Design of a Differential Chaotic on-off keying communication system

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ABSTRACT

Among the available chaotic modulation schemes, differential chaos shift keying (DSCK) offers the perfect noise performance. The power consumption of DCSK is high since it sends chaotic signal in both of 1 and 0 transmission, so it does not represent the optimal choice for some applications like indoor wireless sensing where power consumption is a critical issue. In this paper a novel noncoherent chaotic communication scheme called differential chaos on-off keying (DCOOK) is proposed as a solution of this problem. With the proposed scheme, the DCOOK signal have a structure similar to chaos on-off keying (COOK) scheme with improved performance in noisy and multipath channels by introducing the concept of differential coherency used in DCSK. The simulation results show that the proposed scheme have achieved more than 3 dB gain in signal-to-noise ratio for AWGN and Rayleigh multipath fading channels at BER=10^{-3} over COOK scheme.

Keywords: chaotic communication; noncoherent; modulation; chaos on-off keying; differential chaos keying

تصميم منظومة اتصالات فوضوية ذات قدح ارتفاع تفاضلي

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تعد طريقة تضمين قدح الترحيف التفاضلي الفوضوي (DCSK) ذات اداء ممتاز في الاوساط الضوضائية مقارنة بطرق التضمين الاخرى المستخدمة في الاتصالات الفوضوية. ان الطريقة المذكورة آنفا تستهلك قدرة ارسال عالية كونها ترسل اشارة فوضوية في كلتا حالتي قيمة البيانات 0 و 1 لذلك فهي لا تمثل الخيار الامثل لبعض التطبيقات مثل منظومات التحسس ذات الارسال اللاسلكي داخل الابنية والتي يكون فيها موضوع استهلاك القدرة قضية حساسة. في هذا البحث تم اقتراح طريقة تضمين لاتشاكهية فوضوية تم تسميتها طريقة قدح الارتفاع التفاضلي (DCOOK) لحل هذه المشكلة. إن الطريقة المقترحة ذو تركيب مادي مشابه لطريقة قدح الارتفاع (COOK) الا انها تمتلك اداء محسن في القنوات الضوضائية وقنوات الخفوت وذلك من خلال استخدام مفهوم التفاضل التشاكهي المستخدم في طريقة DCSK. ولقد اوضحت نتائج المحاكاة ان الطريقة المقترحة حققت ربحا يزيد عن 3 dB في نسبة الاشارة الى الضوضاء مقارنة بطريقة COOK عند اختبارها في قناة الضوضاء نوع AWGN وقناة الخفوت نوع Rayleigh عند قيمة معدل خطأ المعلومة الثنائية (BER) مساوي لـ 10^{-3}.

الكلمات الرئيسية: الاتصالات الفوضوية ، لاتشاكهي ، تضمين ، قدح الارتفاع الفوضوي ، القدح التفاضلي الفوضوي

INTRODUCTION

Chaos communications has been an active research area in the last few years. Chaotic signals possess some unique properties such as pseudorandomness, noise-like wide bandwidth and long term unpredictability. They satisfy special requirements of some communication systems. It makes chaos attractive to wideband and security communications (M. Xu and Henry Leung 2010).

At present, the studying of the chaos systems mainly focuses on chaotic digital communications which include chaos digital keying modulation like chaos shift keying (CSK)(H. Dedieu, M. P. Kennedy and M. Hasler 1993), chaotic on-off keying (COOK)(G. Kolumbàn, M. P. Kennedy and G. Kis 1997), differential chaos shift keying (DCSK)(G. Kolumbàn, G. K. Vizvari and W. Schwarz 1996), correlation delay shift keying(CDSK)(M. Sushchik, L. S. Tsimring and A. R. Volkovskii 2000), etc. Because of the sensitivity to initial conditions, it is difficult that chaotic signals realize reliably synchronization in both two sides of transmitter and receiver. Therefore, noncoherent chaos communication systems which don't need chaos-synchronization are the most preferred ones. Among several noncoherent systems proposed, one of the best bit-error rate (BER) performances has been achieved by the DCSK and its variation utilizing frequency modulation, FM-DCSK (G. Kolumbán, G. Kis, Z. Jákó, and M. P. Kennedy 1998).

