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A Double Differential Chaos Shift Keying Scheme for Ultra-Wideband Chaotic Communication Technology Applied in Low-Rate Wireless Personal Area Network

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Abstract**—**The goal of this paper is to describe the design of an ultra-wideband (UWB) system that is optimized for the low-rate wireless personal area network application. To this aim, we propose a system based on direct chaotic communication (DCC) technology. Based on this system, a 2-GHz wide chaotic signal is produced into the UWB spectrum lower band, i.e., 3.1–5.1 GHz. For this system, two simple modulation schemes, namely chaotic on-off keying (COOK) and differential chaos shift keying (DCSK) are evaluated first. We propose a modulation scheme, namely Double DCSK, to improve the performance of UWB DCC. Different characteristics of these systems, with Monte Carlo simulations based on the Additive White Gaussian Noise (AWGN) and the IEEE 802.15.4a standard channel models, are compared.

Keywords**—**Ultra-wideband, UWB, Direct Chaotic Communication, DCC, IEEE 802.15.4a, COOK, DCSK.

I. INTRODUCTION

UWB radio technology has emerged as one of the most promising candidates for WPANs. A bandwidth of more than 7.5 GHz i.e., 3.1-10.6 GHz, can be exploited for unlicensed UWB applications [2]. This large bandwidth indicates a great potential in terms of capacity and flexibility, making UWB technology distinctly attractive. One proposed technology was based on chaotic signaling. Chaotic signals have attractive features that make it proper for the UWB applications, such as inherit wideband characteristics, deterministic and non-periodic behavior and noise-like structure. On the other hand, a chaotic signal has a relatively flat power spectrum density due to its non-periodicity in the time domain, which can easily be tailored to satisfy the strict FCC UWB regulations. The most important characteristic of this type of signal is that it can easily be generated by simple circuits. Here we present the system and performance evaluation of the UWB DCC technology.

The remainder of the paper is organized as follows: Section II describes the principle of DCC technology. Section III presents the system design. Section IV gives an overview of the UWB multipath channel model used for the system performance evaluation. Section V reports the system performance under AWGN and various types of IEEE 802.15.4a multipath channels. Finally, Section VI is conclusion.

II. DCC TECHNOLOGY

There are various conventional methods that can be used to generate chaos, such as chaotic masking and chaotic shift keying. However, these methods required complex traditional transceiver architecture, where chaotic shift keying was used as subcarriers that modulate high-frequency carriers. To overcome this limitation, DCC technology is deployed. Based on this scheme, information-carrying chaotic signals are produced into the determined microwave band without needing a local oscillator and a mixer [1], [2]. Fig. 1 illustrates the principle of DCC signal generation. But in our system, we do not use chaotic pulses. In our scheme, chaotic signals are pass through a sign block and be a NRZ chaotic sequence. Then this sequence keyed in the proper time. So, we have two differences in comparison with simple DCC technology.

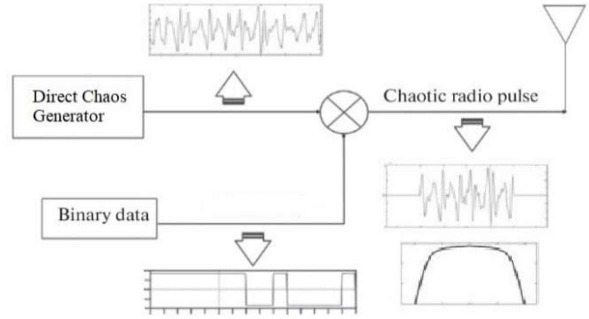

Fig. 1 Principle of DCC signal generation

III. SYSTEM DESIGN

A. Frequency Band Plan

Here, the principle of DCC is deployed in the UWB frequency band plan. Despite the large bandwidth, i.e., 7.5 GHz, that is available for the UWB system, we only utilize the lower band, i.e., 3.1–5.1 GHz, as the operating frequency. The main reason the lower band is exploited is due to the technical constraints in implementing an integrated circuit (IC) at a higher frequency. Typically, a low-cost and low-power IC solution is limited beyond 6 GHz. The chosen band also avoids possible interference with the wireless local area network devices that operate in the 5-GHz band.

