Comparison Performance of the DS Chaotic and IR Chaotic UWB systems

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Abstract—**the IEEE802.15.4a Task Group for Wireless Personal Area Networks (WPAN) is working on an ultra-wideband (UWB) radio standard for the indoor sensor network applications. In 4a Task Group, various modulation and signal sources are being proposed to find the sensor network solutions satisfied with low cost and low power consumption. Among of them, the non-coherent direct sequences (DS) chaotic system using on-off keying (OOK) modulation and impulse radio (IR) chaotic system used pulse position modulation (PPM) are considered in this paper. This paper shows system performance which is shown by virtual simulation using channel model defined by IEEE802.15.4a Task Group Channel Model and compare the results from the real environment test between two schemes Through real environment tests, we can inform that the DS chaotic system is more sensitive for the channel conditions generated reflection and scattering of field test room. The IR chaotic system is more dependent on path loss according to the distance change than channel condition. Thus, we can determine the feasibility and compatibility of chaotic UWB system in order to operate the sensor network systems. Also, we show the possibility that the transceiver of chaotic system can be implemented into low complexity, low cost and low power consumption.**

I. INTRODUCTION

The ultra wideband radio systems [1] will be used in indoor applications, where selective fading caused by multi-path propagation determines the attainable system performance. To overcome the multi-path propagation problem an extremely wide frequency band has been allocated, it extends form 3.1GHz up to 10.6GHz. Since many conventional narrow band systems have been operating in this frequency band, the power radiated in a 1-MHz bandwidth is limited in order to minimize the interferences caused by the UWB radio in the existing present systems. The FCC emission mask allows transmitting -4.3 dBm in a 1-MHz wide frequency slot. The radiated signal must be a wideband signal; the bandwidth of transmitted UWB signal must exceed 500 MHz. Due to the UWB radio will use mobile handheld devices, its simplicity, low manufacturing cost and low power consumption are essential. As a response to IEEE802.15.4a Call for Proposal a few different modulation schemes have been proposed. Among them the impulse radio system and chaotic schemes offer the simplest UWB radio system configuration.

In this paper, we can show the characteristics of the DS chaotic system and Impulse method. The system descriptions of two schemes are represented in Section Ⅱ. And system channel condition and path loss model are introduced in Section Ⅲ. For the implementation, performances and platforms of two system are shown in Section Ⅳ.

II. SYSTEM DESCRIPTION

A. Chaotic Sources

Chaotic signal has two distinguishing characteristics: 1) irregular phase variation and 2) wide bandwidth. When signals are overlapped in conventional communications, the signal is distorted or cancelled out due to phase overlapping chaotic signals can be kept as they are since chaotic signals are noise-like in phase characteristics. Moreover, the wide spectrum has the merit of power and spectral efficiency. Hence, when modulated as OOK (On off Keying), a simple transmitter with low power consumption can be built as shown in Fig. 1 without any need for PLL or frequency converter at the receiver. When chaotic signals are directly switched to produce on and off modulation, the switch is controlled by Rx/Tx_Cont from Modem system block. In the receiver, the OOK signals coming from the antenna are amplified into the detector diode. The detected envelope is sampled and fed into A/D. Overall system architecture is extremely simple enabling small form factor as well as low power/low cost implementation.

Especially, the chaotic oscillator has been researched for several years. Most works were based on empirical implement. The Chua's works among them are described. In Chua's oscillator, four linear elements and Chua's diodes are integrated into chaotic signal generator as shown in Fig. 1.