In DCSK scheme, a reference chaotic waveform c(t) is transmitted during the first half of each data bit. If the bit is a "1", c(t) is transmitted again during the second half. If the bit is a "0", -c(t) is transmitted. Modified versions of DCSK like quadrature chaos shift keying (QCSK)(Z. Galias, and G. M. Maggio 2001), quadrature amplitude chaos shift keying (QACSK)(J. Pan and H. Zhang 2009) and quadrature differential chaotic phase shift keying (QDCPSK)(S. Zhu, Yinlin Xu and Kuixi Yin 2009) were proposed to improve the band usage and transmission speed. In COOK, the chaotic signal is multiplied directly by the bit sequence to be transmitted, i.e. radiation of a chaotic signal is disabled for data bit "0" and enabled for data bit "1".

Although the performance of COOK chaotic modulation lags behind the DCSK, the COOK have an advantage of that it consumes less power since it sends chaotic signal only in case of sending the data bit "1" while no power is sent for case of data bit "0". In this paper, a novel scheme that combines the features of DSCK and COOK, i.e. good BER performance with less power consumption has been proposed. The proposed system is called Differential Chaotic On-Off Keying (DCOOK). The rest of the paper is organized as fellows: In the next section the proposed modulation scheme is introduced. Then, the performance of the proposed scheme is analyzed and compared with some existing schemes. Finally, some conclusions drawn from the work are given at the end of the paper.

DIFFERENTIAL CHAOTIC ON-OFF KEYING (DCOOK) SCHEME

Fig.1 shows the structure of the proposed DCOOK system. At the transmitter, when the data bit is "1" a reference chaotic waveform c(t) is transmitted during the first half of data bit duration T, while a delayed version of c(t) by T/2 is transmitted during the second half (like DCSK). If the bit is a "0", the transmission is disabled (like COOK). Therefore, signal transmitted by DCOOK can be expressed in a symbol period T as:

$$S_{DCOOK}(t)=\begin{cases}\sqrt{E_b}c(t) & when\ d(t)=1\ and\ \ 0\le t<\frac{T}{2}\\ \sqrt{E_b}c(t-\frac{T}{2}) & when\ d(t)=1\ and\ \frac{T}{2}\le t<T\\ 0 & when\ d(t)=0\end{cases}\qquad(1)$$

where d(t) is the transmitted data and E_b is the energy per bit. To get maximum noise performance E_b should have constant value which is possible by applying the chaotic signal to a frequency modulator[6]. At the receiver, the signal is delayed by half a bit period and correlated with the undelayed signal to get the decision variable for producing the output data stream. **Fig.2** shows the signal structure of DCOOK scheme as compared with DCSK and COOK schemes where C_i represents the chaotic signal part (a set of chaotic symbols) corresponds to ith half a bit to be transmitted (chip). It can be seen in this figure that both the principles of differential representation used in DCSK and the on-off representation used in COOK are combined together and depending on the data bit value.

The major advantage of DCOOK scheme as compared with COOK is that it increases the signal space of the decision variable, i.e. increases the separation between the amplitude levels upon which the data is declared to be "0" or "1" after threshold comparison. This can be explained as fellows: In traditional COOK scheme, the detection operation includes performing correlation between the received signal and itself along the data bit duration. This means the received noise in case of "0" transmission would be correlated with itself (i.e. with exactly the same replica) which will produce a nonzero correlation result with always positive value which increases as SNR increases. While in the proposed DCOOK scheme, the detection operation includes performing correlation between the received signal and a delayed version of it along half data bit duration. This means the received noise in case of “0” transmission would be correlated with another noise replica which will produce a correlation result might be positive (lower than that of COOK case) or negative or zero value with almost independency on SNR value. The relation between the correlation results in both cases can be understood mathematically by the following inequality:

$$\int_0^T n^2(t)dt \; > \int_0^{T/2} n(t)n(t-\frac{T}{2})dt \qquad (2)$$

where n(t) is the received AWGN noise. The correlation result in case of “0” transmission for DCOOK scheme; the right hand of eq.2, is less than the corresponding correlation result for COOK; the left hand of eq.2. This is because the some point-to-point multiplication results of noise samples in DCOOK case have negative values which are not the case of COOK scheme. Given that the correlation between the received signal plus noise results in always high positive results in both schemes, the signal space of the decision variable is increased in DCOOK scheme which as a result would improve the noise performance. It is worth noted that the number of chaos symbol per data symbol should be large enough to ensure good noise performance. In DCSK the signal space of the decision variable is bigger than that of DCOOK and the sign is used for decision purpose with zero threshold value independent on noise level. However, the advantage of DCOOK over DCSK is the less power consumption in the transmission side.