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B. COOK

Multifarious modulation outlines can be extended based on the DCC technology such as COOK, DCSK, and pulse-position modulation (PPM) [3], [4]. In this section, we emphasize the COOK modulation scheme. In this scheme, just one chaotic signal is required. The binary numbers "+1" and "−1" are indicated by transition of this signal and null transition, respectively. A positive value or zero, depending on the transmitted binary number is received by the bit energy of the transferred signal [5], [9], [10]. This scheme offers several advantages. First, since it is one of the simplest modulation schemes, its transceiver architecture has less complexity. This simple architecture leads to a product with a very low cost. Second, it has energy efficiency that is 3 dB higher than DCSK and PPM, which can then provide an additional power saving. The main disadvantage of a typical COOK system is that it requires nonzero threshold estimation.

C. DCSK

The threshold-shift problem for the COOK system is disclosed based on bit-energy approximation. In this section, the DCSK modulation layout is rendered, a modulation technique that is mainly designed for non-coherent detection. Furthermore, the threshold level of the demodulator is set to zero.

The block diagram of a DCSK modulator is depicted in Fig. 2 [6]. In this modulation layout, every transmitted binary number is indicated by two successive segments of chaotic signals. The earliest is used as the reference whereas the former carries the data. If a "+1" is to be sent, the data-bearing signal will be equal to the reference signal, and if a "−1" is to be sent, an inverted version of the reference signal will be used as the data-bearing signal. Thus, we have

$$s(t)=\begin{cases}+c(t) & 0\le t\le \frac{T_b}{2}\\ c\left(t-\frac{T_b}{2}\right) & \frac{T_b}{2}\le t\le T_b\end{cases}\tag{1}$$

if "+1" is to be sent, and

$$s(t)=\begin{cases}+c(t) & 0\le t\le \frac{T_b}{2}\\ -c\left(t-\frac{T_b}{2}\right) & \frac{T_b}{2}\le t\le T_b\end{cases}\tag{2}$$

if "−1" is to be sent.

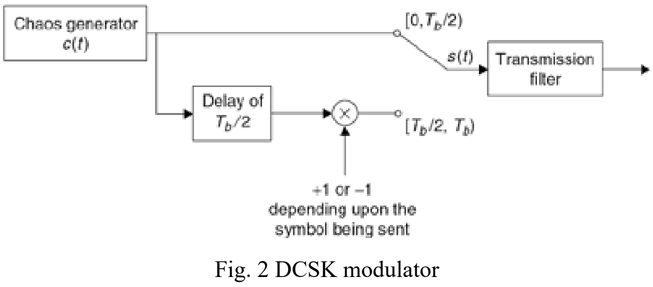

Fig. 2 DCSK modulator

The correlation of the data bearing signal and the reference signal is evaluated at the receiver. This can be done by communicating the entering signal with a half-symbol-delayed form of itself [7], [11]. However, the data rate of DCSK is half of the other systems because it expends half of the time sending the non-information bearing reference signals. This is the main disadvantage of DCSK.

D. Double DCSK

As we showed, non-zero threshold detector is the most important degradation of COOK. This subject removes in DCSK scheme but leads to another problem, which is the complexity and half data rate in compare with COOK. For same data rate in DCSK and COOK we should apply double frequency technology in DCSK, which is made the high cost, because in DCSK we use the $\frac{T_b}{2}$ for the frequency of keying, whereas this time is T_b for the COOK. So, with same frequency technology, COOK has the double data rate than DCSK. For solving this problem in DCSK, we propose Double DCSK scheme. In this method we use two different chaotic sequences. As DCSK, the time period of bit is divided in two segments. In the first segment, the first reference chaotic signal and the product of the second transmitted bit with the second reference chaotic signal, which is half time period of bit delayed, is transmitted. In the second segment, inverse condition is applied. The equation of Double DCSK is shown as:

