

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

**Bell & Howell Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600**

UMI[®]

PREVIEW

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

by

Wichai Deecharoenkul

**A Dissertation Submitted to the Faculty of the
College of Engineering**

**In Partial Fulfillment of the Requirement for the Degree of
Doctor of Philosophy**

**Florida Atlantic University
Boca Raton, Florida
August 2000**

UMI Number: 9969847

Copyright 2000 by
Deecharoenkul, Wichai

All rights reserved.

PREVIEW
UMI[®]

UMI Microform 9969847

Copyright 2000 by Bell & Howell Information and Learning Company.
All rights reserved. This microform edition is protected against
unauthorized copying under Title 17, United States Code.

Bell & Howell Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

© Copyright by Wichai Deechoenkul 2000

PREVIEW

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

by

Wichai Deechareonkul

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.

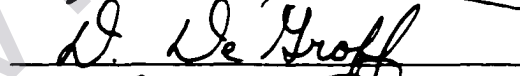
SUPERVISORY COMMITTEE:



Chairperson

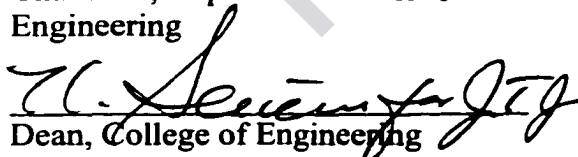





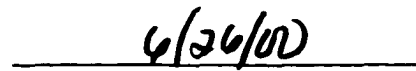





Chairman, Department of Electrical
Engineering


Dean, College of Engineering


Vice Provost


Date

Acknowledgements

I would like to express my sincere thanks to Dr. P.S. Neelakanta for his help and guidance in carrying out of this Ph.D effort.

I also extend my sincere thanks to Dr. Dolores De Groff for her moral and friendly supports throughout my school days at FAU.

I deeply acknowledge the academic help rendered by Drs. Valentine Aalo, Raghavan Sudhakar, Dolores De Groff, and Fernando Medina.

I would like to thank Mr. Joseph Fasulo for his help in developing the computer code used in Chapter 5. I also thank Mr. Patrick Hackett for his help and cooperation.

I gratefully thank my brother, Wisoot Deechoenkul, for his valuable help and support of this Ph.D effort.

I would like to thank my parents for all their encouragement, love, and support, which have been extremely valuable throughout my work.

Finally, I would like to thank my wife, Wandee Deechoenkul, for being always beside me in all my endeavors.

Wichai Deechoenkul

Abstract

Author: Wichai Deecharoenkul
Title: A Complex System Characterization of Modern Telecommunication Systems: Application to ATM Services
Institution: Florida Atlantic University
Dissertation Advisor: Dr. Perambur S. Neelakanta
Degree: Doctor of Philosophy
Year: 2000

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.

Table of Contents

List of Tables	xi
List of Figures.....	xii
Chapter 1 Introduction.....	1
1.1 General	1
1.2 Background.....	2
1.3 Complex Systems: An Overview.....	4
1.4 Existing Research: A Literature Survey.....	6
1.4.1 On complex systems and complexity-metric	6
1.4.2 On fuzzy considerations and fuzzy inference engines.....	8
1.4.3 On call admission control in ATM systems.....	10
1.4.4 On fuzzy inference engines: Applications to ATM CAC.....	22
1.4.5 On neurofuzzy approach to ATM CAC.....	22
1.4.6 On the information-theoretics versus queueing-theoretics aspects of modeling telecommunications traffics	23
1.4.7 On the cybernetic aspects of complex systems	23
1.5 Scope of the Present Studies and Motivations.....	24
1.6 Organization of the Dissertation	25
1.6.1 Chapter 1: Introduction.....	25
1.6.2 Chapter 2: Complex Systems and Their Characteristics: A Telecommunications System View Point	25
1.6.3 Chapter 3: Cell Transfer Delay and Cell Delay Variations in ATM Telecommunications Systems: A Complexity-Metric Based Analysis in the Information-Theoretics Plan.....	26
1.6.4 Chapter 4: Traffic-flow Control in ATM Systems: A Complexity-Metric Based Analysis.....	26
1.6.5 Chapter 5: Call Admission Control in ATM Networks Using a Complexity-Metric Based Neurofuzzy System.....	26
1.6.6 Chapter 6: Complexity Aspects of Cybernetic Systems: Application to Modern Telecommunications	27
1.6.7 Chapter 7: Results, Discussion, and Conclusions	27
1.6.8 Chapter 8: Summary	27
1.7 Concluding Remarks.....	27

