A Complex System Characterization of Modern Telecommunication Systems: Application to ATM Services

by

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This dissertation was prepared under the direction of the candidate's dissertation advisor, Dr. Perambur S. Neelakanta, Department of Electrical Engineering, and has been approved by the members of his supervisory committee. It was submitted to the faculty of the College of Engineering and was accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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Abstract

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The research addressed and reported in this dissertation primarily refers to the scope of characterizing modern telecommunication services as complex systems. The qualifying attributes, which allow such a characterization are three-folded: (i) Size of the network supporting massive traffics; (ii) heterogeneous characteristics of the traffics constituted by a mix of data, voice and video transmissions; and (iii) quality of service (QOS) considerations as met by a variety resources.

Commensurate with the scope of the research indicated above, the underlying principles of information-theoretics are adopted as the background concept of the studies performed and a complexity-metric is defined via entropy considerations. Hence, the following aspects of modern telecommunications are studied: The first one refers to using entropy as a metric to assess the traffic characteristics in ATM telecommunications. Relevant heterogeneous traffic is modeled and analyzed in terms of the complexity-metric. Impairment considerations (such as cell-losses) due to queueing and/or finite-buffer sizes are estimated via information-loss specifications. The results are compared with those of conventional queueing-theoretics based analysis.

The second consideration uses the complexity-metric to implement the so-called call admission control (CAC) in ATM transmissions. The complexity-metric is considered as a decision-theoretic parameter and a fuzzy inference engine is constructed to facilitate a real-time CAC.

The third contribution of this research is pertinent to the development of an artificial neural network (ANN) implemented to perform CAC using the complexity-metric as the training parameter characterizing the input calls, which compete to get admission into the network. The real-time performance of the ANN in such CAC implementations is demonstrated.

The fourth effort of this research is directed to portray the cybernetic perspectives of a complex system. Again, the interacting structure of the technology and economics of telecommunication systems is considered and the associated complexity is elucidated in terms of the entropy profile of the subsystems. Hence, optimized (or suboptimal) alternative designs of a network based on technoeconomical considerations are obtained.

This dissertation also includes relevant literature survey and background details. It concludes with a discussion on the results and inferences on the research carried out. Further, the scope for future study is identified and open-questions are enumerated.

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Chapter 1

Introduction

This introductory chapter outlines the scope of the research pursued and enumerates the objectives of the tasks carried out. Relevant background details and a survey of existing works are presented to portray the significance of the research envisaged

1.1 General

The research pursued as described in this dissertation refers to relevant considerations pertinent to modern telecommunications. Specifically, the subject-matter addresses modeling a telecommunication infrastructure as a complex system; and, a complex-metric, which cohesively represents the complexity profile of the traffic characteristics and the resources deployed, is defined and evaluated. Hence, the use and applications of the complexity-metric are indicated.

The objectives of the research efforts carried out thereof can be briefly summarized as follows:

- Representation of a modern telecommunication service as a complex system
- Development of a complexity-metric to depict the complexity of the telecommunications system in terms of the associated collective attributes of traffic parameters and resource profiles
- Casting and viewing the ATM telecommunications in the perspectives of a complex system, taking into consideration relevant fuzzy and stochastical attributes in the information-theoretic (IT) frame work
- Verification of IT-based analyses against queueing-theoretic (QT) based considerations

- Using the IT-based complexity-metric to establish a threshold measure for call admission control (CAC) strategies in the ATM systems
- Implementation of ATM-CAC using the complexity-metric via a fuzzy inference engine
- Implementation of ATM-CAC using the complexity-metric via neurofuzzy network (artificial fuzzy neural network)
- Presenting an introductory survey on the cybernetic aspects of modern telecommunication systems and developing alternative designs specified via complexity of the associated technoeconomical considerations
- Enumerating open-questions that exist with a deliberation on the scope for further research in the area of interest.

Commensurate with the above goals, this dissertation is written and organized with the details on research performed and results obtained thereof. The present chapter outlines the organization of the dissertation with an elaboration on background considerations as indicated in the following section.

1.2 Background

This is the age of information wherein the telecommunications constitute the backbone architecture for a global information highway — a facilitation that permits a communication "any where, any time and of any type".

As the web of telecommunications spans and spreads through the dissemination efforts involving voice, data and video in an unlimited fashion, the associated traffic characteristics and the resource facility deployed have been grotesquely growing in terms of the associated,

- Size of resources
- Volume of traffics
- Stochasticity of the variables involved

- Interactiveness of the subsystems
- Unclear overlaps of functional attributes
- Underlying economics
- Fast-changing technology
- Societal demands on services.

The result is that the telecommunications of the present time depicts a complex-system. A primary objective of this research is to investigate whether such a representation is a valid connation of the items indicated above. Hence, it is pursued to evaluate a "metric" — a single measure that can cohesively and collectively assay the entwined considerations justifiably. Once such a metric is deduced, the next attempt is to probe the possibilities of using this metric for engineering applications in the telecommunications services in vogue. As a subject-system, the ATM service is considered and studied of its complexity. The associated metric is used thereof in implementing effectively the call admission procedure on real-time basis.