If two bits are respectively "1" and "1",

$$s(t)=\begin{cases}c_1(t),\ c_2\left(t-\frac{T_b}{2}\right) & for \quad 0\le t\le \frac{T_b}{2}\\ c_1\left(t-\frac{T_b}{2}\right),\ c_2(t) & for \quad \frac{T_b}{2}\le t\le T_b\end{cases}\tag{3}$$

If two bits are respectively "1" and "-1",

$$s(t)=\begin{cases}c_1(t),\ -c_2\left(t-\frac{T_b}{2}\right) & for \quad 0\le t\le \frac{T_b}{2}\\ c_1\left(t-\frac{T_b}{2}\right),\ c_2(t) & for \quad \frac{T_b}{2}\le t\le T_b\end{cases}\tag{4}$$

If two bits are respectively "-1" and "1",

$$s(t)=\begin{cases}c_1(t),\ c_2\left(t-\frac{T_b}{2}\right) & for \quad 0\le t\le \frac{T_b}{2}\\ -c_1\left(t-\frac{T_b}{2}\right),\ c_2(t) & for \quad \frac{T_b}{2}\le t\le T_b\end{cases}\tag{5}$$

If two bits are respectively "-1" and "-1",

$$s(t)=\begin{cases}c_1(t),-c_2\left(t-\frac{T_b}{2}\right) & for \quad 0\le t\le \frac{T_b}{2}\\ -c_1\left(t-\frac{T_b}{2}\right),\ c_2(t) & for \quad \frac{T_b}{2}\le t\le T_b\end{cases}\tag{6}$$

As shown in the equations, in every bit period, two bits are transmitted, that leads to double data rate in comparison with DCSK. In the other hand, Double DCSK has the fix zero threshold detector that is an advantage in comparison with COOK. Fig. 3 shows the modulator and demodulator of the Double DCSK scheme. The important thing in this scheme is the high complexity and higher cost than COOK and DCSK. So, we should have tradeoff between the cost and complexity, which is the disadvantage of this scheme, and high data rate and fix zero threshold detector, which is the advantage of Double DCSK.

IV. UWB CHANNEL MODELS

Meticulous models of channel are critical for performance appraisal and the UWB communication systems design. A channel-modeling subcommittee was established under the IEEE 802.15.4a Task Group to expand new model of channel for system appraisal of the IEEE 802.15.4a standard [8].

Here, the UWB multipath channel model that is adopted by the IEEE 802.15.4a standard will be briefly described. This model is valid from 2–10 GHz frequency range in a number of different environments, including indoor residential, indoor office, outdoor industrial, agricultural areas, and body-area networks, under both line-of-sight (LOS) and non-LOS (NLOS) scenarios. In total, nine channel models (i.e., CM1–CM9) are defined in the IEEE 802.15.4a channel model final report. CM1 and CM2 are according to indoor residential areas, respectively. These environments are particularly important for home networks. CM3 and CM4 are according to indoor office areas, respectively, and CM5 and CM6 are according to outdoor areas, respectively. Industrial environments are one of the most important environments for IEEE 802.15.4a applications. These environments are represented by CM7 and CM8 for LOS and NLOS scenarios, respectively. Finally, CM9 modeled the agricultural areas.

V. SYSTEM PERFORMANCE

In this section, the system performance of COOK, DCSK and Double DCSK schemes based on the UWB-DCC technology is evaluated. It is thus desirable to perform system evaluation through Monte Carlo simulations in AWGN channel. To ensure a realistic evaluation, these schemes are evaluated based on simulations in various types of multipath channels, as described in Section IV. Here, we have chosen to use three of the channel models, i.e., CM1, CM5, and CM8, to demonstrate the feasibility and performance of the proposed system. CM1 is used as an example of the “best operating scenario” since it has the smallest delay spread with the strongest first arriving path. Then, CM5 is used as an example of the “outdoor scenario.” It has been well reported that the outdoor scenario is significantly different from indoor scenarios. Finally, CM8 is used as an example of the “worst operating scenario,” representing severe multipath dispersion with a very weak first arriving path.