Chapter 2	Complex Systems and Their Characteristics: A Telecommunications System View Point.....	28
2.1	Introduction	28
2.2	How Much “Complex” is a Complex System?	31
2.2.1	The scale of complexity	31
2.3	System Complexity: An Information-Theoretic Perspective	31
2.4	Concluding Remarks	38
Chapter 3	Cell Transfer Delay and Cell Delay Variations in ATM Telecommunications Systems: A Complexity-Metric Based Analysis in the Information-Theoretics Plane.....	39
3.1	Introduction	39
3.2	A Brief Review on ATM systems.....	42
3.2.1	Quality of service (QOS) parameters.....	45
3.2.2	Cell transfer delay (CTD) and cell delay variations (CDV)	46
3.3	Modeling of Mixed (Voice, Video, and Data) Traffic Flow in ATM Transmissions.....	49
3.3.1	Queueing-theoretic models	49
3.3.2	Large-deviation theoretic model	55
3.3.3	Information-theoretic model: A complexity-metric approach	57
3.4	Simulation Studies, Results, and Discussions	68
3.4.1	Simulation parameters	68
3.4.2	Simulation experiments	71
3.5	Discussions	82
3.6	Concluding Remarks	83
Chapter 4	Traffic Flow Control in ATM Systems: A Complexity-Metric Based Analysis.....	85
4.1	Introduction	85
4.2	Traffic Flow Control in ATM Systems	85
4.2.1	Call admission control (CAC).....	88
4.3	Stochastic and Fuzzy Attributes of CAC.....	93
4.4	Part I: Fuzzy Attributes of Cell-loss Characteristics.....	97
4.4.1	Bifurcation of the fuzzy domain and membership attribution to fuzzy sets.....	100
4.5	Part II: Fuzzy Attributes of CLR and Their Implications on CAC.....	101
4.5.1	Fuzzy complexity based CAC.....	103
4.5.2	Linguistic description of fuzzy on the complexity of an ATM connectivity.....	105
4.5.3	Concept of possibility distribution and construction of fuzzy look-up table.....	111
4.5.4	Call admission boundary	114
4.5.5	Fuzzy CAC procedure	117

4.6	Methods of Clustering of Simple, Fuzzy, and Complex Calls	122
4.6.1	Centroid method of clustering.....	122
4.6.2	Modal method of clustering	123
4.6.3	Simulations, Results, and Discussions	123
4.7	Concluding Remarks	137
Chapter 5	Call Admission Control in ATM Networks Using a Complexity-Metric Based Neurofuzzy System.....	139
5.1	Introduction	139
5.2	A Complexity-Metric for ATM Systems: A Brief Revisitation	141
5.3	Proposed Neurofuzzy System Based ATM CAC Procedure	144
5.4	Simulation Experiment.....	147
5.5	Evaluation of the Complexity-Metric: A Revisitation	153
5.6	Call Admission Boundary	158
5.7	ANN Implementation	159
5.8	Results and Discussion.....	165
5.9	Concluding Remarks	167
Chapter 6	Complexity Aspects of Cybernetic Systems: Application to Modern Telecommunications	168
6.1	Introduction	168
6.2	Complexity Aspects of Cybernetic Systems	169
6.3	Cybernetic Aspects of Large Systems.....	171
6.4	Infomatics of Cybernetic Processes	174
6.5	Disorganization in a Complex System	175
6.6	Cybernetic Profiles of Modern Telecommunications Systems	178
6.6.1	Performance issues: A cybernetic profile	182
6.6.2	Technology and economic issues: Cybernetic-based criterion analysis of complex systems	183
6.6.3	Generalized cost equation	185
6.7	Criterion Analysis of Equations in Terms of Complexity-Metric	187
6.8	Examples of Techno-Economics Related Optimization in Telecommunications	188
6.8.1	Example I.....	188
6.8.2	Example II.....	191
6.9	Heuristics of Complexity System and Cybernetic Analysis: Scope for Application in Large Systems.....	196
6.10	Concluding Remarks	197
Chapter 7	Results, Discussions, and Conclusions.....	198
7.1	Complex System Attributes of Telecommunications Services	198
7.2	Representation of Telecommunications Traffic Characteristics via Complexity-Metric	199

