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Study on Link16 System with Frequency Hopping Collision Interference

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Abstract

Aiming at studying the jamming methods of Link16 system, the anti-jamming techniques adopted by Link16 are studied and a simulation model is established in the paper. Based on the conventional static multi-tone interference which is used frequently at present, a new dynamic jamming method named Frequency Hopping Collision (FHC) interference is put forward. The features and jamming performance of FHC interference in the condition of different frequency hopping rate are analyzed and simulated. According to the analysis and simulation results, the jamming performance, advantages and disadvantages of the two jamming methods are compared in the same conditions. It is concluded that the new FHC interference has advantages over multi-tone interference from the aspects of utilization rate of jamming power and complexity of realization in jammer and also provides a new way for the jamming of Link16 system.

Keywords: *Link16, anti-jamming, jamming, dynamic, collision*

1. Introduction

Tactical Data Information Link (TADIL) has played and continues to play a vital role in the modern warfare because the speed and accuracy of tactical information transmission can be extremely important in mission success. A TADIL must be able to efficiently receive, manage and transmit all relevant data in a timely and accurate manner. Link16, a kind of TADIL currently installed and operated in the U.S Air Force and North Atlantic Treaty Organization (NATO), is the centric weapon system for Joint Tactical Information Distribution System (JTIDS) which is the communication terminal of Link16 operating in the L-band. Link16 is the key facility to achieve an effective link between information sources, command and control centers, aircraft, missiles and other platforms and thus is an important means to strengthen the comprehensive integration of C4I (Command, Control, Communication, Computer and Intelligence) system.

The basic paradigm of the future military environment is rapidly changing from the platform-centric to the network-centric with sensor-to-shooter concept. For the network-centric mission accomplishment, the role of Link16 is being more emphasized. With the development of modern science and technology, the core of the future war is the combat of Electronic Countermeasure (ECM). Anti-jamming and jamming methods are two important parts in the ECM. Link16 is a good example of a waveform designed to resist interference. Therefore, the study of anti-jamming techniques in the Link16 and how to interfere with Link16 system effectively is of great significance in the long term.

Previous researches have mainly focused on the analysis of the anti-jamming and transmission performance of Link16. The jamming methods of Link16 system are paid less attention in a relatively small amount of researches. For example, in the Ref. [1], an analysis of the jamming performance of Link16 over tone, partial-band

and pulse interference is derived and a modified TADIL system with the cognitive anti-jamming capability is first proposed. In the Ref. [2], a performance analysis of a Link16 compatible waveform using errors-and-erasures decoding under the jamming of pulse noise interference is examined. In comparison with Ref. [2], Ref. [3] employs an alternative error correction coding scheme for physical layer waveform and investigates the performance of Link16 with it in both AWGN (Additive White Gaussian Noise) and pulse noise interference. As we can see, the jamming methods of Link16 mostly focus on the tone interference, multi-tone interference, partial band interference and pulse noise interference at present. A new approach for the jamming of Link16 is proposed in the paper.

2. Link16 System Simulation Model

For the reliable Link16 operation, safe and secure real-time data exchange under the jamming environment is mandatory because Link16 has a strong ability of anti-jamming performance with various kinds of anti-jamming techniques including Cyclic Redundancy Check (CRC), Reed Solomon (RS) code, interleaving, Cyclic Code Shift Keying (CCSK) and fast Frequency Hopping (FH). In the paper, as seen in Figure 1, we construct a Link16 simulation model using Matlab/ Simulink and evaluate the jamming capability for the Link16 in terms of Bit Error Rate (BER) performance.