The results reported in this section are obtained through Monte Carlo simulations with MATLAB, where 2 million of data bits were transmitted. For AWGN channel, we report the performance in processing gain (PG) that chaotic sequence has a 5 GHz sample rate. Figs. 4, 5 and 6 show the BER performances of the COOK, DCSK and Double DCSK systems, respectively. From the result, we see that double DCSK is the best scheme in AWGN channel and DCSK is the worst. For the UWB channel models, we take a 100 MHz bit rate, so the PG is equal with 50. As expected, CM8 has the worst error rate performance due to the harsh multipath effect. CM1 shows the best error rate performance due to its less dispersive multipath effect. Figs. 7, 8 and 9 show the BER performance of the COOK, DCSK and Double DCSK, respectively. In this case too, Double DCSK has the best performance and COOK has a little degradation in compare with that. DCSK as in AWGN channel, has the worst performance.

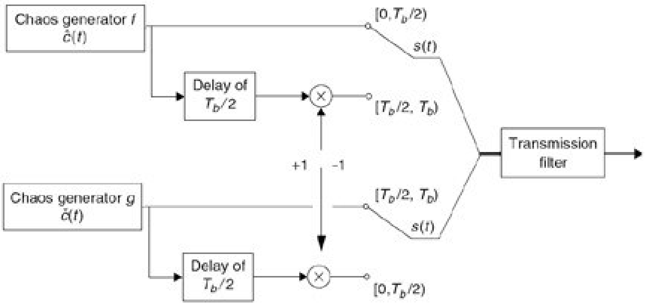

Fig. 3 (a) Double DCSK modulator

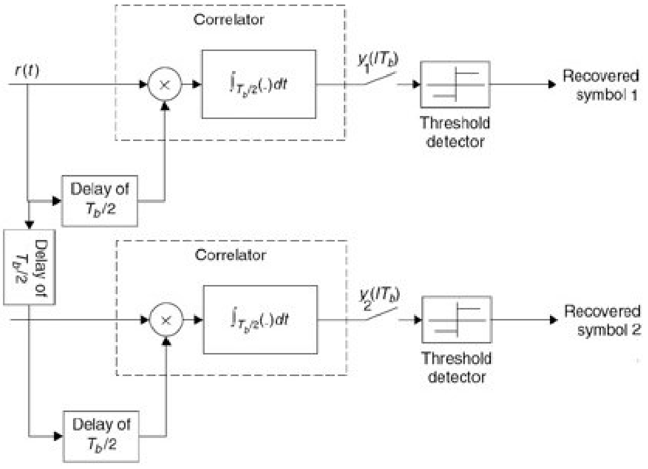

Fig. 3 (b) Double DCSK demodulator

VI. CONCLUSION

Chaotic communication is able to be used in UWB-DCC. In this paper the COOK and DCSK modulation schemes have been studied. COOK is good enough to be used in DCC but the main important problem of this scheme is the non-fix threshold in detector. DCSK has the zero-fix threshold detector but its degradation is the half data rate than COOK. We propose the Double DCSK scheme to have the benefits of both COOK and DCSK schemes, (data rate in COOK and zero-fix threshold in DCSK) but it has a high complexity and cost than those schemes. As a result, in all UWB channel models, Double DCSK shows the better performance than COOK and DCSK, but we should note that again, in this scheme complexity and cost are higher than COOK and DCSK.

