, then the maximum likelihood diversity combining can be calculated as follows:

$$\lambda_i = \sum_{k=1}^{L} \ln I_0(\frac{2X_{ik}\sqrt{E_c}}{N_i}) + \sum_{k=1}^{L} \ln I_0(\frac{2X_{ik}\sqrt{E_c}}{N_0})$$

(1)

As is $i = 0,1,2\ldots,M - 1$. Which symbol is transmitted through the selection of the value of the maximum $\lambda_i$. In the above equation, $I_0(x)$ is the zero order modified Beckinsale function. It is easy to see that $N_i$ is determined by the $N_j$, $\rho$ and value of the side information. $N_k/2$ is noise variance for each hop. Calculating the required information of $\lambda_i$ is equivalent to calculating the SNR and the noise variance of each hop.

Considering realization, we can approximate maximum-likelihood technology and find out the performance of two changing ML method is not very weak and approaches to optimum diversity combining, so we regarded it as sub-optimum. In reference [3] and [4], the performance of the optimum combining scheme was evaluated and the optimum structure of a maximum-likelihood (ML) receiver for a fast frequency-hopped binary frequency-shift-keying (FFH/BFSK) spread-spectrum (SS) communication system was derived.

In front of the maximum likelihood diversity combining algorithm is got by the nonlinear function $\ln I_0(x)$ sum. But the calculation quantity and complexity are relatively high, especially for hardware implementation language. using Taylor series expansions for $\ln I_0(x)$, the system must exist certain error. On the basis of this, we have to simplify the maximum likelihood diversity combining algorithm, and get the sub optimal diversity combining algorithm. Although the performance of the algorithm is superior to the maximum likelihood algorithm, the complexity of the algorithm is greatly reduced, and the algorithm is easy to implement.

From the maximum likelihood diversity merging algorithm, it is found that the decision transform is the summation of the nonlinear function $\ln I_0(x)$. When $x$ is small, approximate formula can be written as followed $[5,6]$.

$$I_o(x) = (1+\frac{1}{4}x^2)\ \text{and } \ln I_o(1+\frac{1}{4}x^2) \approx \frac{1}{4}x^2$$

(2)

when $x$ is bigger,

$$\ln I_0(x) \approx x - \frac{1}{2}\ln(2\pi x) \approx x$$

(3)

Therefore, considering only the final result, we can get the approximate expression of $\ln I_0(x)$.

As shown in Figure 1, in our simulation, $E_s/N_0 = 13.35dB$, when $L = 2$, the system uses $\ln I_0(x)$ and $f(x)$ is difficult to distinguish in the worst case scenario.
If we are able to allow for a relatively small range of signal to noise ratio degradation, we can use the square accumulation to simplify the approximation. Equation (1) by (2) simplified, $\lambda_i$ is expressed as follows, it is ML2:

$$
\lambda_i = \frac{E_c}{N_f^2} \sum_{k=1}^{L} X_{ik}^2 + \frac{E_c}{N_0^2} \sum_{k=j+1}^{L} X_{ik}^2
$$

$$
= \frac{1}{2} \left( \frac{E_c}{N_f} \sum_{k=1}^{L} X_{ik}^2 + \frac{E_c}{N_0} \sum_{k=j+1}^{L} X_{ik}^2 \right)
$$

(4)

Therefore, it is needed to know the noise variance of each hop to achieve the optimal diversity combination. At this time as shown in Figure 3 in the form of ML2.

When the signal-to-noise ratio is relatively large, Equation (1) by (3) simplified form the ML1. Worth noting is Equation (4) to calculate the value of $\lambda_i$ and the following formula very similar.

$$
\lambda_i = \frac{E_c}{N_f} \sum_{k=1}^{L} X_{ik}^2 + \frac{E_c}{N_0} \sum_{k=j+1}^{L} X_{ik}^2
$$

(5)

Realization of Simplified Diversity Combining Algorithms

In practical applications, the data for each hop is sampled at the I path and the Q path. Here, assuming that the system is implemented in a homology environment, the received signal is not affected by the frequency difference.

The first step is to calculate the signal to noise ratio.

When the general modulation signal is QPSK(Quadrature Phase Shift Key), the traditional two- and four- order moment estimation algorithms can be used. The proposed algorithm is a typical NDA( Non data aided), M2M4 is an adaptive algorithm which uses the correlation between the two moments of the signal and the four moments to estimate the SNR. The advantage of this method is that it is not used to recover the carrier phase, and does not require the receiver to make a decision. M2M4 estimator uses the two order and four order statistical moments of the received data to estimate the signal to noise ratio in reference [8]. In fact, the form of the signal estimator is:

$$
SNR = \frac{\sqrt{2M_2^2-M_4}}{M_2-\sqrt{2M_2^2-M_4}}
$$

$$
= \frac{1}{\sqrt{2-\left(\frac{M_4}{M_2^2}+1\right)}} - 1
$$

(6)

M2 is two order moments for the received data;
M4 is four order moments for the received data.

M2M4 algorithm has low computation and high precision. It is used in the communication system of constant modulus and non constant modulus. In FPGA(Field Programmable Gate Array) implementation, the need to be the formula (6) for the following derivation.

$$
SNR_{db} = 10\log_{10}(SNR)
$$

(7)

Using the formula (6), (7) only need to do a division operation, and then use the look-up table can be obtained $SNR_{db}$

Tabulation method is as follows, table address 0 addr 255, and the address table:
Simples SNR is:

$$\text{SNR} = \frac{1}{\sqrt{2 - (\frac{K}{256} + 1)}}$$

Actual implementation, through the table to find out the $10\log_{10}\text{SNR}$. So the signal to noise ratio can be obtained through the simplified algorithm in practical application.

The second step is to calculate the noise power.

- Signal power: $E_s = \sqrt{2M_2^2 - M_4}$

- Noise power: $E_n = M_2 - E_s$

The third step is to calculate the signal-to-noise ratio and noise power into the formula (4) and (5), calculated $\lambda$.

The fourth step is that the $L$ branch diversity signal energy is accumulated.

A decision variable is obtained for each branch of each branch by a weighted envelope value,

$$z_m = \sum_{k=1}^{L} z_{mk}$$

As is $m = 1, 2, \ldots, M$.

Final decision:

$$m = \text{Index}[\max(z_1, z_2, \ldots, z_M)]$$

**Compare of Simplified Diversity Combining Algorithms**

We compare the operation of three kinds of diversity combining algorithms. ML algorithm needs Besseli, logarithmic, multiplication and addition calculation and ML1 algorithm requires multiplications and additions, ML2 calculus requires squaring, multiplication and addition operations. The diversity number is defined as $L$, and the operation of three diversity combining algorithms is shown in Table 1. ML1 algorithm is the smallest, and the complexity of ML is the largest.

<table>
<thead>
<tr>
<th>Algorithms</th>
<th>Calculation</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Multiplication</td>
</tr>
<tr>
<td>ML</td>
<td>2L</td>
</tr>
<tr>
<td>ML1</td>
<td>L</td>
</tr>
<tr>
<td>ML2</td>
<td>4L</td>
</tr>
</tbody>
</table>

when the SNR is high and ML1 and ml is very close, when signal to noise than the relatively small, ML and ML2 is very close.

**Conclusion**

Based on the analysis of the maximum likelihood of the merging algorithm based on the simplified approximations, analysis and experimental results show that the simplified algorithm with minimal loss of performance, can be approximately considered is lossless. However, in the hardware easier to implement. The next step will be to analyze the various factors that affect the performance of MFSK/FFH system.
References