SIMULATION RESULTS

A simulation model has been implemented for DCOOK system, as well as COOK and DCSK for performance comparison purpose. Hennon mapping given by:

$$x_{n+1} = 1 + bx_n + ax_n^2 \qquad (3)$$

where a and b are constants and a=-1.4 and b=0.3 is used to generate the chaotic signal. The values of a and b are selected such that the chaotic signal have good randomness properties (C. Y. Li, J. S. Chen, and T. Y. Chang 2006). According to the article by (M. A. B. Faran, A. Kachouri and M. Samet 2006), we define the chip rate equals 0.05 µs and T=4 µsec. **Fig.3** shows the integrator outputs for DCOOK as compared with COOK and DCSK systems in relation to the transmitted data values at E_b/N_o=6 dB. It can seen in this figure that the integrator output at decision points for d(t)=0 in DCOOK system is changing between low positive and negative values while it is always positive in COOK system (its amplitude depend on signal-to-noise ratio value). Hence the signal space of the decision variable is increased in DCOOK system as compared with COOK system (but less than DCSK system) and a successful decision about data value can be achieved with a little positive threshold.

Fig.4 shows a very important feature in DCOOK system which is the threshold level is almost constant and has very little dependency on signal-to-noise ratio change. Oppositely, the optimum threshold in COOK system is very sensitive to the signal-to-noise ratio change. The DCSK detector has constant threshold value which is zero due to bipolar nature of integrator results as explained in the previous section. **Fig.5** shows the performance of DCOOK as compared with COOK and DCSK in AWGN channel. It is clear in the figure that the noise performance of the proposed DCOOK is superior as compared with COOK for all signal-to-noise ratio values. At $P_e=10^{-3}$, a 3.6 dB gain in signal-to-noise ratio has been obtained. However, this performance lags behind DCSK system by less than 2 dB at the significant BER values. **Fig.6** shows the corresponding performance in Rayleigh fading channel. In this case we used in our simulations two paths; the second path delay was 75 ns with attenuation of -3 dB which simulates the multipath environment inside office buildings. Here the performance of DCOOK is once again better than COOK for all signal-to-noise ratio values. At $P_e=10^{-3}$, a 3 dB gain in signal-to-noise ratio has been obtained. This performance lags behind DCSK system by about 1.5 dB at the significant BER values.

CONCLUSIONS

The proposed DCOOK scheme represents a model of chaotic modulation scheme with which the compromise between the noise performance and power consumption can be achieved. The proposed scheme increases the signal space of the decision variable by using the concept of differential correlation instead of self correlation. The optimum threshold value of the proposed scheme detector is found to be almost constant and independent on signal-to-noise ratio value.

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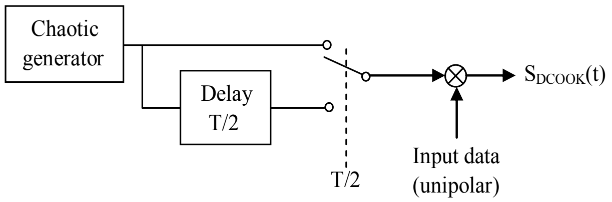
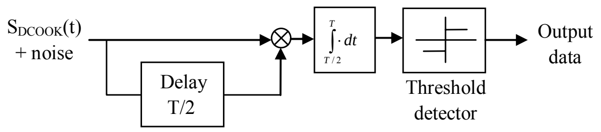
LIST OF SYMBOLS

AWGN: Additive White Gaussian Noise
a: constant used in Hennon mapping
b: constant used in Hennon mapping
BER: Bit Error Rate
c(t): chaotic waveform
C_i: set of chaotic symbols
CDSK: Correlation Delay Shift Keying
COOK: Chaotic On-Off Keying
CSK: Chaos Shift Keying
DCOOK: Differential Chaos On-Off Keying
DCSK: Differential Chaos Shift Keying
d(t): transmitted data
E_b: energy per bit
FM-DCSK: Frequency Modulated DCSK
QCSK: Quadrature Chaos Shift Keying
QACSK: Quadrature Amplitude Chaos Shift Keying
n(t): noise signal
T: bit duration
x_n: nth Hennon-mapped chaotic symbol



