1. Introduction

Many works have recently described digital modulations using chaotic carriers. In general, though, they largely underperform their equivalent conventional counterparts under Additive White Gaussian Noise (AWGN) channel conditions. The first objective of this chapter is to comparatively review and evaluate the performance of chaos-based systems by means of their discrete-time low-pass equivalents with particular emphasis on Chaos Shift Keying (CSK), Differential CSK (DCSK) and some of their variants (Section 2) as they provide clues to the low performance of chaotic modulation and thereby pave the way for result improvement.

A natural system improvement step is examined in Section 3 by explicitly using generating map information to estimate the received noise-embedded chaotic signal leading to better Bit Error Rate (BER) performance. This is done by contrasting two techniques (a) Maximum Likelihood Estimation (MLE) and (b) the Modified Viterbi Algorithm (MVA) under discrete-time one-dimensional chaotic maps.

After arguing for MVA’s superior qualities in practice we illustrate the results for the Modified Maximum Likelihood Chaos Shift Keying (MMLCSK) using one and two maps (Section 4) both of which have better symbol error rate characteristics than previous noncoherent chaos communication schemes.

The intended chapter structure closely follows the section division adopted in this extended abstract.

2. Digital modulations using chaotic carriers: a review

Interest in chaotic signals for Telecommunication Engineering applications is associated with their intrinsic wideband character added to the fact that the cross-correlations of chaotic signals generated by different initial conditions are low (Kennedy et al., 2000; Kennedy & Kolumban, 2000; Stavroulakis, 2005; Lau & Tse, 2003) which makes them natural candidates for use as information spreading signals in spread spectrum communication systems (Lathi, 1998; Lau & Tse, 2003).
As a result, a large number of chaos-based digital modulations (see e.g. (Lau & Tse, 2003; Kennedy et al., 2000) and references therein) have been proposed. Alas, their performance is worse than that of conventional digital modulation schemes in terms of BER for AWGN channels.

This section's final version will describe and analyze various recently proposed digital modulation systems using chaos via their low-pass discrete-time equivalent models. This will be used to explain why they perform poorly in AWGN channel and hint as to what one can do to improve. The unified discrete-time approach is a direct extension of the approach in (Kolumban et al., 1997; 1998) who do their analysis in continuous time which is inconvenient when working with chaotic maps.

A summary of the currently available chaos-based systems is provided in Table 1 where the X marks system shortcomings. The Threshold column concerns the problem of decision threshold dependence on the level of the noise power of the channel. The Energy column indicates the problem of energy per symbol variability whereas the Sync. column is a reminder of the need of recovering chaotic functions basis at the receiver. The last column (Map Info) notes the fact that the modulation does not use the properties of the chaotic attractor in the estimation of the transmitted symbol.

Table 1. Problems of chaotic modulations studied in the section.

<table>
<thead>
<tr>
<th>System</th>
<th>Threshold</th>
<th>Energy</th>
<th>Sync.</th>
<th>Map Info</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coherent CSK</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Noncoherent CSK</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>DCSK</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>FM-DCSK</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Among latter modulations, the Frequency Modulated-DCSK (FM-DCSK) is the best choice as it dispenses with chaotic synchronization, is decision threshold independent and its average energy per symbol is constant.

The analyzed non-coherent and differential receivers have a common feature: they do not use any characteristic of the dynamics of the system that generates chaotic signals for demodulation and are limited to estimating received signal characteristics which are compared to a properly chosen decision threshold.

We argue that a priori knowledge of the generating maps can be profitably used in two ways by the receiver:

1. via synchronization in coherent demodulators or
2. to improve effective received signal to noise ratio.

In the presence of noise and/or channel distortion, chaos synchronization performs poorly as consequence of its sensitive dependence on initial conditions (Lau & Tse, 2003; Kennedy et al., 2000). Hence, the remainder of the chapter is devoted to the the second alternative.

3. Estimation of chaotic signals

To improve the effective received signal to noise ratio, we recast the issue as an estimation problem (Eisencraft & Baccalá, 2008) where an N-point sequence \( s'(n) \) is observed and modeled as \( s'(n) = s(n) + w(n), 0 \leq n \leq N - 1 \), where \( s(n) \) is an orbit of the one-dimensional
system $s(n) = f(s(n - 1))$ and $w(n)$ is zero mean AWGN with variance $\sigma^2$. The $f(.)$ map is defined over an interval $U$ and the goal is to estimate $\hat{s}(n)$ of the orbit $s(n)$.

The final chapter version will describe and compare two approaches: (a) Maximum Likelihood Estimation (MLE) (Papadopoulos & Wornell, 1993) and (b) the Modified Viterbi Algorithm (MVA) (Kisel et al., 2001; Eisencraft et al., 2009) whose estimation gains for tent map orbits corrupted by AWGN is shown in Figure 1 which covers the usual operating SNR $\leq 20$ dB range where MVA’s performance is superior.

These results, plus the fact that MVA can be applied to broader map classes have induced its choice in the communication applications illustrated in the section that follows.

4. Chaotic signals estimation: applications in communication

In the final version this section is to illustrate MVA for the Modified Maximum Likelihood Chaos Shift Keying (MMLCSK) modulation in the cases of using one and two maps which are based on those proposed by (Kisel et al., 2001) after proper modification for using nonuniform partitions as required for MVA.

4.1 MMLCSK using two maps

In this system, each symbol is associated with a different map $f_1(.)$ and $f_2(.)$. To transmit a 0, the transmitter sends an $N$-point orbit $s_1(.)$ of $f_1(.)$ and to transmit a 1, it sends an $N$-point orbit $s_2(.)$ of $f_2(.)$.

Maps must be chosen so that their state transition probabilities matrix $A_1$ and $A_2$ are different. Estimating $s_1(n)$ using MVA with $A_2$ must produce a small estimation gain or even a negative (in dB) one. The same must happen when trying to estimate $s_2(n)$ using $A_1$.

The receiver for MMLCSK using two maps is shown in Figure 2 where Viterbi decoders seek to estimate the original $s(n)$ using $A_1$ or $A_2$. For each symbol, the estimated state sequences are $\hat{q}_1$ and $\hat{q}_2$.

4.2 MMLCK using one map

As an alternative, it is possible to construct a communication system based on MVA estimation using just one map. In this case, according to the symbol that is intended to be communicated, the chaotic signal is directly transmitted or an invertible transformation is applied on the
sequence. This operation must modify the sequence so that there is no more than one single valid orbit of the used map.

In the binary case, for maps that are not odd, this transformation can be, for instance, $T(s) = -s$ which can be undone multiplying again the sequence by $-1$. To transmit a 0, we send an $N$-point orbit $s_1(.)$ of $f_1(.)$. To transmit a 1, we send $-s_1(.)$. The receiver for this system is shown in Figure 3.

In the final version of the chapter will contain numerical results for the BERs attained by both versions of the MMLCSK for a large range of SNRs which turn out to be lower than those attained by the chaotic modulations described in Section 2.

5. Concluding Remarks

Final comments will be gathered a final chapter section.

6. References


