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A SWITCHING SCHEME BETWEEN CONVENTIONAL AND CHAOS-BASED COMMUNICATION SYSTEMS

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Abstract: Many communication systems based on the synchronization of chaotic systems have been proposed as an alternative spread spectrum modulation that improves the level of privacy in data transmission. However, due to the lack of robustness of complete chaotic synchronization, even minor channel impairments are enough to hinder communication. In this paper, we propose a communication system that includes an adaptive equalizer and a switching scheme to switch between a chaos-based modulation and a conventional one. Preliminary simulation results show that the switching and equalization algorithms can successfully recover the transmitted sequence in different non-ideal scenarios.

keywords: Analysis and Control of Nonlinear Dynamical Systems with Practical Applications, Chaos and Global Nonlinear Dynamics, Synchronization in Nonlinear Systems.

1. INTRODUCTION AND FORMULATION

In a digital chaos-based communication system (CBCS), each bit of information is transmitted using a different fragment of a chaotic signal [1–3]. Thus, it differs fundamentally from the conventional digital communication systems, where each symbol is associated with a constant and predefined waveform. Although CBCSs may have interesting features, like an improvement in security [4, 5], they can present poor performance in terms of bit error rate (BER) when compared with conventional communication systems. Inspired, for instance, by Wireless Fidelity (Wi-Fi) technology, which switches the modulation depending on the communication channel quality, we propose an algorithm to switch between the chaos-based communication system and the conventional one, which can ensure a low BER in different non-ideal scenarios.

The CBCS under consideration is shown in Fig. 1 [15, 18], where a binary signal $m(n) \in \{-1, +1\}$ is encoded by using the first component of the master state vector $\mathbf{x}(n)$, via a encoding function $s(n) = c\,(x_1(n), m(n))$, so that $m(n)$ can be recovered using the inverse function with respect to $m(n)$, i.e., $m(n) = c^{-1}\,(x_1(n), s(n))$. Then, the signal $s(n)$ is fed back into the CSG and transmitted through a communication channel. We assume an M-tap adaptive equalizer, with input regressor vector $\mathbf{r}(n)$ and output $\hat{s}(n) = \mathbf{r}^T(n)\mathbf{w}(n-1)$, where $(\cdot)^T$ indicates transposition and $\mathbf{w}(n-1)$ is the equalizer weight vector. The equalizer must mitigate the intersymbol interference (ISI) introduced by the channel and recover the encoded signal $s(n)$ with an unavoidable delay of Δ samples.

Under some conditions, the message $m(n)$ can be recovered by minimizing the square of the estimation error $e(n) = m(n-\Delta) - \hat{m}(n)$[18]. We are assuming that there is a training sequence $\{m(n-\Delta)\}$, known in advance at the receiver. In this case, the equalizer works in the *training mode* and updates its coefficients in a supervised manner, using the estimation error in conjunction with an adaptive algorithm. If we intend to transmit information using $m(n)$, the receiver will not have access to $\{m(n-\Delta)\}$ and this sequence will be replaced by the output of the decision device [6, 22]. In this case, the equalizer works in the so-called *decision-directed*

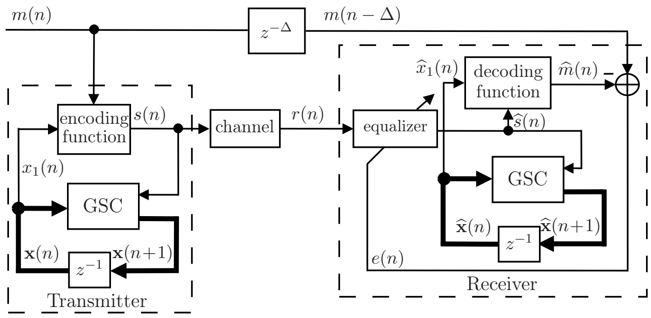

Figure 1 – Chaos-based communication system with an equalizer.

Table 1 – Operation modes of the switching algorithm.

Number	Modulation	Training or decision-directed
1	BPSK	Training
2	Chaotic	Training
3	Chaotic	Decision-directed
4	BPSK	Decision-directed

mode.

In this paper, the Hénon map [19] is used in both CSGs of Fig. 1. Therefore, the equations governing the global dynamical system can be written as

$$\mathbf{x}(n+1) = \mathbf{A}\mathbf{x}(n) + \mathbf{b} + \mathbf{f}\left(s(n)\right), \tag{1}$$

$$\widehat{\mathbf{x}}(n+1) = \mathbf{A}\widehat{\mathbf{x}}(n) + \mathbf{b} + \mathbf{f}\left(\hat{s}(n)\right), \tag{2}$$

where $\mathbf{x}(n) \triangleq [x_1(n) \quad x_2(n)]^T$, $\widehat{\mathbf{x}}(n) \triangleq [\widehat{x}_1(n) \quad \widehat{x}_2(n)]^T$,

$$\mathbf{A} = \begin{bmatrix} 0 & 1 \\ \beta & 0 \end{bmatrix}, \mathbf{b} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}, \mathbf{f}\left(s(n)\right) = \begin{bmatrix} -\alpha s^2(n) \\ 0 \end{bmatrix}, \tag{3}$$

being α and β real constant parameters of the map.

