

# Study of LDPC Coded SFH System with Partial-Band Interference

Chao Gong<sup>2</sup>, Manxi Wang<sup>1</sup>, Daoxing Guo<sup>2</sup>, Xiaofei Pan<sup>2</sup>

<sup>1</sup>The State Key Laboratory of Complex Electromagnetic Environmental Effects on Electronics & Information System, China

<sup>2</sup>College of communications engineering PLA University of Science & Technology, China

Email: jllshh@163.com

Received July, 2013

## ABSTRACT

The application of Low Density Parity Check (LDPC) code in the anti-interference systems has drawn an increasing attention, due to its admirable performance which is very close to the theory limit. This paper focuses on a LDPC encoded slow frequency hopping (SFH) communication system with partial-band interference. Firstly, a modified soft-decision algorithm based on the utilization of interference information is proposed, and its performance is compared with some other soft-decision methods. Secondly, with numerical simulation, the influence of code rate, code length and the number of symbols per hops on the performance of the system with partial band noise interference is illustrated and examined in detail. Considering the great influence of hops per symbol on the performance, interleaver should be used and its influence on the performance is further examined by simulation. Finally, some constructive advises for the design of LDPC coded SFH system are given. Simulation results show that, with a reasonable design, the SFH system with LDPC code could achieve a desirable performance.

**Keywords:** LDPC; SFH; Soft-decision; Partial-band Interference

## 1. Introduction

Frequency hopping (FH) transmissions, whose carrier frequency hops under control of a pseudorandom pattern, is an attractive access method in wireless communication, due to its special ability to anti interference and provides continuous communication under a severe interference situation [1]. In the civil communication, FH is often used in the wireless communication system working in unlicensed industrial, scientific and medical (ISM) band, such as Bluetooth and ZigBee, to overcome the interference coming from other electronic equipment working in the same frequency band. While in the military communication, FH, which is almost to be a characteristic of military communication system, is widely used in the short-wave, microwave and satellite communication to overcome intentional interference. For example, both of America's domain tactical wireless networks (JTIDS) and the Milstar satellite communication system base on frequency hopping transmission [3]. Apart from that, FH is also used in the cognitive radios due to the available frequency changes from time to time [4].

So far, researchers all along pay attention to the enhancement of FH systems' anti-interference performance, some useful methods, such as channel coded diversity, interleave, are widely used. As an excellent channel code method, LDPC, which is close to the theory limit, has

drawn an increasingly attention of researchers from worldwide, especially its application in the FH communication. In [5], some diversity methods based on LDPC-FH system were examined. And the paper [6] focused on the technology of interference erasure in the LDPC-FH communication. The performance of LDPC encoded fast frequency hopping (FFH) system under partial-band noise interference was analyzed in paper [7], and the performance of LDPC encoded FFH system with partial band multitone interference was given by [8]. In this paper, we are focused on the performance of LDPC-SFH system under partial-band noise interference.

There are some theory methods for the analysis of the performance of LDPC, some of which is illustrated in [9], such as *density evolution*, *Gaussian approximate*, *extrinsic information transfer (EXIT) charts*. All of those methods pay attention to the performance of certain kind of LDPC, rather than that of certain type of LDPC. However, in practice, the choice of LDPC is limited to the feasibility of hardware, code length, code rate and code's structure and so on, which causes the real performance of LDPC has a large difference with the theory bound. In the interference environment, the channel is no longer to be an additive white Gaussian noise (AWGN) channel, which makes it even more difficult for the analysis of performance of LDPC. As the approximation

and simplification have to be used for theory analysis, the result will be imprecise. In the practical system design, numerical simulation with certain type available code is a feasible and effective way for analysis. Based on above considerations, numerical simulation is exploited in this paper for analysis of application of LDPC on the SFH system, and some key points of designing anti-interference communication are analyzed further.