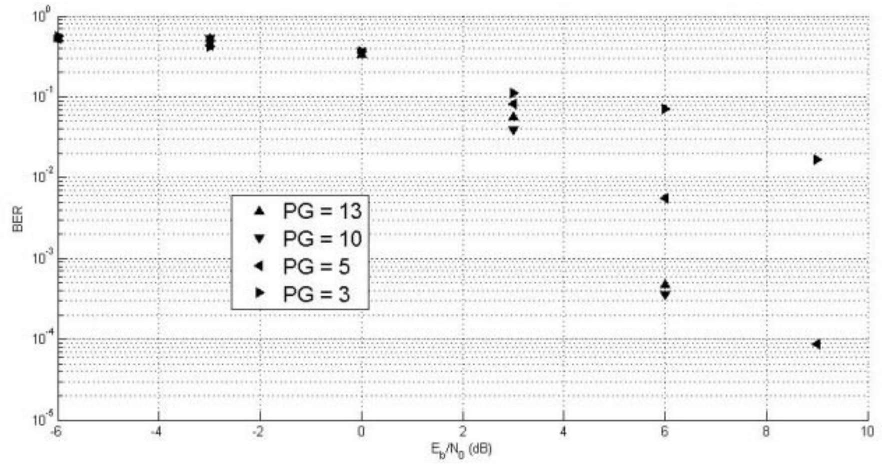

Fig. 4 COOK performance under AWGN channel

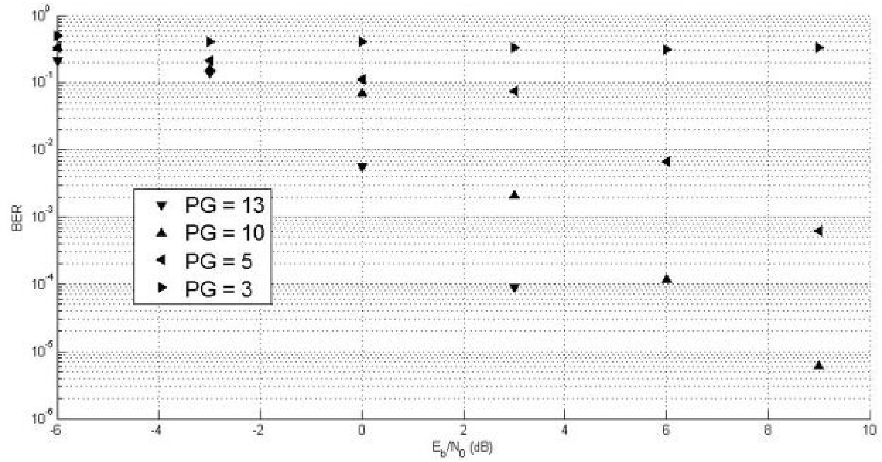

Fig. 5 DCSK performance under AWGN channel

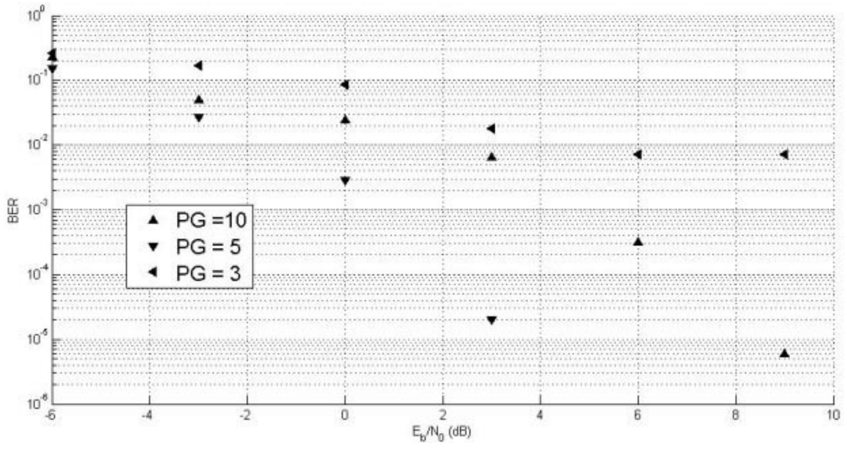

Fig. 6 Double DCSK performance under AWGN channel

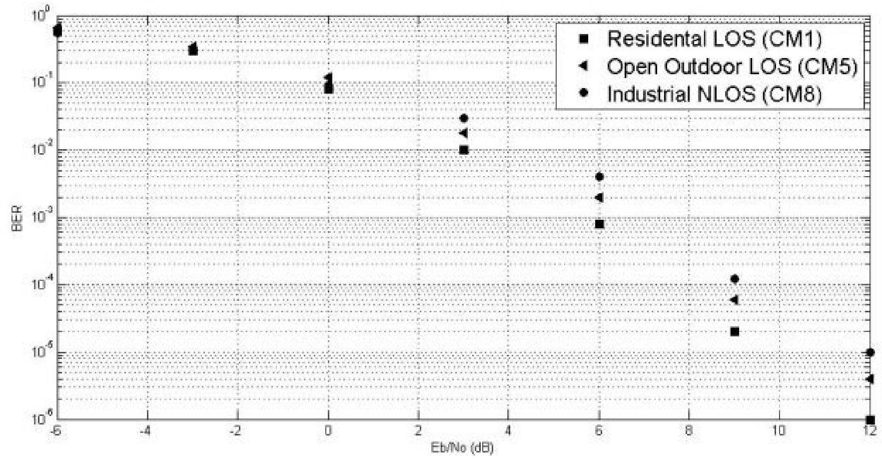

