Analysis of Initial Value Effect of Differential Chaotic Shift Keying Communication System

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ABSTRACT. Chaotic signals have many unique properties, chaotic digital modulation technology has many advantages over traditional digital modulation technology, so it has good application value in the field of information security. In order to analyze the differential chaotic shift keying technology more comprehensively, based on the research of the DCSK, FM-DCSK and RM-DCSK differential chaotic shift keying techniques, the MATLAB simulation platform is used to simulate the balance of the different sequences and the initial values of different chaotic keying systems are used to simulate the error performance of different systems. The experimental results show that the peak of the balance of chaotic map may lead to the peak value of the system error rate. Therefore, the peak point should be avoided when the initial value of the sequence is selected. Different digital modulation techniques and chaotic mapping systems have their own characteristics, and when the reasonable parameters are selected according to the characteristics, the system performance can be optimized.

1. INTRODUCTION
Chaotic signals have non-periodicity, good autocorrelation and cross-correlation, broadband-like characteristics like white noise, easy to generate and numerous, which make it show broad application prospects in secure communication, especially military and national information security plays a huge role.

Chaotic digital modulation technology uses a non-periodic chaotic signal to replace the traditional sinusoidal carrier, and achieves spectrum expansion while completing digital modulation. The differential chaotic shift keying DCSK adopts the T-R method to transmit both the reference signal and the information signal to the receiver without the channel estimation and the spreading code synchronization required for the conventional spread spectrum. In order to solve the problem of BER performance deterioration caused by the continuous change of bit energy of the transmitted signal in DCSK, Kolumbán et al. proposed frequency-modulated differential chaotic shift keying (FM-DCSK)
two years later, using a chaotic FM signal with constant power instead of the Chaotic signal of DCSK system. With the deepening of research, Yang Hua proposed reference signal modulation differential chaotic shift keying (RM-DCSK), so that each piece of information signal and reference signal carries 1 bit of information, which improves the bit transmission rate, communication confidentiality and the error performance is better.

2. TYPICAL CHAOTIC DIGITAL MODULATION SYSTEM

2.1 Differential Chaotic Shift Keying (DCSK)
In order to overcome the threshold drift problem of CSK in non-coherent demodulation, Kolumban proposed a new non-coherent chaotic digital modulation technology - DCSK in 1996. In DCSK, each bit time is equally divided into 2 time slots. The first time slot is used to transmit a chaotic sequence as a reference signal sample, and is therefore referred to as a reference time slot; in the second time slot, a chaotic sequence of the same length is transmitted as an information signal sample, and thus is referred to as an information time slot. The information transmission rate is slow and the confidentiality is deteriorated.

\[
\begin{align*}
\text{Delay } \beta \\
\text{Chaotic signal generator} \\
x_i \\
\text{Delay } \beta \\
\text{Binary information } b_k \\
r_i \\
\text{Threshold judgment}
\end{align*}
\]

Figure 1. DCDK transmitter.

Taking the bipolar binary information bit \( b_k \) as an example, the signal expression of the DCSK system transmitted in the \( k \)th bit time is

\[
s_i = \begin{cases} 
   x_i & 2k\beta < i \leq (2k+1)\beta \\
   b_kx_i-\beta & (2k+1)\beta < i \leq 2(k+1)\beta
\end{cases}
\]

(1)

Where \( \beta \) represents the number of samples of the transmitted signal in each time slot.

2.2 FM differential chaotic shift keying (FM-DCSK)
In order to overcome the increase of bit error rate caused by bit energy variation, an FM-DCSK scheme is proposed to transform the chaotic carrier signal into a constant power waveform with chaotic frequency by frequency modulation. The frequency modulation module has constant output power and limited bandwidth. The chaotic modulation signal is added to the FM modulator to change the chaotic basis function used as a carrier in DCSK into an FM modulated chaotic FM waveform.
2.3 Reference Signal Frequency Modulation Differential Chaos Keying (RM-DCSK)

The RM-DCSK system was proposed to better obtain the DCSK transmission rate. The RM-DCSK also modulates the reference time slot so that the transmission rate is doubled without losing the DCSK bit error rate performance. The modulated $b_{2k}$ modulated chaotic signal $b_{2k}x_k$ is not only the current information signal but also the reference signal of the next time slot; the modulated $b_{2k+1}$ modulated chaotic signal $b_{2k+1}b_{2k}x_k$ is transmitted together with the reference signal of the next time slot as the signal of the current time slot.

**RM-DCSK Signal Expression:**

\[
S_i = \begin{cases} 
  b_{2k}x_i & 2k\beta < i \leq (2k + 1)\beta \\
  \frac{1}{\sqrt{2}}(b_{2k+1}b_{2k}x_{i-\beta} + x_i) & (2k + 1)\beta < i \leq 2(k + 1)\beta 
\end{cases}
\]  

(2)

Among them, the chaotic sequence satisfies the following relationship:

\[x_{(2k+1)\beta+m} = x_{2(k+1)\beta+m}, \quad \forall k \in \{0, 1, \ldots\}, 0 < m \leq \beta\]  

(3)

Figure 5 is a repeating chaotic sequence generator (RCG). In order to realize the sequence relationship described in the above equation, the system works: in the even time slot, the switch turns on the lower branch; in the odd time slot, the switch turns on the upper branch.