(a) Transmitter



(b) Receiver

Fig.1 Block diagram of the DCOOK system

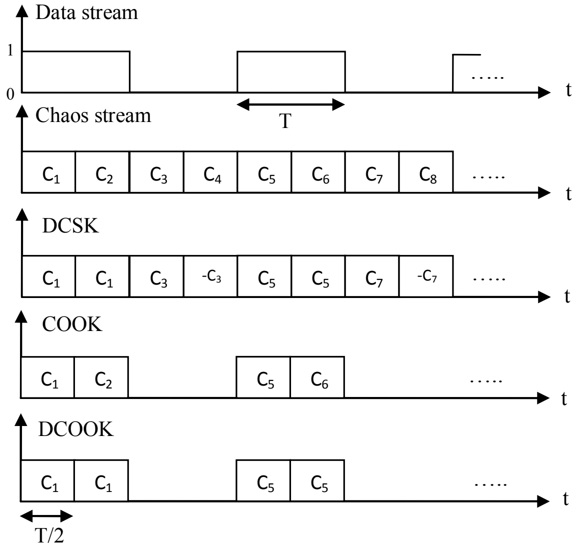


Fig.2 Signal structure of DCOOK scheme as compared with COOK and DCSK schemes.

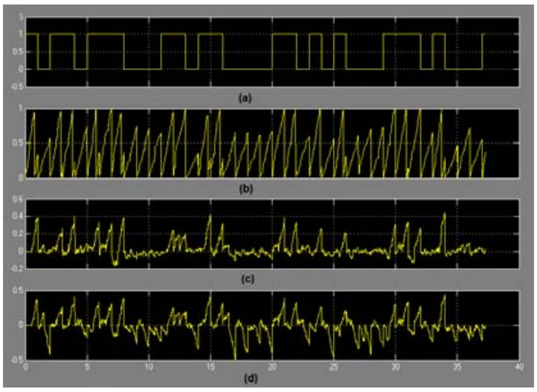


Fig.3 (a) Transmitted data
(b) COOK integrator output
(c) DCOOK integrator output
(d) DCSK integrator output

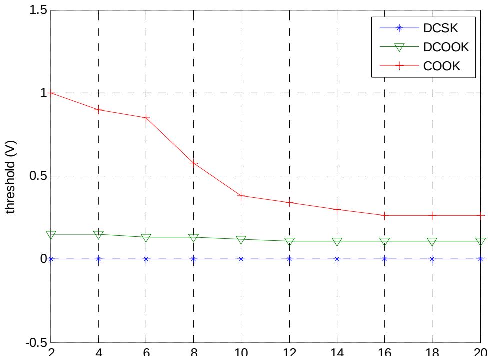


Fig.4 The sensitivity of optimum threshold to signal-to-noise ratio change in DCOOK as compared with COOK and DCSK.

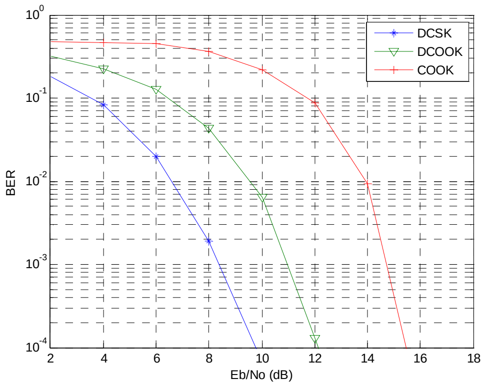


Fig.5 Performance of DCOOK as compared with COOK and DCSK in AWGN channel.

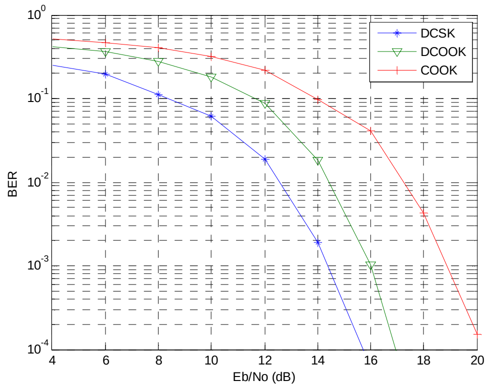


Fig.6 Performance of DCOOK as compared with COOK and DCSK in Rayleigh fading channel.