### 2. System Model

The system model in this paper is shown as **Figure 1**. The transmitter consists of encoder, interleaver, and modulator and up frequency converter. By the number of ‘1’ in every row and column of check matrix, LDPC can be divided into kinds: regular LDPC and irregular LDPC. Generally, performance of irregular LDPC is better than regular LDPC, which is at the cost of more complex realization of hardware. With a tradeoff between performance and complexity degree of hardware realization, this paper chooses quasi-cyclic regular binary LDPC [10] as channel code. In the SFH system, number of symbols per hop (SPH) is more than one, when the signal is jammed, it will bring about burst symbol errors. If number of burst symbol errors in a coded packet is larger than threshold number of decoding, decoding error will occur. In order to alleviate the burst errors influence and reduce frame error rate In practice, the coded bit stream is interleaved in the transmitter, making burst errors decentralize into every packet equally. The following simulation will show that interleaving do improved the performance of system with short code length dramatically when the code length is short. While it comes to long code length, impact of interlacing is not obvious, so it can conclude that interleaver is unnecessary for the system, and it can be chosen depending on the length of code. In the SFH system, FSK, DPSK, PSK is widely used, PSK has a

higher bandwidth efficiency, so BPSK is used in this paper. Under the control of FH pattern, the modulated signal is transmitted through the up frequency converter, as **Figure 1** shows. As the control methods of FH pattern isn’t the content of this paper, we don’t introduce it here. The transmitting signal is given by

$$x_{ij} = c_{ij}e^{j(2\pi f_i nT + \theta_i)}, \quad i = 1, 2, \dots, N \quad (1)$$

where  $c_{ij} = \pm 1$  is information sequence,  $f_i$  is carrier frequency,  $T$  is symbol interval,  $\theta_i$  is initial phase per hop,  $N$  is number of symbols per hop.

The channel model that we employ is an example of a block-interference channel, including additive white Gaussian noise (AWGN) and partial-band interference, which has been used in several previous investigations of FH communication [11]. Model of partial-band interference is given by bandwidth-limited white Gaussian noise with a  $\rho$  band rate, here  $\rho$  is the partial-band interference factor, and it is a constant but unknown number for both transmitter and receiver. We assume all the symbols in a FH time slot are jammed when the signal in certain moment of the slot is hit by the interference signal, and vice versa. The probability of FH signal jammed is  $\rho$ , power spectral density (PSD) of interference signal in the current time slot is  $\rho^{-1}N_I$ , and in other slot without interference, the PSD is 0. Power of the interference signal is in direct proportion to  $N_I$  and irrelevant with  $\rho$ . AWGN diffuse during the transmitting, and PSD is  $N_0$ , rate of bit power to PSD of AWGN is given by  $ENR = 10 \log_{10}(\xi_b / N_0)$ , rate of bit power to PSD of interference signal is given by  $EIR = 10 \log_{10}(\xi_b / N_I)$ . The receive signal is given by

$$\tilde{x}_{ij} = c_{ij}e^{j(2\pi f_i nT + \theta_i)} + n_{ij} + w_{ij}, \quad i = 1, 2, \dots, N \quad (2)$$

where  $n_{ij}$  is wide-band white Gaussian noise, and  $w_{ij}$  is partial-band interference.

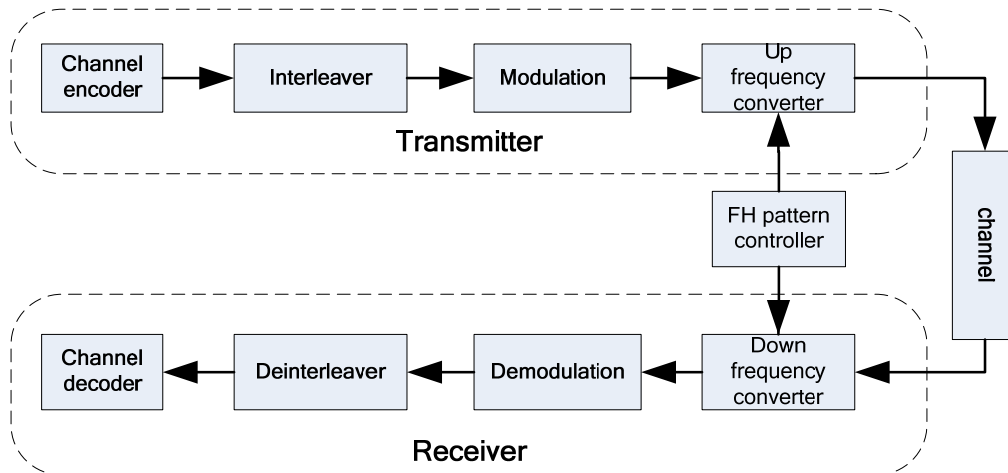


Figure 1. Model of LDPC-SFH system.