More detailed explanations were introduced in [1]

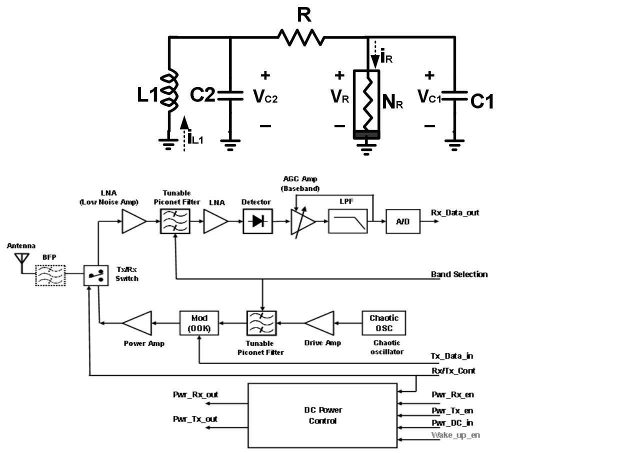

Fig. 1. Chaotic Oscillation circuit and transceiver structure included chaotic generator

B. IR Chaotic System

In IR Chaotic combined with 2PPM, the UWB signal can be schematized to be generated as follows in Fig. 2.

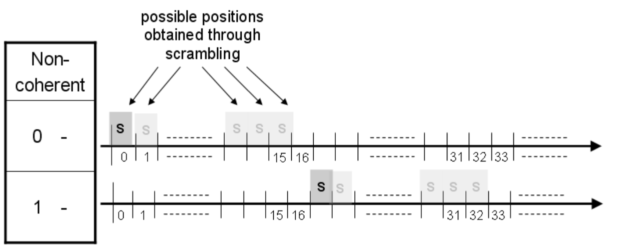

Fig. 2. Packet structures of IR Chaotic signal to determine generating sources

Given the binary sequence to transmit

$$\mathbf{b} = (\ldots, b_0, b_1, \ldots, b_k, b_{k+1}, \ldots) \quad (1)$$

generated at a rate of $R_b = 1/T_b\ [bps]$, the first system repeats each bit N_s times and generates a binary sequence

$$(\ldots, b_0, b_0, \ldots, b_0, b_1, \ldots, b_1, b_k, \ldots, b_k, b_{k+1}, \ldots, b_{k+1} \ldots) = (\ldots, a_0, a_1, \ldots, a_j, a_{j+1}, \ldots) \quad (2)$$

at a rate of $R_{cb} = N_s / T_b = 1/T_s\ [bps]$.

A second block called a transmission coder applies an integer-valued code

$$\mathbf{c} = (\ldots, c_0, c_1, \ldots, c_j, c_{j+1}, \ldots) \quad (3)$$

to the binary sequence

$$\mathbf{a} = (\ldots, a_0, a_1, \ldots, a_j, a_{j+1}, \ldots) \quad (4)$$

and generates a new sequence $\mathbf{d}$.

$$\mathbf{d} = \mathbf{c}T_c + \mathbf{a}\varepsilon \quad (5)$$

where, T_c and ε are constant terms that satisfy condition $c_j T_c + \varepsilon < T_s$ for all c_j. The coded real-valued sequence $\mathbf{d}$ enters a third system, the PPM modulator, which generates a sequence of unit pulses at a rate of $R_p = N_s / T_b = 1/T_s\ [pps]$. These pulses are located at times $jT_s + d_j$. The carrier frequency of this scheme is determined by multiplying the chaotic source. Above all, for chaotic source property, center frequency and bandwidth required to standard are generated easily. Chaotic oscillator makes a center frequency shift and the chaotic filter determines the bandwidth likely spectrum mask.

C. DS Chaotic System

Signals with an ultra wide bandwidth can be generated by first coding the binary sequence to be transmitted with pseudorandom or specialized sequences for UWB OOK system [2]. In detail, the above signal can be generated data format shown in Fig. 3. Given the binary sequence to be transmitted

$$\mathbf{b} = (\ldots, b_0, b_1, \ldots, b_k, b_{k+1}, \ldots) \quad (6)$$

and generated at a rate of $R_b = 1/T_b\ [bps]$, the first part repeats each bit N_s times and generates a binary sequence

$$(\ldots, b_0, b_0, \ldots, b_0, b_1, \ldots, b_1, b_k, \ldots, b_k, b_{k+1}, \ldots, b_{k+1} \ldots) = \mathbf{a}^* \quad (7)$$

at a $R_{cb} = N_s / T_b = 1/T_s\ [bps]$. The transmission coder applies a binary code