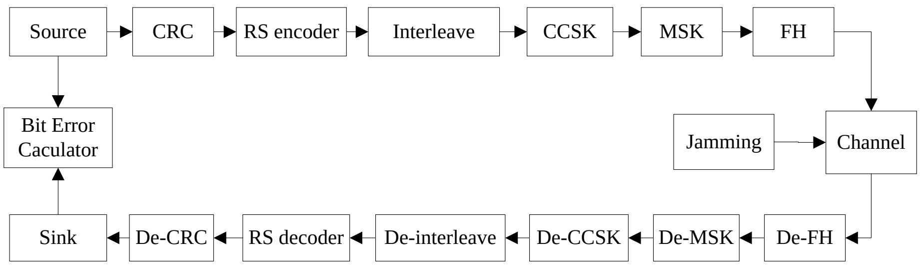

Figure 1. Link16 Simulator Block Diagram

3. Key Anti-Jamming Techniques of Link16

As mentioned before, Link16 adopts a variety of anti-jamming techniques, including channel coding technique, spread spectrum technique and modulation technique. In the paper, we mainly discuss CCSK, FH, RS code and Interleave in the next.

3.1. CCSK Module

CCSK is a kind of M-ray Direct Sequence Spread Spectrum (DSSS) technique. Link16 uses CCSK which is one of the two modulations (the other one is MSK) for baseband modulation and spreading spectrum, where each incoming 5-bit symbol is transformed into a corresponding 32-chip sequence. The CCSK 32-chip sequences chosen for Link16 are listed in Table 1. As can be seen from the table, 32 sequences are derived by cyclically shifting S_0 to the left between one and 31 times to obtain a unique sequence for all possible combinations of five bits. Therefore, the process gain of CCSK is about 8dB.

Table 1. 32-Chip CCSK Sequence Chosen for Link16

5-bit symbol	32-chip CCSK sequence chosen for Link16
00000	S_0=01111100111010010000101011101100
00001	S_1=11111001110100100001010111011000
00010	S_2=11110011101001000010101110110001
…….	……
11111	S_{31}=00111110011101001000010101110110

At the CCSK symbol demodulator, the determination of which 5-bit was received is accomplished by computing the cross-correlation between the received 32-chip sequence and all possible 32 sequences. The decision is made by choosing the 5-bit symbol corresponding to the branch with the largest cross-correlation value. For instance, if S_0 is sent in the absence of noise and jamming, the cross-correlation yields

$$R_i = \begin{cases} 32 & i = 0 \\ -4,0,4 & 1 \le i \le 31 \end{cases} \tag{1}$$

Where i is the number of the cross-correlation branch, that is, the times of cyclically shifting S_0. In this case, the decision made at the CCSK symbol demodulator is that S_0 is received since R_0=32 is the largest. Note that (1) shows that CCSK is not orthogonal since the value is 4 and -4 other than zero when $1 \le i \le 31$. The 32-chip sequence allows six chip errors in the received sequence without making a symbol error. Therefore, the function of CCSK is not only spreading spectrum but also correcting errors.

3.2. Frequency Hopping Module

FH has excellent anti-jamming performance and the ability of multi-access network, which is widely used in military communication. Unlike DSSS, FH achieves anti-jamming capability by "dodging" jamming signals. Its anti-jamming performance mainly relies on the total number of frequency points and bandwidth for hopping. In many military anti-jamming communication systems, FH have been or will be adopted.

Link16 chooses 51 hopping frequencies between 960MHz to 1215MHz according to the spectral interval of 3MHz and randomly hops to one of those hopping frequencies every 13usec. The process gain of FH is about 17dB.The interval between two operating adjacent FH points is greater than or equal to 30MHz, and it can be called wide interval FH. We establish a simulation model with FH and de-DH as shown in Figure 2.

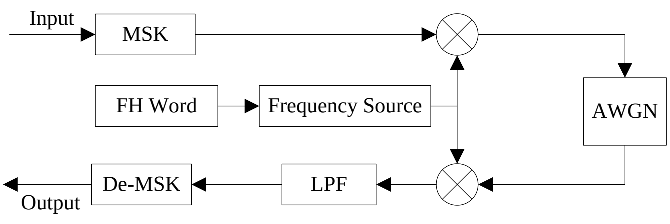

Figure 2. FH and de-FH Module

3.3. RS and Interleave Module

RS code is an M-ray BCH code and has a strong ability of correcting burst errors. Link16 uses RS (31, 15) which has the ability of correcting 8 symbols each code word to encode the messages. Each code word has 31 symbols including 15 message symbols and

16 symbols with additional error detection in transmitting end so that the errors can be corrected at the receiving end.