In order to encode the message, we use the function proposed in [21] and given as

$$s(n) = \gamma_1 x_1(n) - \gamma_2\left[m(n) + 1\right] \text{sign}\left[\gamma_1 x_1(n)\right], \tag{4}$$

where γ_1 and γ_2 are positive constants and sign$[\cdot]$ is the signal function. The corresponding decoding function is

$$\widehat{m}(n) = \frac{\gamma_1(n)\widehat{x}_1(n) - \widehat{s}(n)}{\gamma_2(n)\text{sign}[\gamma_1(n)\widehat{x}_1(n)]} - 1. \tag{5}$$

The equalization algorithm is obtained following the same steps of [18], but assuming (4) as encoding function.

Finally, for each block of L samples, the switching is triggered based on a threshold applied to the mean square error (MSE), i.e.,

$$\text{MSE}(n_0) = \frac{1}{L}\sum_{k=n_0}^{n_0+L-1} e^2(k),$$

with $n_0 = 0, L, 2L, \cdots$. We consider four states for the switching as shown in Table 1, where BPSK stands for binary phase-shift keying. If MSE is greater than -30 dB, BPSK is used. On the hand, when the channel conditions get better and MSE becomes lower than -30 dB, the system returns to the chaotic regime.

2. SIMULATIONS

Considering the communication system using the Hénon map with parameters $\alpha = 1.4$ and $\beta = 0.3$, we show next an example to illustrate the proposed switching scheme. In this simulation, the state vectors were initialized with $\mathbf{x}(0) = \mathbf{0}$ and $\widehat{\mathbf{x}}(0) = [\,0.1 \quad -0.1\,]^T$, respectively and we assume the transmission of a binary message $m(n) \in \{-1,\ +1\}$ with the equalizer initialized as $\mathbf{w}(-1) = \mathbf{0}$.

We first assume that the encoded sequence $s(n)$ is initially transmitted through Channel 1 with transfer function $H_1(z) = -0.005 + 0.009z^{-1} - 0.024z^{-2} + 0.850z^{-3} - 0.218z^{-4} + 0.050z^{-5} - 0.016z^{-6}$, which is changed abruptly at $n = 150 \times 10^3$ to Channel 2 with transfer function $H_2(z) = -0.004 + 0.030z^{-1} - 0.104z^{-2} + 0.520z^{-3} + 0.273z^{-4} - 0.074z^{-5} + 0.020z^{-6}$ and changed back to Channel 1 at $n = 300 \times 10^3$, in the absence of noise [18, 24].

Figure 2 shows the errors in the recovered message (a), the squared error (b), and the operation mode of the communication system (c), according to Table 1. For the first iterations, when Channel 1 is used, we can observe that the system switches to chaotic modulation in decision-directed mode (State 3), after a brief transient. During this transient, there are some wrong estimations of $m(n)$ but after the switching algorithm stabilizes in State 3, the message is recovered without errors. After the abrupt variation to Channel 2 at $n = 150 \times 10^3$, the algorithm switches to BPSK modulation in decision-directed mode (State 4), after a transient period. This is due to the fact that Channel 2 inserts more ISI than Channel 1, hindering the utilization of the chaotic modulation, as we can notice by the squared error level. When the communication channel is changed back to Channel 1, at $n = 300 \times 10^3$, the algorithm switches back to chaotic modulation in decision-directed mode (State 3), after a transient period.

3. CONCLUSION

In this paper, we proposed an adaptive scheme that switches between the chaos-based communication system and the conventional one. The switching is triggered based on a threshold applied to the MSE. Simulation results show that the switching and equalization algorithms can successfully recover the transmitted sequence.

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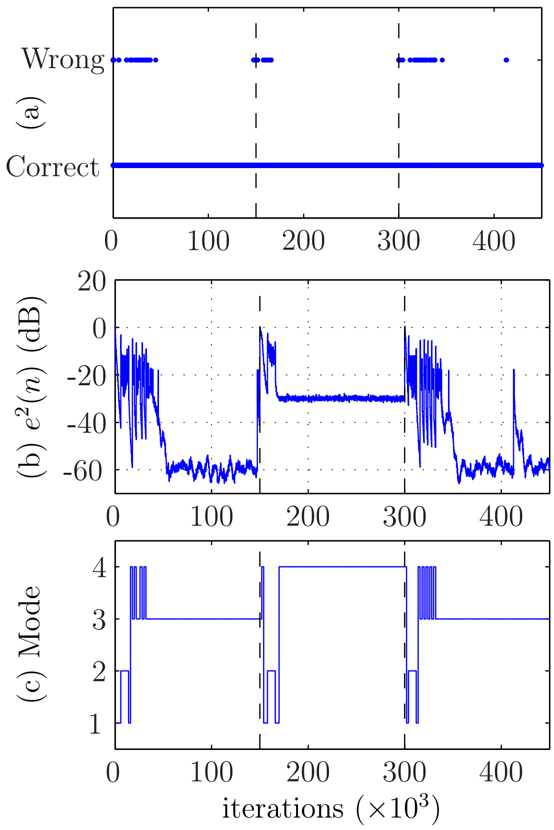

Figure 2 – (a) Errors in the recovered message, (b) squared error, and (c) operarion mode according to Table 1 along iterations. Communication system using the Hénon map and the switching schemed described. Abrupt variation from Channel 1 to Channel 2 at $n = 150 \times 10^3$ and from Channel 2 back to Channel 1 at $n = 300 \times 10^3$

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