7.3	Complexity-Metric Based Fuzzy Inference Engines: Telecommunications System Applications	201
7.4	Complexity-Metric Based Neurofuzzy Network: Its Application in CAC Strategies.....	203
7.5	Complex System versus Cybernetic Considerations: Optimization Procedure for Alternative Designs.....	205
7.6	Limitations of the Present Study and Scope for Future Research	206
	7.6.1 Limitation of the present study	206
	7.6.2 Scope for future studies: Open-questions	208
7.7	Concluding Remarks.....	209
Chapter 8	Summary	210
Appendix 3.1	A complexity-metric for the acceptable threshold of CLR.....	213
Appendix 3.2	Fractional loading factor of sources emitting cells in an interrupted fashion	220
Appendix 3.3	ARMA process model of video sequences	221
Appendix 3.3A	MATLAB™ codes to compute the cell delay of the least priority traffic (QT and IT methods) as per Simulation # 1.....	223
Appendix 3.3B	MATLAB™ codes to compute the cell delay of the least priority traffic as per Simulation # 2.....	238
Appendix 3.3C	MATLAB™ codes to compute the cell-loss ratio versus buffer size	242
Appendix 4.1	MATLAB™ codes for the computation of fuzzy and defuzzified $V(s_i)$.....	244
Appendix 5.1	The C++ codes to emulate the ANN	251
	Bibliography.....	303

List of Tables

Table 3.1	Description of source characteristics adopted in the simulations	68
Table 3.2	Details on traffic (source) types used in Simulation # 1	69
Table 3.3	Details on traffic (source) types used in Simulation # 2	70
Table 3.4	Details on traffic (source) types used in Simulation # 3	70
Table 4.1	Rate reservation method of CAC algorithm	92
Table 4.2	Decision table on $\{s_i\}$ given $\{X_i, Z_i\}$: Crisp domain representation	109
Table 4.3	Fuzzy decision table on $\{s_i^{(f)}\}$ given $\{X_i^{(f)}, Z_i^{(f)}\}$	110
Table 4.4	Source descriptions	118
Table 4.5a	Data Set I – Traffic (source) types, $\{X_i\}$	119
Table 4.5b	Data Set I – Profile of the resources, $\{Z_i\}$	120
Table 4.6a	Data Set II – Traffic (source) types, $\{X_i\}$	121
Table 4.6b	Data Set II – Profile of the resources, $\{Z_i\}$	122
Table 4.7a	Listing of normalized (s_i) values obtained via Approach # 1 and # 2 for the data set I	126
Table 4.7b	Listing of normalized (s_i) values obtained via Approach # 1 and # 2 for the data set II	127
Table 4.8a	Call accept/reject decisions (Data set I / Approach # 1 and # 2)	132
Table 4.8b	Call accept/reject decisions (Data set II / Approach # 1 and # 2)	133
Table 4.9	Summary of accept/reject decisions	135

Table 5.1	Summary of definitions of service categories and parameters used in Tables 5.2-5.5	148
Table 5.2	Traffic (source) types, $\{X_i\}$ (Data sets I and II)	149
Table 5.3	Profile of the resources, $\{Z_i\}$ (Data sets I and II)	150
Table 5.4	Traffic (source) types, $\{X_i\}$ (Data sets III A and III B)	151
Table 5.5	Profile of the resources, $\{Z_i\}$ (Data sets III A and III B)	152
Table 6.1	Relative cost coefficients of alternative LAN architectures being designed	195
Table 6.2	Computed complexity and relative total cost of alternative designs	195