The interleaving technique is mainly used in the channel with memory, especially wireless channel. The basic thought between interleaving and RS technique is different. RS code is to adapt to the channel while interleaving is to transform the channel inversely. Interleaving and de-interleaving techniques are used in Link16 to transform the burst channel with memory into random channel without memory as shown in Figure 3. And Link16 adopts matrix interleaving technique.

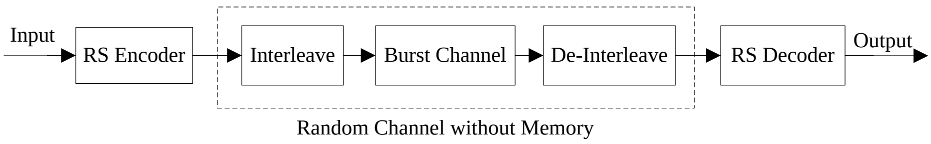

Figure 3. RS and Interleave Block Diagram

Compared with using RS code alone, Link16 uses the combination techniques of the RS code and interleaving technique so that anti-jamming performance is improved several orders of magnitude.

4. The Jamming Strategy Analysis

Owing to the strong capacity of anti-jamming and encryption in the Link16, there is a very small possibility of acquiring military information from the enemy directly. As a result, it is more realistic to disturb or destroy the correct information transmission of Link16, compress and reduce its coverage area.

As mentioned above, the hopping frequencies of Link16 changes every 13usec, so the times of frequency changing are 76923 every second. Link16 uses so high frequency hopping rate that conventional tracking interference can’t achieve a good result apparently. In addition, the duration of every single pulse signal is 6.4usec, so the propagation distance of each pulse is less than 2km. The propagation distance yields

$$S = V \cdot T = 3 \times 10^{8} m/s \times 6.4us = 1.92km \tag{2}$$

Where $V=3\times 10^{8}$m/s is the velocity of electromagnetic wave traveling in the vacuum, T is duration of the single pulse signal.

According to the propagation distance S, we know that the jammer should be placed in the distance of 2km from the anti-jammer. It is apparent that the jammer is in the range of being attacked by the enemy. As a consequence, we can’t use the method of tracking interference to interfere with the Link16.

Time Hopping (TH) is another spreading spectrum technique which is rarely used alone and used with other spreading spectrum techniques frequently. Link16 adopts a hybrid technology of CCSK, FH and TH. The realization of TH is random delay in the start of time slot. As a result, the enemy can’t grasp the start time of the Link16 and they can’t attack the synchronous heads intentionally with high jamming power. Moreover, the loss of jamming power is about 25dB when only CCSK and FH are taken into account. The cost of jamming power is too high. As a result, the high power centralized interference is also useless for Link16.

From the above, we know that the tracking interference and high power centralized interference is invalid in the jamming of Link16. As has been argued, the 51 frequency hopping points are known to us, so the jamming of Link16 can be performed from the aspects of these fixed frequency hopping points even if we don’t know their variation rule.

5. Introduction of Jamming Methods

The conventional jamming methods for the Link16 including tone, multi-tone and partial-band interference which are static interference are choosing proper number of FH points as a target interfered at present. In the paper, a new dynamic method called FHC interference is proposed to interfere with Link16 and the two jamming methods will be discussed briefly in the next.

5.1. Multi-Tone Interference

Link16 has a strong ability of error correction due to the use of the hybrid technique of RS code and interleave. For example, Link16 can work properly if one FH point is interfered with because the amount of errors is in the range of error correction. We should choose enough FH points so that errors exceed the limit of the error correction ability of RS code. However, the number of FH points interfered is not the more the better. Because the more the number of FH points interfered is, the lower the utilization rate of the jamming power is, and the more complex the realization of jammer is. Consequently, the choice about the number of FH points interfered is very important in the multi-tone interference. The diagram of multi-tone spot interference is shown in Figure 4.