$$\mathbf{c} = (\ldots, c_0, c_1, \ldots, c_j, c_{j+1}, \ldots) \quad (8)$$

, compose ± 1's and period N_p to the sequence

$$\mathbf{a} = (\ldots, a_0, a_1, \ldots, a_j, a_{j+1}, \ldots) \quad (9)$$

and then generates a new sequence

$$\mathbf{d} = \mathbf{a} \cdot \mathbf{c} \quad (10)$$

N_p is commonly assumed to be equal to N_s. A more general assumption is to set N_p as a multiple N_s. Sequence $\mathbf{d}$ enters a third part, the OOK modulator, which generates a sequence of unit pulses. These pulses are located at times jT_s.

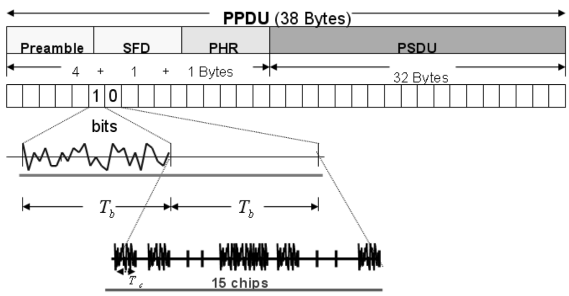

Fig. 3. Packet structures of DS Chaotic signal to determine generating sources

D. Channel Model

An accurate channel model is essential important for correct simulation of system performance. There are several models developed and proposed in last years that address wideband multi-path channels can be applied on UWB systems. Overview of several of such models is given in [3] published by IEEE802.15.4a working group. The IEEE Channel-Modeling sub-committee published a model based on the cluster approach, formalized by Saleh and Valenzuela channel model (S-V model) is not UWB-specific, it was matched for UWB applications with a couple of slight modifications. In addition, independent fading is assumed for each cluster as well as each ray within the cluster. Therefore the multi-path model consists of the following, discrete time impulse response:

$$h_{dist}(t) = \sum_{l=0}^{L} \sum_{k=0}^{K} a_{k,l} \exp\left(j\varphi_{k,l}\right) \delta\left(t - T_l - \tau_{k,l}\right) \qquad (11)$$

where, $a_{k,l}$ is tap weight of the kth component in the lth cluster, T_l is the delay of the lth cluster, $\tau_{k,l}$ is the delay of the MPC relative to the lth cluster arrival time T_l. The phases $\varphi_{k,l}$ are uniformly distributed, i.e., for a bandpass system, the phase is taken as a uniformly distributed random variable form the range $[0, 2\pi]$. There are five different channel models; Residential environment, Indoor office environment, Outdoor environment, Open outdoor environment and Industrial environment. Especially, for Indoor office environment applied to this simulation, we estimated that test room filed environment is matched to this channel model. And its parameters are presented in TABLE I .

E. Path-loss Model

The path loss in a narrowband system is conventionally defined as

$$PL(d) = \frac{E\{P_{Rx}(d, f_c)\}}{P_{Tx}} \qquad (12)$$

where, P_{Tx} and P_{Rx} are transmit and receive power, respectively, as seen at the antenna connectors of transmitter and receiver d is the distance between transmitter and receiver, f_c is the center frequency, and the expectation $E\{\ \}$ is taken over an area that is large enough to allow averaging out of the shadowing as well as the small scale fading. To simplify computations, we assume that the path loss as a function of the distance and frequency can be written as a product of the terms

$$PL(f, d) = PL(f)PL(d) \qquad (13)$$

The frequency dependence of the path loss is given as

$$\sqrt{PL(f,d)} \propto f^{-k} \text{ and } PL(d) = PL_0 + 10n\log_{10}\left(\frac{d}{d_0}\right) \qquad (14)$$

where, the reference distance d_0 is set to 1m, and PL_0 is the path loss at the reference distance. n is the path loss exponent.