Consistent with the objectives indicated above, it is imperative to study the underlying concepts of complexity in view of relevant considerations available in the literature. Hence, briefed in Section 1.3 is an overview of complex systems and furnished in the subsequent section is a summary of the literature survey on complex systems and the measures of complexity. In the later sections, details on the ATM CAC are reviewed in the context of published works and existing practice on the topic. Also, considered are the pertinent information on fuzzy and stochastical attributes of ATM CAC as deliberated in the state-of-the-art literature.

1.3 Complex-Systems: An Overview

1.3.1 What is a complex system?

In a naïve manner, Haken [1.1] describes complex systems as those "composed of many parts, or elements, or components which may be of the same or different kinds. The components or parts may be connected in a more or less complicated fashion".

Curtis [1.2] describes complexity as " an attribute of the interaction between two systems that describes the resources one system will expend in interacting with the other system". For example, when translated to a large system (such as a telecommunication system) the above definition of complexity aptly describes the intricacies of an assembly in which one subsystem expends its state in deciding the state of another subsystem in a complex manner through spatiotemporal interactions.

Consistent with the fact that complexity refers to a large system with interacting subsystems, the stochastic complexity addresses the notion of algorithm complexity applied to the information structure of the system, defined in terms of the associated probabilistic considerations. As Rissanen [1.3] points out this stochastic complexity is equitable to the algorithmic notion of information described in the classical efforts of Solomonoff [1.4], Kolmogorov and Chaitin, and is almost reduces to the maximum likelihood based predictives.

Quantitatively, in order to compare different complex systems or to evaluate any given complex system, a quantitative entity, say, "a measure of the algebraic degree of complexity" or " algorithmic complexity" is necessary. For example, in the classical Turing (computational) machine, the minimum length of a program and the initial data presented depict the degree of complexity of the machine [1.5]. But, the feasibility of evaluating this degree of complexity (vis-à-vis, Turing machine) is rather questionable in view of Goedel's theorem, which indicates the nonfeasibility of solving for a minimum program and a minimum number of initial data via a universal fashion. This is true in almost all complex systems. However, attempts have been made to find at least appropriate methods of quantifying the complexity using information theory [1.3], statistical mechanics [1.6], equilibrium strategies applied to Markov processes [1.7] etc.

The relation between the algorithmic complexity and information content of a system was originally studied by Fisher [1.8] and the underlying intuitiveness of information has been addressed by Kullback-Leibler [1.9] and Gokhale and Kullback [1.10]. Relevant considerations have been directly linked to the negentropic concept or Shannon's information content.

Another way of formalizing complexity is due to Kolmogorov [1.11], who, as indicated earlier, evolved the concept of algorithmic complexity on the basis of generalized entropy considerations. His concept is important for its ability to distinguish between random and regular sequences. He has enunciated several axioms concerning the complexity aspects of an output sequence resulting from an input sequence and processed by an algorithm implemented on a real or theoretical automaton. The concepts of Kolmogorov complexity can be viewed as a basis for information theory without recourse to probability concepts and also as a theoretical foundation for probability itself. As stated by Li and Vitanyi [1.12], Kolmogorov complexity can be interpreted as the amount of information contained in an object about itself. Typical applications of Kolmogorov's results refer to grammar complexity of computer and natural languages measured via syntactical measures through the general principles of Shannon's perspectives of information (negative entropy). Kolmogorov's complexity has also been applied to study the one-dimensional strings of biological origin, similar to strings originating from computer and/or natural languages [1.13].

Notwithstanding the aforesaid avenues of quantifying the system complexity, pragmatic algorithms representing the system complexity are rather sparse. Hence, attempted here is a systematic formalism of evaluating a complexity parameter using the maximum entropy considerations following the procedure due to Ferdinand [1.14]; and, it is conveniently adopted to describe the "complexity" of telecommunication systems.

Another perspective of complex system is the inherent cybernetics, which allows the design of such systems to operate or function under constraints at least over a bounded regime of the variables involved. In other words, the optimal (or suboptimal) solutions involving, for example the technological factors, economics-based considerations and resource deployment in realizing practical complex systems (such as telecommunications systems) can be viewed in terms of the associated cybernetic issues.

1.4 Existing Research: A Literature Survey

1.4.1 On complex systems and complexity-metric

As indicated above, the considerations and underlying principles of equating entropy of a system to the complexity profile (of the system), have been heuristically proposed in [1.14]. But the pragmatic aspects of applying relevant concepts to complex systems are presented in a few publications [1.15-1.20] as summarized below:

1.4.1.A Ferdinand's model [1.14]

Using the basic principles of information-theory, the error behavior in systems is analyzed in [1.14]. The results indicated thereof are configuration independent and have