As **Figure 1** shows, receiver consists of decoder, deinterleaver, demodulator and down frequency converter. With the same FH pattern, the receiver change the FH signal to lowpass or fixed band pass signal, and the demodulator estimate the carrier phase and symbol timing in order to realize carrier and symbol synchronization, and then the information sequence will be obtained by soft-decision method. Signal after carrier and symbol synchronization is given by (3),

$$y_{ij} = c_{ij} + \tilde{n}_{ij} + \tilde{w}_{ij}, \quad i = 1, 2, \dots, N \quad (3)$$

where  $\tilde{n}_{ij}$ ,  $\tilde{w}_{ij}$  is wide-band white Gaussian noise and partial-band interference after carrier and symbol synchronization respectively. In this paper, we don't focus on carrier and symbol synchronization, so we assume carrier phase and symbol timing are estimated correctly in the following. Soft-decision methods will be discussed in the following section detailedly. Deinterleaver reorder the receive sequence to make it same as the original sequence, and finally channel decoder decodes the sequence after soft-decision. Decoding methods of LDPC is sorted into two kinds: hard-decision and soft-decision. Generally speaking, performance of soft-decision methods is better than those of hard-decision. Considering the complexity of hardware realization, modifying-minimum-sum soft-decision method [12], which has low complexity for hardware realization and good performance close to the optimum method, is used in this paper.

### 3. Modifying Soft-decision

The probability of transmitting signal should be proportional to the value of soft-decision for modifying-minimum-sum soft-decision method (MMSSD). Without interference,  $y_{ij}$  maintain its probability statistic characteristic, which could give probability of transmitting signal directly, so the sequence can be decoded with direct-decision (DD). While there is interference with the received signal, the probability statistic characteristic of  $y_{ij}$  with and without interference will be different, so it will represent different probability of transmitting signal in the two conditions. In this case, probability of signal can't archive from  $y_{ij}$  directly, which lead to drastic deterioration of performance is DD method is used. As **Figure 2** shows, when  $\rho = 1$ , performance based on direct soft-decision is very close to that the method with perfect channel side information (PCSI). However, with the decreasing of  $\rho$ , the performance will deteriorate drastically. To solve above problem, we can estimate ENR of signal in every hop, and then modify the soft-decision value accordingly. In [12], a simple square signal to noise ratio estimator is introduced, where the estimator is given by (4)

$$\lambda_i = \frac{\left[ \frac{1}{N} \sum_{i=0}^{N-1} |y_{ij}| \right]^2}{\frac{1}{N-1} \sum_{i=0}^{N-1} y_{ij}^2 - \frac{1}{N(N-1)} \left[ \sum_{i=0}^{N-1} |y_{ij}| \right]^2} \quad (4)$$

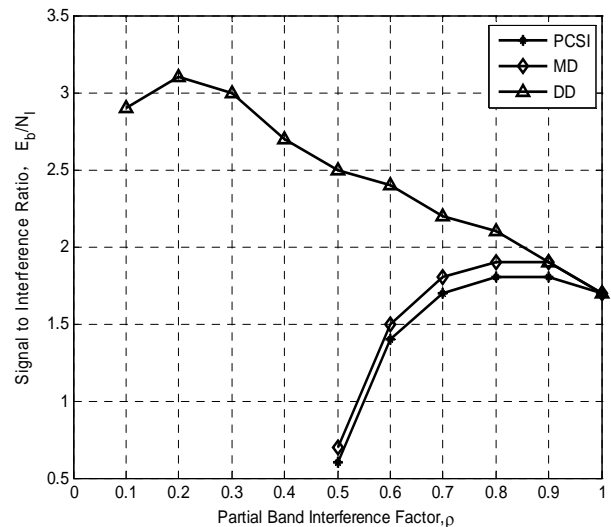
With the estimated value of ENR in  $i$ th FH time slot, we can modify value of soft-decision with (5)

$$z_{ij} = y_{ij} \lambda_i \quad (5)$$

When the EIR is low, it is imprecise to estimate the EIR by above method, however, simulation suggests that the precision of the estimation can meet the need of LDPC-SFH system, and comparing with DD, we have got admirable performance improvement. **Figure 2** shows three soft-decision methods' performance, where the vertical axis is the required value of EIR to archive a packet error probability of 10<sup>-2</sup>. We found that the EIR increases no more than 0.2dB to reduce the packet error probability from 10<sup>-2</sup> to 10<sup>-3</sup>. In general, most wireless networks, such as Ad hoc network, could work normally with a frame error rate of 10<sup>-2</sup>. The AWGN is considered in the following simulation, though PSD of partial-band interference signal is far higher than that of AWGN. In the simulation of this paper, we assume  $\rho$  is a exact known number and the methods of modifying the soft-decision value are the same, when the interference signal is known. From the **Figure 2** we can see that the performance of modifying the value of soft-decision based on estimating ENR with square-ENR estimator is close to that of PCSI.