**Figure 5. Repeating chaotic signal generator**

The complexity of the RM-DCSK transmitter is slightly increased relative to the DCSK transmitter architecture, but the RM-DCSK transmission rate is twice that of DCSK.
3. SIMULATION ANALYSIS OF THE INFLUENCE OF INITIAL VALUE OF MAPPING SYSTEM ON DIFFERENT SYSTEM PERFORMANCE

3.1 The balance of chaotic signal

Figure 8 to Figure 11 are the effects of the initial values of four chaotic maps on the balance. When the modified Logistic mapping fractal parameter is 2, the initial value is 10000 different values of 0~1. Figure 9 shows that the initial value has little effect on the balance, but when the initial value is 0.5, there is a peak. The Logistic map has three peaks at initial values of 0.25, 0.5, and 0.75. The initial values of the Chebyshev map and the Tent map have little effect on the balance, and there is no peak.
3.2 Impact analysis on DCSK system

The whole experiment was carried out under the Gaussian white noise channel. Fig.12 and Fig.14 are the relationship between the BER and Logistic mapping of the DCSK system when the fractal parameter is 4 and the fractal parameter is 3.6. It can be clearly seen that when the fractal parameter is 4 and the initial value is 0.5, the error performance is particularly bad. This is because the expression of the Logistic map is $x_{n+1} = rx_n(1 + x_n)$, when $r = 4$ and the initial value is 0.5, the Logistic sequence value is calculated as shown in Fig.13, and a large number of codes that appear will be 0, so the bit error rate is increased.
According to the DCSK system signal form (as shown in equation (1)), except for the case where error codes are generated when various parameters are selected, the balance of different sequences has little effect on the error performance of the system. The remaining chaotic maps of modified Logistic map, Chebyshev map and Tent map have no error code loss, and have good error performance.

3.3 Impact analysis on FM-DCSK system

Since the signal expression of the FM-DCSK system is similar to that of the DCSK system, the relationship between the error performance of the FM-DCSK system and the initial value of the mapping is also the same as that of the DCSK system. It is not specifically shown here, but there are also differences. When the Logistic fractal parameter is 4 and the initial value is 0.5, most of the codes in the DCSK system will be 0, but the FM-DCSK system avoids this situation due to the addition of FM modulation.
3.4 Impact analysis on RM-DCSK system

The improved Logistic mapping expression is $x_{n+1} = 1 - r(x_n)^2$, when $r = 2$, it can be known that the initial value is 0.5, which is the peak of the balance of the mapping. The generated chaotic signal sequence value is shown in Figure 16, all values are 0.5, and the RM-DCSK system signal is expressed. The second term of equation (2), $\frac{1}{\sqrt{2}}(b_{2k+1}b_{2k}x_i - \beta + x_i)$ may be added to 0, and errors or losses may occur, resulting in an increase in the bit error rate.

![Figure 15. RM-DCSK system BER and improved Logistic mapping initial value relationship](image1)

![Figure 16. Improved Logistic Map Sequence Value](image2)

Logistic map balance is shown in Figure 9. There are three peak points of 0.25, 0.5 and 0.75. The sequence values are shown in Figure 18. For the RM-DCSK system, the information leakage is too large due to the signal structure. Errors or loss, resulting in a higher system error rate. Therefore, when the initial values are 0.25, 0.5, and 0.75, the BER performance of the system is not good, and the initial value is 0.8.

![Figure 17. RM-DCSK system BER and Logistic mapping initial value relationship](image3)
Sequence value with an initial value of 0.25

Sequence value with an initial value of 0.5

Sequence value with an initial value of 0.75

Figure 18. Different initial value Logistic map sequence values

The Chebyshev map (Fig. 10) and the Tent map (Fig. 11) do not have a balance peak in the simulation, but the Tent map in the literature has a balance peak, and the system initial value and system should be reasonably selected for the Tent system. The parameters are detailed in the book here. Combined with the relevant simulation experiments, it can be concluded that different initial values of Chebyshev mapping and Tent mapping have less influence on the error performance of the system.

4. CONCLUSION

At present, in the field of communication and information security, chaotic keying technology has been paid more and more attention by scholars. Due to the robustness of chaotic synchronization, DCSK system is proposed to overcome the problem of threshold drift in CSK. FM-DCSK is proposed to reduce the estimated data rate without limiting the data rate and constant energy per bit. RM-DCSK is a classical modulation scheme proposed to increase the DCSK transmission rate. By analyzing the traditional differential chaos keying, the influence of the initial values of different chaotic mapping systems on the error of three classical differential shift chaotic keying systems is discussed. It can be seen from the simulation results that for the DCSK system, when the fractal parameter is 4 and the initial value is 0.5, the error performance should be avoided as much as possible. The FM-DCSK system has not found an initial value point that should be specifically avoided due to its system characteristics. The RM-DCSK system should avoid all the balance peak points of these four mappings. Different chaotic maps have different characteristics such as balance. No chaotic signal can be applied to all problems. For different problems and evaluation criteria, the performance of the communication scheme can be optimized by reasonable parameter setting.

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