PREVIEW

List of Figures

Figure 3.1	ATM multiplexing	45
Figure 3.2	Cell-transfer delay and the probability distribution of delay jitter	46
Figure 3.3	Queueing system.....	51
Figure 3.4	Queueing system notation	53
Figure 3.5	Application of M/D/1 and M/M/1 queueing systems relevant to the ATM environment.....	54
Figure 3.6	Illustration of large-deviation rate parameters.....	56
Figure 3.7	Flow-chart on queueing-theoretic based computation of CDV	72
Figure 3.8	Flow-chart of information-theoretics based computation of CDV resulting from statistical multiplexing (I) and finite-buffer based congested queueing considerations (II) (CDV equivalent of cell-losses, CLR I and CLR II).....	73
Figure 3.9	Cell-delay of the least priority traffic (data traffic) versus cell population as per Simulation # 1	75
Figure 3.10	Correlated time frames of Eqn. (A3.1) in respect of details furnished in Table 3.3	78
Figure 3.11	Cell-delay of the least priority traffic (data traffic) versus cell population	79
Figure 3.12	Cell-loss ratio versus buffer size (Simulation # 3) with $\rho \equiv \ell_3^* = 0.7$	81
Figure 3.13	Cell-loss ratio versus buffer size (Simulation # 3) with $\rho \equiv \ell_3^* = 0.8$	82
Figure 4.1	ATM multiplexing and switching.....	86
Figure 4.2	Graphical representation of B(s).....	101

Figure 4.3	Graphical representation of membership belongingness and overlapping element of the set $\{X_i, Z_i, s_i\}$	108
Figure 4.4	Histogram of Δ_i (Δ_{im} is the modal value)	112
Figure 4.5	Bifurcation and membership functions	113
Figure 4.6	The call admission boundary surface of an i^{th} call.....	116
Figure 4.7	Flow-chart of computing fuzzy and defuzzified values of s_i	125
Figure 4.8a	Simulated results pertinent to data set I – Approach # 1.....	128
Figure 4.8b	Simulated results pertinent to data set I – Approach # 2.....	129
Figure 4.9a	Simulated results pertinent to data set II – Approach # 1	130
Figure 4.9b	Simulated results pertinent to data set II – Approach # 2	131
Figure 4.10	Normalized sigmoidal nonlinearity depicting the bounding limit on call acceptance/rejection criterion.....	137
Figure 5.1	$\{s_i\}$ versus $\{X_i, Z_i\}$: Crisp domain representation of $N = 24$ calls	143
Figure 5.2	Fuzzy decision structure: $\{s_i^{(f)}\}$ versus $\{X_i^{(f)}, Z_i^{(f)}\}$	143
Figure 5.3	Complexity-metric based fuzzy neural network for call admission control applications in ATM systems.....	145
Figure 5.4	Bifurcation and membership functions	157
Figure 5.5	Target and predicted decision functions, $V(s_i)$ computed by the test ANN over the calls of “simple” category.....	161
Figure 5.6	Target and predicted decision functions, $V(s_i)$ computed by the test ANN over the calls of “fuzzy” category.....	162
Figure 5.7	Target and predicted decision functions, $V(s_i)$ computed by the test ANN over the calls of “complex” category	163
Figure 5.8	Target and predicted decision functions, $V(s_i)$ computed by the test ANN for a randomly selected set of call types	164
Figure 6.1	Information traffic in the complex cybernetic	171

Figure 6.2	Parameter spread-space of a complex system	176
Figure 6.3	AEI versus system variable x	185
Figure 6.4	Router-centric architecture	191
Figure 6.5	ATM-centric architecture	192
Figure 6.6	A balanced architecture of mixed backbones	192
Figure 6.7	π_{ei} values versus percentage deviation of the exponent set $\{a, \dots, h\}$	196

PREVIEW

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 complexity-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 stochastic 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 connotation 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 stochastic 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