### 4. Performance of Anti-interference

The following numerical simulation bases on the system model and MMSSD introduced in above sections, which

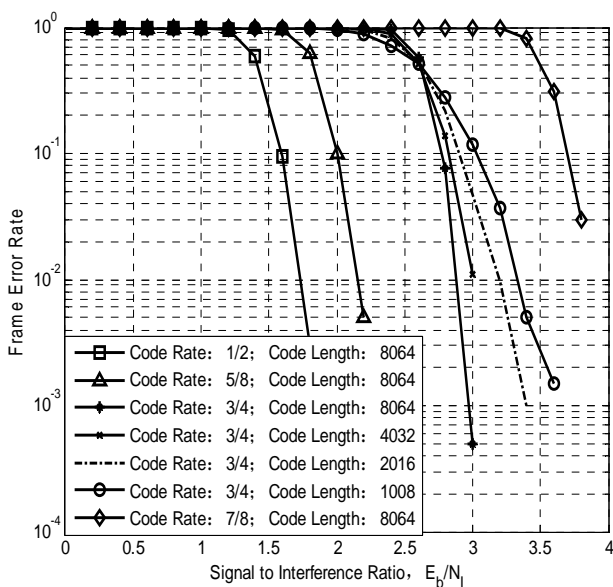


**Figure 2.** Performances of different soft-decision methods.

will give performance of LDPC-SFH system with different code rate, code length, SPH and way of interleaving. In the simulation, two cases are considered: the first is that, code length is fixed-8064, value of code rate getting from 1/2, 5/8 and 7/8; the second is code rate fixed-3/4, and code rate varying with 8064, 4032, 2016 and 1008. Performance of above cases with AWGN channel is shown in **Figure 3**. In order to make a clear analysis, here, we introduce two basic conceptions: first is that the  $\hat{\rho}$  corresponding to the highest value of EIR is represented as worst partial-band interference (WPBJ) factor, second is throughput, which is a key standard of a system, is given by ratio of number of available source sequences to that of encoded transmitting packet sequences. Besides, we also assume that it is a available packet only when the receiving sequences are all right, otherwise, the packet is un available.

**4.1. Influences of Code Rate**

Code rate is a vital factor of the performance, when code length is fixed, with decreasing of code rate, performance is improving, which don't result in decreasing of system's throughput, as **Figure 4** shown, performance of system with 1/2, 5/8, 3/4 and 7/8 code rate and a fixed code length 8064 are given. When  $\rho = 1$ , difference of Interference-to-Signal (JNS) threshold of four code rate is about 2dB, which will enlarge with decreasing of  $\rho$ . When  $\rho < 0.5$ , JNS threshold of LDPC with a 1/2 code rate is lower than 0dB; when  $\rho = 0.2$ , JNS threshold of LDPC with a 7/8 code rate is larger than 7dB. Different code rate have different performance with the worst partial-band interference, and with increasing of code rate,  $\hat{\rho}$  is decreasing, and so is the threshold of  $\rho$ .