TABLE I

THE IEEE UWB CHANNEL MODEL CHARACTERISTICS FOR OFFICE INDOOR SCENARIOS

	Office			
	LOS	NLOS	comments	
Pathloss				
n	1.63	3.07		
σ_S	1.9	3.9		
PL_0 [dB]	35.4	59.9		
A_{ant}	3 dB	3 dB		
κ	0.03	0.71		
Power delay profile				
$\bar{L}$	5.4	1	The NLOS case is described by a single PDP shape	
Λ [1/ns]	0.016	NA		
λ_1, λ_2 [1/ns], β	0.19, 2.97, 0.0184	NA		
Γ [ns]	14.6	NA		
k_γ	0	NA		
γ_0 [ns]	6.4	NA		
$\sigma_{cluster}$ [dB]		NA		
Small-scale fading				
m_0	0.42dB	0.50dB		
k_m	0	0		
$\hat{m}_0$	0.31	0.25		
$\hat{k}_m$	0	0		
$\tilde{m}_0$				
χ	NA	0.86		
γ_{rise}	NA	15.21		
γ_1	NA	11.84		

F. Receiver and Signal Detection

To detect the received signal is important. This is because non-coherent system which is not including the PLL to synchronize the clock has weakness for channel distortion. But, in UWB systems, simple receiver is more important in order to have low cost and low power consumption than hard complexity system can recover the transmitted signals. And these issues that need to be taken into consideration whenever making a decision in the technique to be used [4]. In non-coherent communication systems, the channel estimation is based only on signal envelope. There are several demodulation or detection techniques that could be implemented, such as simple energy detection. In Fig. 4 the envelope of received signals into 4 over-sampled in which the pulse duration of IR chaotic and chip duration of DS chaotic signal are shown.

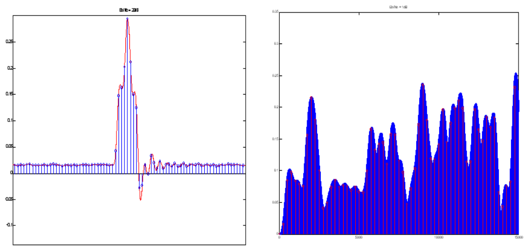

Fig. 4. Four over-sampled received signals (a) IR chaotic signal (b) DS chaotic signal

III. SYSTEM PERFORMANCE

Non-coherent demodulation, such as envelope detection or square-law detection, is commonly used to decrease the complexity and cost of the receivers. Therefore, if the transceiver complexity and cost are the primary concerns, a scheme that enables non-coherent demodulation OOK should be considered. When considering the reflection, diffraction and scattering effects, we knew that the transmitted signal arrives at the receiver which suffers multiple paths having different delays. The chaotic signal in an indoor channel that employs a chaotic pulse of the form of

$$C(t) = \int_{0}^{T_C} c(\tau) d\tau \quad (15)$$

The received IR Chaotic UWB signal which exists in continuous time can be written as symbol mapping and system scheme in Fig. 5. The PHY symbol can be expressed with the following equations (16) ~ (17).

$$x^{(k)}(t) = c(t)\left[p(t - g_0^{(k)} T_{PPM} - H^{(k)} T_{DC} \right] \quad (16)$$

where, $$p(t) = \begin{cases} 1; |t| \le \frac{T_{DC}}{2} \\ 0; \quad other \end{cases} \quad (17)$$

$x^{(k)}(t)$ is the waveform of the k^{th} information bearing symbol, g_0 and g_1 are the modulation symbols obtained from a mapping of the coded bits, $p(t)$ is the transmitted pulse shape at the input to the antenna, T_{PPM} is the time shift occurred due to the change of g_0 symbol type, T_{DC} is the spreading chips time and $H^{(k)}$ is the hopping sequence. Through the symbol expression, the received signal quantized to over-sampling is represented as,