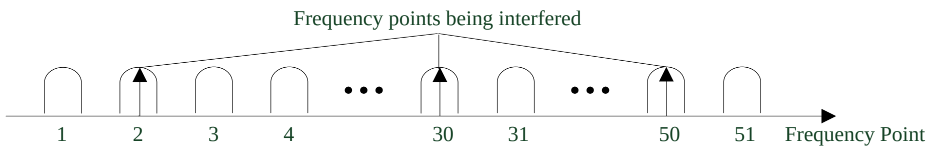

Figure 4. Multi-Tone Interference Diagram

5.2. FHC Interference

FHC interference is a new type of dynamic jamming. In FHC interference, we can use much faster rate of pseudorandom FH jamming signal in the full or part of the spectral band to collide with FH points adopted by Link16 after we obtain the information of the FH communication spectral band of the system. The faster the frequency hopping speed of the jamming is, the more likely the collision between jamming and signal is. As shown in the Figure 5, the 30th frequency point is being interfered. The next point to be interfered is random in the rest of the points else 1st, 2nd, 30th and 50th which were interfered in a cycle

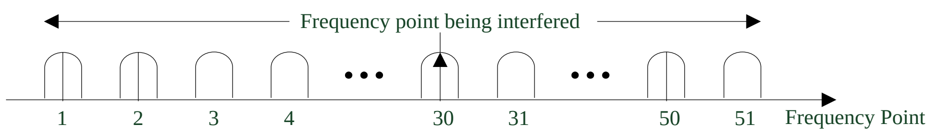

Figure 5. FHC Interference Diagram

Compared with multi-tone interference, the FHC interference has a higher utilization rate of the jamming power. In multi-tone interference, there are several jamming frequency points in an instant. Consequently, the power of jamming is assigned to these frequency points on average so that each points gets lower power. In contrast with multi-tone interference, there is only one jamming frequency point in FHC interference in an instant so that the whole power of the jamming is focused on this point. The hopping frequency points of Link16 can be collided with jamming many times in the duration of one symbol and can achieve the effect of broad band barrage interference with high power when the rate of frequency hopping of jamming is fast enough.

6. Jamming Performance Analysis

The paper chooses AWGN as the communication channel of the Link16 and Signal to Noise Ratio (SNR) of the AWGN channel is set as 10dB in the simulation of the jamming performance all the time. We define Jamming Signal Ratio (JSR) measured in dB as the ratio of the power of jamming to the power of signal. In the paper, the measurement of the jamming performance is the increase of BER in the Link16 simulation module.

6.1. Multi-Tone Interference Simulation

The jamming signal uses the same frequency as the carrier of Link16 and the waveform of the jamming is sinusoidal wave. We simulate the jamming performance of Link16 in the condition of different jamming frequency points respectively. The number of jamming frequency points is defined as N with a set of 5, 10, 20, 30, 40 and 51 in the simulation. In order to achieve persuasive simulation results, the jamming frequency points we choose should distribute over the 51 points uniformly. The BER of the Link16 system in the condition of different values of N is shown in Figure. 6.

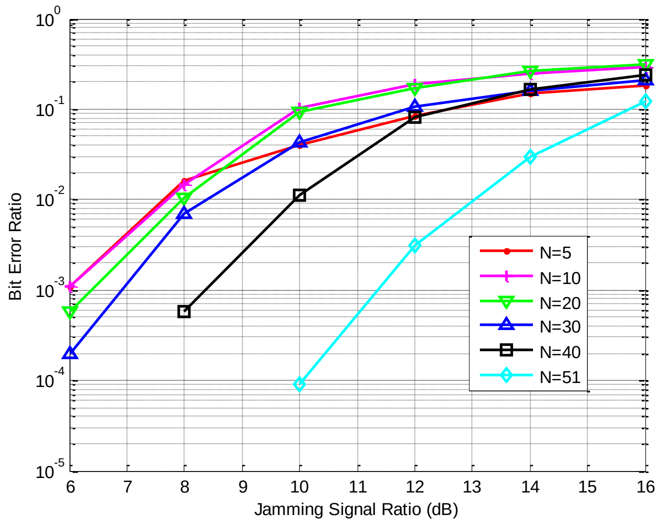

Figure 6. Multi-Tone Interference Performance

As can be seen from Figure 6, we can get better jamming performance with small jamming frequency points when the JSR is small. For example, the BER is about 10^{-3} when the number of jamming frequency points is 5 and 10. However, the BER is zero when it is 40 or 51. With JSR greater than 10dB and increasing, the BER plot flattens out gradually. That is to say, with the increase of JSR, the power of jamming is no longer a key factor that affects the jamming performance of Link16. If the requested BER is around 10^{-1}, we can choose 10 to 20 jamming frequency points in order to getting better jamming performance relatively with minimal cost of jamming power.

