Chaos Communication Performance Analysis: Taking Advantage of Statistical Theory

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Abstract—This paper seeks to outline and illustrate the statistical basis of performance modelling of chaos-based communication systems. It is argued that likelihood decoding of message bits and theoretical derivation of decoder error probability leads to exact results and enhanced engineering insights. Moreover, the exact results, replacing earlier Gaussian approximations, suggest ways to optimally design such systems. The main emphasis will be on coherent chaos shift-keying communication, both in its single- and multiple- user versions.

I. INTRODUCTION

Chaos-based communication involves using segments of chaotic waves to carry messages rather than the traditional sinosoidal waves. A highly informative set of papers on the topic [1], [2], [3], [4], [5], [6] was published in 2002 as a special issue of the *Proceedings of the IEEE*. These papers diversely portrayed the area as it was emerging at the time. More recently there have been a linked pair of monographs [7], [8] taking a more unified view involving simple Gaussian approximation (SGA) and simulation. As evidenced by the mentioned publications, many of the key developments in chaos-communications are due to the authors: Hasler, Kennedy, Kolumban, Lau, Mazzini, Rovatti, Schimming, Setti, Sushchik, Swartz, and Tse, and these motivate the statistical emphasis of this paper. The aim here is more specialized and is to reveal the role of statistical theory in giving useful and interpretable exact performance results, and thereby to emphasise the engineering gains which can be obtained from this perspective. Earlier results which were transfered from conventional communication systems or derived with SGA did not fully incorporate the new joint chaotic-statistical interplay and sometimes tended to under-appreciate or over-complicate theoretical matters. A particular feature of chaos communications systems is the interplay of dynamical and statistical behaviour, and more particularly, the statistical aspects of chaotic spreading and channel noise. One aim here is to show simple and interpretable exact-based results combining both these aspects, as opposed to earlier computational and approximate results. A grander aim of the paper is to demonstrate the beneficial impact of statistical skills and insights in communications engineering and hopefully more generally in nonlinear electronic engineering.

Key questions, particularly to those unfamiliar with the area, are "what is chaos and why chaos communications?" Very briefly, by chaos is meant sequences of numerical values, either sequentially generated by special nonlinear mathematical recursions, or generated by physical electronic means, exhibiting statistical chaotic signatures, such as Lyapunov exponents measuring sensitivity to starting values. Although essentially deterministic, they exhibit statistical characteristics. Chaos communications uses such chaotic sequences, which can be apparently noisy with spread spectra, to carry message bits; they replace conventional sinosoidal carriers, and have further layers of security and robustness. Concerning the need for chaos communications when there are already highly developed conventional communication technologies, this has to be in specialized secure or challenging environments. An area now emerging is that of laser-chaos communications where synchronized chaos is generated by lasers.

By expanding a little on chaotic sequences, their use in the area can be explained and maybe de-mystified. Theoretically, mathematical chaos is generated recursively by chaotic maps, special kinds of mathematical function, such as shift, quadratic or Tchebyshev maps, see [9] for instance. Providing one does not know their method of generation, these sequences appear statistical. They can be linearly autouncorrelated or not, and also may or may not be nonlinearly autocorrelated. But always the sequences are functionally dependent, and thus the opposite, one might say, of independent and identically distributed values. As well as being easy to numerically simulate, they have a distinct advantage in that their use in theoretical performance assessment calculations involves only one-dimensional integrals, rather than otherwise often intractable many-dimensional integrals. The statistical invariance theory of the sequences dealing with their stationarity is elegantly covered in [10] and is distinct from the dynamical theory dealing with their path behaviour of divergence and bifurcation [9]. Another useful point to make is that quantizing a chaotic sequence destroys its chaotic behaviour while just modifying its statistical behaviour. A particular case is the way a congruential random number generator can be seen as a quantitized form of a chaotic shift map.

Although a limitation, the paper is restricted to employing discrete rather than continuous time. In some ways this is unnatural for communications, but the modelling undertaken is in discrete time and most processes are observed in discrete time. Such modelling is referred to as discrete time baseband. The models to be presented are mathematical extractions of real systems, without electronic intricacies, but never-the-less will allow theoretical investigation of performance and design issues.

The subject of chaos-based communications has been developing somewhat independently in its theoretical and practical respects over recent years. Theoretical work in physics and electronics is now well-advanced and

Statistical Theory Of Communication

I. Ravi Kumar

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