$$y(n) = \sum_{l=0}^{L-1} h(l,n) x(n - \tau_l) + n(n) \quad (18)$$

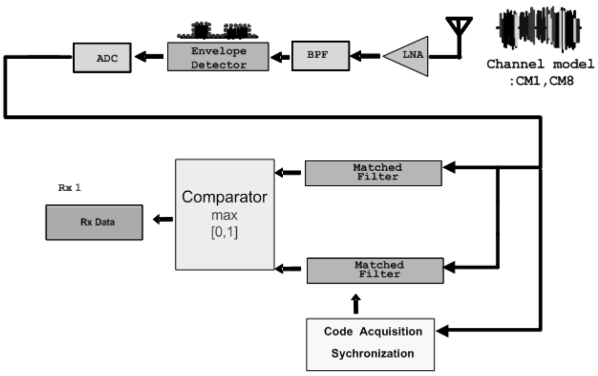

Fig. 5. IR chaotic communication scheme

The schematic diagram of the proposed non-coherent chaotic spread spectrum communication scheme is shown in Fig. 6. The information signal is spread on to N consecutive samples of the transmitted chaotic signal. The resulting chaotic signal is directly converted to the desired radio frequency band in the chaotic unit. Thus, channel distorted signal can be equalized by scaling the estimated mean with the inverse of the channel gain. The estimate of the transmitted symbol can be given as,

$$y(n) = \sum_{m=0}^{L-1} \frac{x_m(n)}{\sum_{l=0}^{L-1} h(l,n)} + \sum_{m=0}^{L-1} \frac{n_m(n)}{\sum_{l=0}^{L-1} h(l,n)} \quad (19)$$

where, $y(n) = \sum_{l=0}^{L-1} h(l,n)$ is the channel gain and N is the processing gain of the chaotic spread spectrum system. Practically, the demodulation process can be simplified by applying a threshold μ.

$$d = \begin{cases} 1, if \ \hat{y} > \mu \\ 0, if \ \hat{y} \le \mu \end{cases} \quad (20)$$

And TABLE II displays the parameters which show bisymmetric comparison of the system parameters between the two systems.

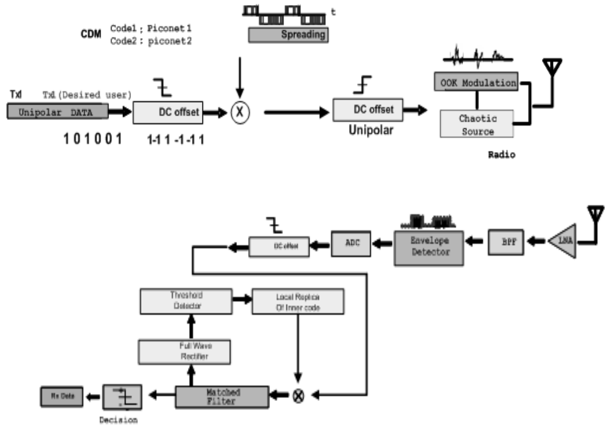

Fig. 6. DS chaotic communication scheme

TABLE II

SYSTEM PARAMETERS

	IR Chaotic	DS Chaotic
Data rate [bps]	1Mbps	1Mbps
Packet Length [byte]	32byte	32byte
Bit time [sec]	486n	1024n
Modulation	PPM-OOK	DS-OOK
Demodulation	Non-coherent	Non-coherent
Sampling Freq. [Hz]	30G	20G
Bandwidth [Hz]	0.5G	0.5G
Center Freq. [Hz]	4G	4G

IV. EXPERIMENT RESULTS

First, in this section, we study the performance of the proposed DS chaotic communication and IR chaotic scheme adopted IEEE802.15.4a standard. For the same channel environment, the packet error rate (PER) of the envelop detection receivers with being non-coherent method are plotted. Here, we can kwon that the two differences in which the results of simulation and real measurement are compared in Fig. 9. PER measured at real test room and PER obtained through the computer simulation which used the channel model defined IEEE802.15.4a standard are found that their results are depend on how to be given status as an environments, that is, channel condition. DS chaotic is more sensitive for the given channel because the spreading chips are experienced the channel distortion on many different paths, whereas, they can recover the damage caused path loss which means power decreasing.

While, IR chaotic system is mainly affected on power attenuations as increasing or decreasing of the distances.