6.2. FHC Interference Simulation

The jamming signal in FHC interference is the same as multi-tone interference in the simulation. The rate of frequency hopping of the jamming signal is T times of Link16. T is set as 20, 40, 50, 65 and 100. The BER performance of Link16 system with different T is shown in Figure 7.

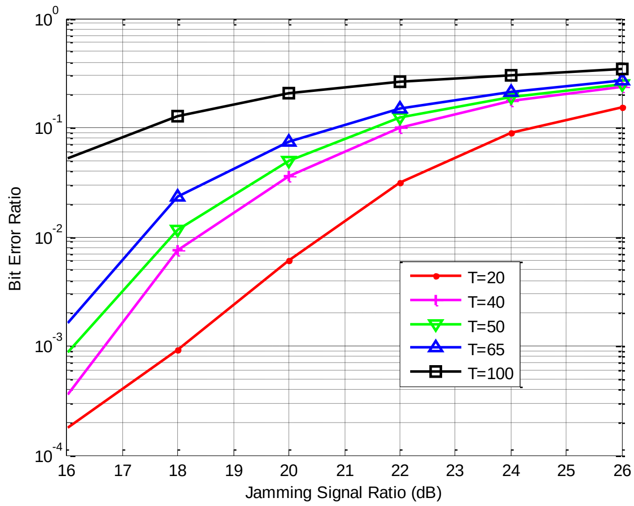

Figure 7. FHC Interference Performance

Figure 7 shows that the jamming performance gets better and better with the increase of JSR and T. But the realization of jammer becomes more and more complex as well. If the requested BER is 10^{-1}, it can meet the requirement in the condition of T=100 and JSR=18dB or T=40 and JSR=24dB. Considering the high frequency hopping rate of Link16, the later one is more proper for the sake of getting same jamming performance with minimal cost. In order to interfere with Link16 effectively and get better jamming performance, we should choose proper T and JSR which are two critical factors in FHC interference based on the actual situation.

6.3. Comparisons of the Jamming Performance

According to the simulation results and analysis of multi-tone and FHC interference, the differences between the two jamming methods are listed in Table 2 when the given BER of 10^{-1} is achieved.

Table 2. Comparisons of the Two Jamming Methods

Factor	Multi-tone interference	FHC interference
Numbers of FH points interfered	10 to 20	1
JSR	10.5dB	21dB
Utilization of jamming power	Low	High
Complexity of realization	Complex	Simple

From Table 2, in order to get the same jamming performance, even though the jamming power of new FHC interference is about 10dB higher than multi-tone interference, the utilization rate of jamming power is higher and the complexity in realization of jammer is much simpler in FHC interference than those in multi-tone interference. It can be concluded that FHC interference has advantages over multi-tone interference from the respects of utilization rate of jamming power and complexity of realization.

7. Conclusion

The key anti-jamming techniques including CCSK, FH, RS code and interleaving in Link16 are analyzed and modeled. A Link16 simulator which is the measurement model of jamming performance is established. According to the conventional static jamming methods like tone and multi-tone interference, we put forward a new dynamic jamming method named FHC interference. Both multi-tone and FHC interference are simulated in the same condition. From the comparison of the static multi-tone interference and new dynamic FHC interference, we conclude that the realization of FHC jammer is much simpler and the utilization rate of jamming power is much higher. Compared with the static interference, the new dynamic FHC interference is a great threat to the correct information transmission and exchange of Link16 system and provides a new way for us to interfere with Link16 as well.

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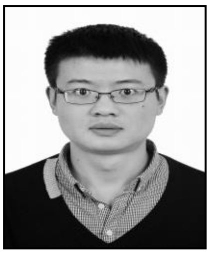

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