Fig. 7 COOK performance under 3 UWB channels

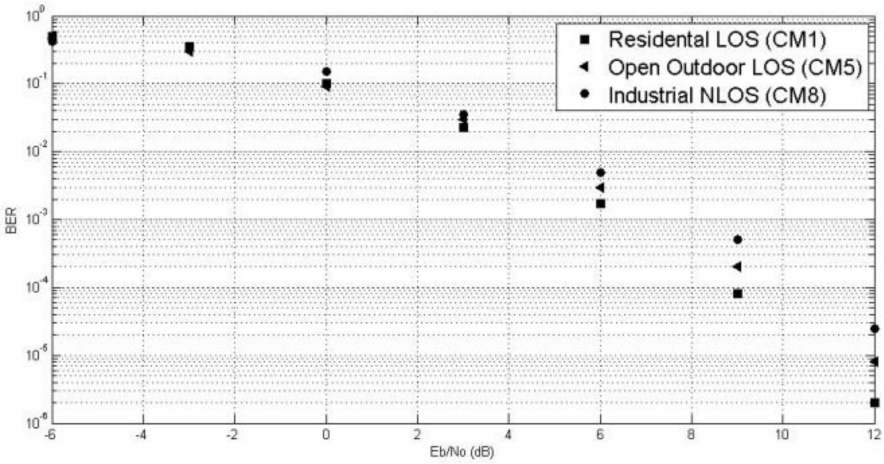

Fig. 8 DCSK performance under 3 UWB channels

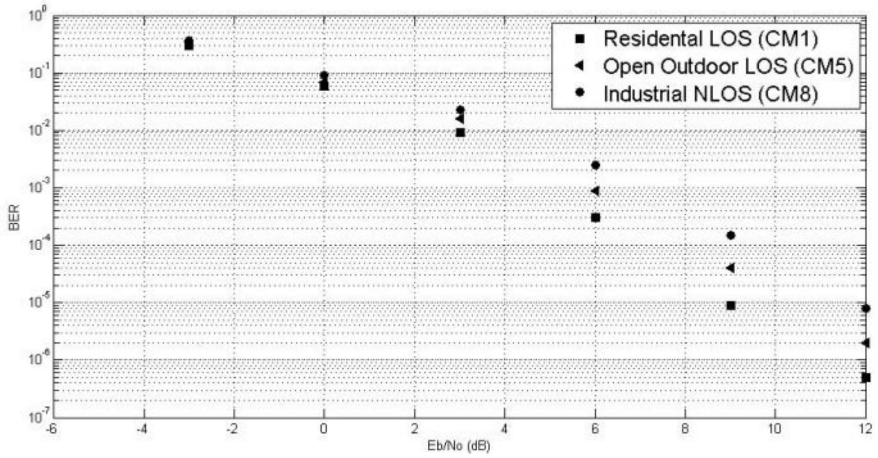

Fig. 9 Double DCSK performance under 3 UWB channels

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