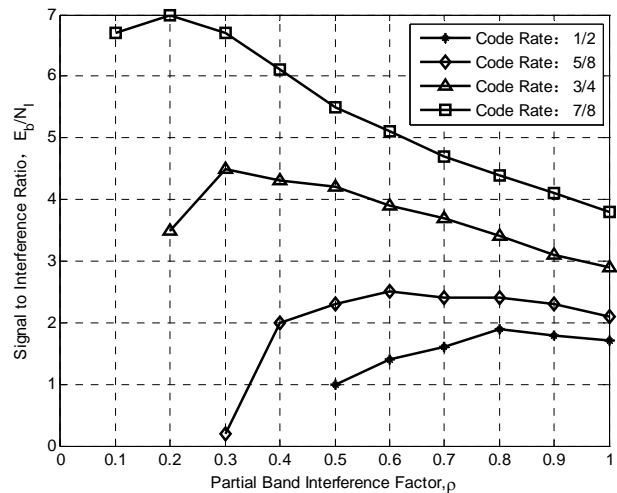


**Figure 3. Performances of different code.**

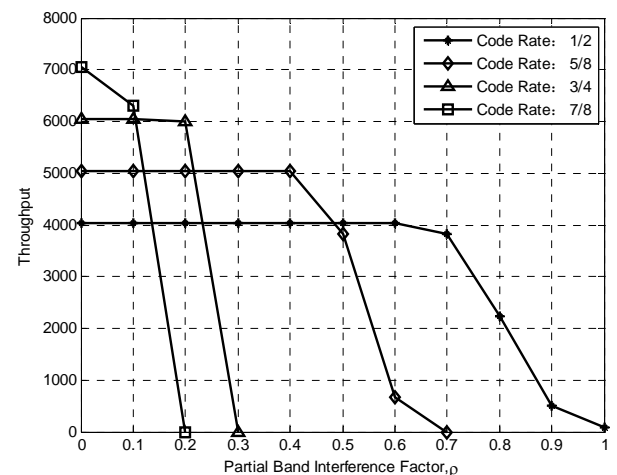
In **Figure 5**, throughput of different code rate is shown. We can see, low code rate has a stronger adaptability to drastic change of  $\rho$ , and there is an inconspicuous change of throughput, with  $\rho$  changing from 0 to 0.7, when LDPC code rate is 1/2. However, when  $\rho$  is very small, the throughput of code with low rate is lower comparatively, which leads to low transmission efficiency. Therefore, in practice, throughput could improve with a proper LDPC designed depending on  $\rho$ , and code length of a system could be designed depending on throughput and cost of hardware.

**4.2. Influences of Code Length**

In **Figure 6**, performance of LDPC with a 3/4 code rate under 8064,4032,2016,1008 code length are shown, while number of symbols is 336 ( $N = 336$ ). When  $\rho = 1$ , performance of the four codes are very close, difference between maximum code length and minimum code length



**Figure 4. Performances of different code rate with partial-band interference.**



**Figure 5. Throughput of different code rate.**

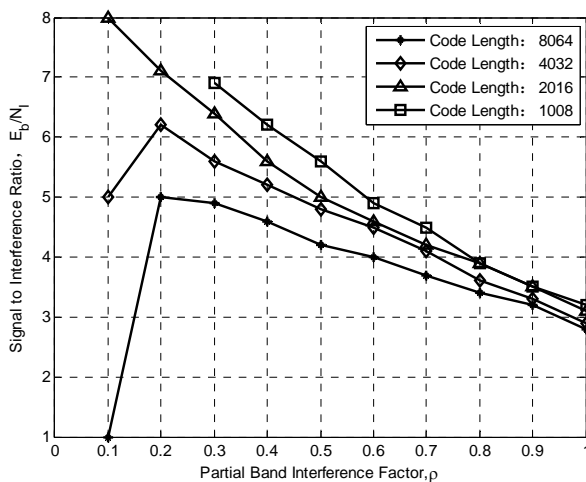
is only 0.5 dB, however, which will enlarge with decreasing of  $\rho$ . After JNS of code 8064 and 4032 reach to the highest, it will decreasing along with the decreasing of  $\rho$ , and then JNS of 2018 and 1008 is in direct proportion to  $\rho$ . The main reason of that is, short code has a weak ability of anti-outburst-wrong, moreover, its performance also depend on the value of  $N$ .

