

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 sinusoidal 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, Rovati, 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 transferred 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 sinusoidal 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 autocorrelated 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 quantized 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

Y. W. Lee



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seminal reference particularly for anyone working in the field of communications as well as in other areas of statistical physics Originally published in 1960 **The Statistical Theory of Communication Aids Mechanical Engineering Design** Jan R. Schnittger,1984 **Non-Gaussian Statistical Communication Theory** David Middleton,2012-05-11 The book is based on the observation that communication is the central operation of discovery in all the sciences In its active mode we use it to interrogate the physical world sending appropriate signals and receiving nature's reply In the passive mode we receive nature's signals directly Since we never know a priori what particular return signal will be forthcoming we must necessarily adopt a probabilistic model of communication This has developed over the approximately seventy years since its beginning into a Statistical Communication Theory or SCT Here it is the set or ensemble of possible results which is meaningful From this ensemble we attempt to construct in the appropriate model format based on our understanding of the observed physical data and on the associated statistical mechanism analytically represented by suitable probability measures Since its inception in the late 30's of the last century and in particular subsequent to World War II SCT has grown into a major field of study As we have noted above SCT is applicable to all branches of science The latter itself is inherently and ultimately probabilistic at all levels Moreover in the natural world there is always a random background noise as well as an inherent a priori uncertainty in the presentation of deterministic observations i.e. those which are specifically obtained a posteriori The purpose of the book is to introduce Non Gaussian statistical communication theory and demonstrate how the theory improves probabilistic model The book was originally planned to include 24 chapters as seen in the table of preface Dr Middleton completed first 10 chapters prior to his passing in 2008 Bibliography which represents remaining chapters are put together by the author's close colleagues Drs Vincent Poor Leon Cohen and John Anderson email pressbooks@ieee.org to request Ch 10 *Compr. Statistical Theory of Communication* I. Ravi Kumar,2001 **An Introduction to Statistical Communication Theory** John Bowman Thomas,1969 **Statistical Communication Theory and Applications** Harold Roy Raemer,1969 *Statistical Theory of Signal Detection* Carl W. Helstrom,2013-10-22 Statistical Theory of Signal Detection Second Edition provides an elementary introduction to the theory of statistical testing of hypotheses that is related to the detection of signals in radar and communications technology This book presents a comprehensive survey of digital communication systems Organized into 11 chapters this edition begins with an overview of the theory of signal detection and the typical detection problem This text then examines the goals of the detection system which are defined through an analogy with the testing of statistical hypotheses Other chapters consider the noise fluctuations in terms of probability distributions whereby the statistical information is used to design a receiver that attains the maximum rate of successful detections in a long series of trials This book discusses as well the criteria of success and failure in statistical situations The final chapter deals with the types of stochastic signals This book is a valuable resource for mathematicians and engineers **Statistical Communication Theory and Its Applications** Boris Ruvimovich Levin,1982 [Statistical Theory Applied to](#)

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1. Understanding the eBook Statistical Theory Of Communication
 - The Rise of Digital Reading Statistical Theory Of Communication
 - Advantages of eBooks Over Traditional Books
2. Identifying Statistical Theory Of Communication
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Statistical Theory Of Communication
 - User-Friendly Interface
4. Exploring eBook Recommendations from Statistical Theory Of Communication
 - Personalized Recommendations
 - Statistical Theory Of Communication User Reviews and Ratings
 - Statistical Theory Of Communication and Bestseller Lists
5. Accessing Statistical Theory Of Communication Free and Paid eBooks

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 - Statistical Theory Of Communication Budget-Friendly Options
6. Navigating Statistical Theory Of Communication eBook Formats
 - ePub, PDF, MOBI, and More
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 - Statistical Theory Of Communication Enhanced eBook Features
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 - Adjustable Fonts and Text Sizes of Statistical Theory Of Communication
 - Highlighting and Note-Taking Statistical Theory Of Communication
 - Interactive Elements Statistical Theory Of Communication
 8. Staying Engaged with Statistical Theory Of Communication
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Statistical Theory Of Communication
 9. Balancing eBooks and Physical Books Statistical Theory Of Communication
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Statistical Theory Of Communication
 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
 11. Cultivating a Reading Routine Statistical Theory Of Communication
 - Setting Reading Goals Statistical Theory Of Communication
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Statistical Theory Of Communication
 - Fact-Checking eBook Content of Statistical Theory Of Communication
 - Distinguishing Credible Sources
 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development

- Exploring Educational eBooks
- 14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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