A. Test Environments

In this paper, channel model is applied indoor office NLOS environment defined IEEE802.15.4a standard. And PER of the real indoor office environment using the platforms which have compatible IR and DS chaotic system is depicted in Fig. 7. The test room is consisting of block such as wall or partition to obtain the multi-path effect and has many gates made of iron which can cause decreasing signal strength and changing traveling direction. For Fig. 7, as shown that measured distance is 30meter and written 'A', 'B', 'C', 'D' and 'E' are areas which can be considered various channel conditions. The dotted Black Arrow represented SOI moving path. In Fig. 8, the real test of platform described in picture was performed between the system of interest (SOI) and Anchor 3 having the DS and IR transceiver platforms.

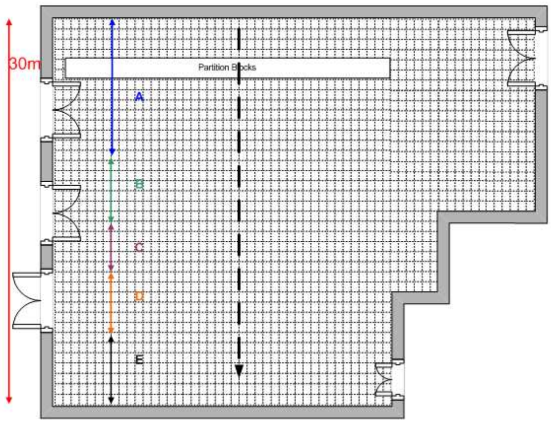

Fig. 7. Indoor Office channel environment set up for the BER and PER measurements

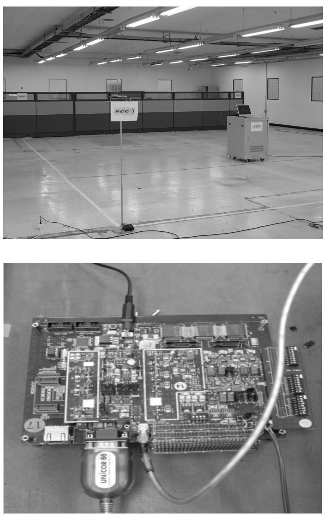

Fig. 8. Test room and platform for field test

B. Performance

In this paper the PER simulation is executed 1000 packets and 100 loops for repetition. From Fig. 9, it is noted the curves of measured and simulated data are shown. In case of the PER of measured DS-chaotic graph, it is described that the curve is changing as given different the channel condition made by the area 'A', 'B', 'C', 'D' and 'E' . The first change of the curve is found the range of 11m~13m in the area of 'A'. And the second one is represented in the spacing of 15m~17m. Its gap is the same as door spacing. Other indexes are expressed in Fig. 9. Differently the PER of Measured DS-chaotic, the PER of measured IR-chaotic has higher packet error rate as the increasing distance due to power attenuation. Thus, DS system is sensitive channel environment and IR one is dependent on power loss.

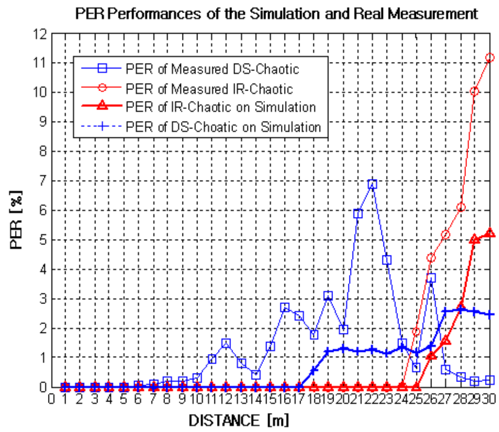

Fig. 9. PER performances of the simulation and real measurement

V. CONCLUSION

In this paper, through the comparison of two system, DS-chaotic system and IR-chaotic, we known that DS-chaotic signal is affected channel environment more than IR-chaotic signal. And IR-chaotic signal is dependent on the change of distance indicated signal power's increase and decrease. Thus, using the characteristics of two systems, we can determine the feasibility and compatibility of sensor network system. Especially, we can see that the chaotic sources have many advantages of power and frequency control for the application sides. Thus, we have to use the advantage and disadvantage of two systems complementarily to adapt the channel variation.

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