### 4.3. Influences of Symbols per Hop

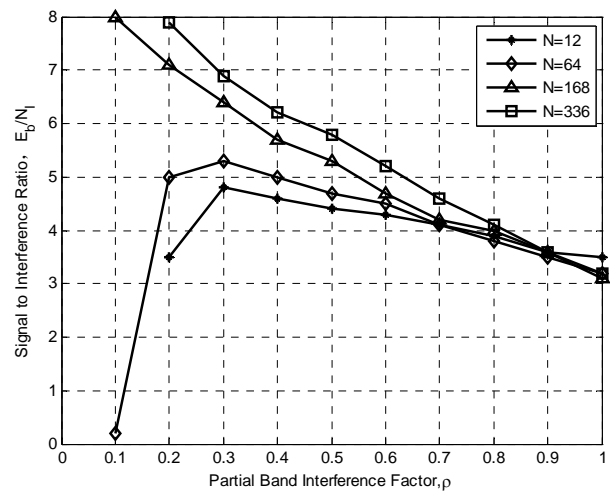
Influence of symbols per hop on the performance is shown from two aspects: on one hand, a increasing  $N$  will exaggerate the outburst wrong, and performance of system will also decrease, especially when  $\rho$  is very small; on the other hand, amount of data processed by ENR estimator will also increase for  $N$ 's increasing, which lead to a more precise estimation and higher performance. As **Figure 7** shows, when code length is 1008, code rate is 3/4, and  $N=12$ , performance keeps good with most value of  $\rho$ , and when  $\rho=0.1$ , EIR reaches to the highest. From **Figure 7**, we can conclude that number symbols  $N$  is another factor which should be in a proper range during practical system design, and it is better design when value of  $N$  is chosen depending on the change of  $\rho$ . In practice, there is a simpler and available method of choosing  $N$ , basing on interleaving, which makes outburst wrong sequence dispersing into all the transmitting packets, therefore, even with a large  $N$ , performance still keeps a good level.

### 4.4. Influence of Interleaving

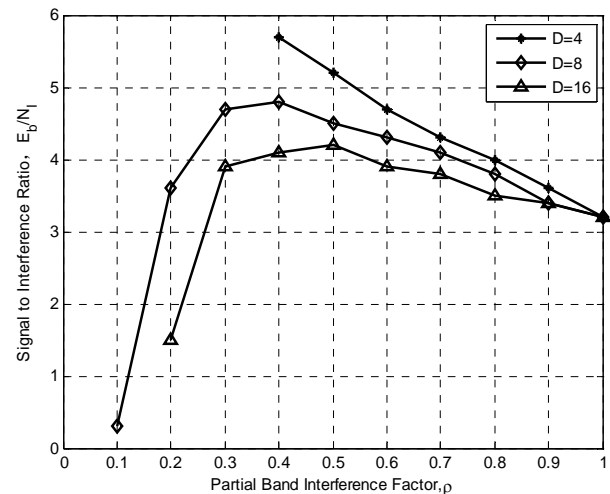
The key parameter of interleaver is the deep degree of interleaving ( $D$ ), in the simulation, different values of  $D$ , which is 4, 8, and 16, are considered, while code length is 1008 and code rate is 3/4. As **Figure 8** shows, with increasing of  $D$ , performance is also increasing. In



**Figure 6.** Performances of different code length with partial-band interference.



**Figure 7.** Performances of different symbols per hop with partial-band interference and code rate 3/4.



**Figure 8.** Performances of different deep degree of interleaving with partial-band interference.

general, a bigger  $D$  makes random wrong sequences discrete further, which could improve the performance, however, a bigger  $D$  will also means increasing of transmitting delay of the system. Therefore, both  $D$  and transmitting delay should be taken into consideration. Meanwhile, a proper  $D$  also depend on exact value of code length and methods of interleaving.

### 5. Advises for System Design

When it comes to design a higher performance LDPC-SFH communication system, code rate, code length, symbols per hop and deep degree of interleaving are key parameters. Different code rate will result in different performance, it is better for a low code rate when throughput of system is not considered in the design. But a higher code rate can benefit for the throughput when

$\rho$  is small, it is advised the system's code rate could adjust to the change of  $\rho$ . As is analyzed in above section, when  $\rho$  is small, it will bring about a drastic difference of EIR with different code length, so a longer code will our best choice, however, which is only at cost of complexity of hardware. And of cause, considering the complexity of hardware, short will be better, when symbols per hop is small and sequences is interleaved, performance could also meet the need of design.

## 6. Conclusions

This paper focuses on the design and performance analyses of LDPC-SFH system in partial-band interference channel. A new soft-decision method based on the estimation of EIR hop by hop is proposed, performance could be improved drastically as illustrated by simulation. The Influences of code rate, code length, symbols per hop and deep degree of interleaving are also analyzed with numerical simulation. Furthermore, some constructive advises for practical system design are given based on the former work. The results of this paper will be benefit for the design of anti-jamming communication systems.

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