MODELING AND PERFORMANCE EVALUATION OF SELF-SIMILAR BEHAVIOR OF MPEG-4 VIDEO TRAFFIC GENERATORS

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TO MY PARENTS,

MY LOVELY WIFE,

MY BROTHERS AND SISTERS,

MY BROTHERS AND SISTERS IN LAW.

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ABSTRACT

Variable bit rate (VBR) Moving Pictures Expert Group (MPEG) video is one of the major applications used on networks. Effective design and performance analysis of such networks thus depends on accurate modeling of MPEG video traffic. Recent studies of real traffic data in modern computer networks have shown that traffic exhibits long-range dependence (LRD) properties over a wide range of time scales. The predominant way to quantify the long-range dependence is the value of the Hurst parameter, which shapes the autocorrelations of LRD processes, and it is needed for determining variance of such a process. Thus, correct and efficient estimation of the Hurst parameter is important in traffic analysis. There are several different methods to estimate the Hurst parameter, we have evaluated the most commonly used methods for estimating the self-similarity parameter H using appropriately long sequences of data. Estimators considered include, wavelet-based, R/S-statistic, variance-time, absolute-based and Periodogram-based. Our results have pointed to the wavelet-based estimator and R/S-based estimator as the most efficient estimators of the Hurst parameter. There is still a considerable debate about how to model the VBR video traffic. Many models have been proposed for the modeling of traffic sources. However, further work is required to verify their accuracy for modeling the MPEG video traffic. This thesis evaluates three different traffic source models, namely the Hosking-based model, the RMD-based model and chaotic map-based model in terms of their statistical characteristics and to compare their outputs with the empirical traces to validate their effectiveness for modeling the MPEG-4 video traces. A comparison of the packet loss rate, queuing delay and throughput performance of RMD-based generator and chaotic-based generator with the performance of the real trace is used in validation of the models. Our simulation results show that the chaotic-based model capture the statistical characteristic of empirical traces better than Hosking-based and RMD-based models.

ABSTRAK

Video Kumpulan Pakar Gambar Bergerak Kadar Bit Boleh Ubah (MPEG VBR) merupakan salah satu aplikasi utama digunakan dalam rangkaian. Analisa prestasi dan rekabentuk berkesan rangkaian sebegini bergantung pada pemodelan trafik video yang tepat. Kajian terkini data trafik nyata pada rangkaian komputer moden mendapati trafik menunjukkan ciri pergantungan jarak panjang (PJP) "serupa diri" pada skala masa jarak lebar. Kaedah utama menentu nilai pergantungan jarak panjang adalah dengan menggunakan nilai parameter Hurst, yang membentuk auto-korelasi proses PJP. Nilai Hurst diperlukan untuk menentukan varians proses PJP. Oleh itu, anggaran parameter Hurst yang tepat dan efisyen amat penting dalam analisa trafik. Terdapat beberapa kaedah untuk menganggar nilai Hurst. Kami telah menggunakan kaedah lazim untuk menganggar parameter H menggunakan data berurutan panjang. Penganggar yang digunakan termasuk asas-wavelet, statistik R/S, masa-varians, asas absolut dan asas Periodogram. Keputusan yang kami perolehi: menunjukkan penganggar berasas wavelet dan berasas R/S sebagai penganggar paling efisyen. Masih terdapat perdebatan bagaimana memodel trafik video VBR. Banyak model yang telah dicadangkan bagi memodel sumber trafik. Walau bagaimanapun, kajian lanjut diperlukan untuk mengesah ketepatan trafik video MPEG. Dalam tesis ini, kami menilai tiga jenis model trafik MPEG VBR iaitu model berasas Hosking, model berasas RMD dan model berasas chaotic dari sudut ciri-ciri statistik dan membandingkan keluaran setiap satu dengan kesan empirikal sebagai pengesahan keberkesanan memodel kesan video MPEG-4. Perbandingan kadar hilang sel, lengah beratur, dan prestasi truput penjana asas RMD dan asas chaotic dibuat dengan prestasi trafik sebenar untuk mengesah model-model. Hasil simulasi, menunjukkan model berasas chaotic menghampiri ciri-ciri statistik kesan empirikal berbanding model berasaskan RMD dan Hosking

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$\overset{d}{\Rightarrow}$	-	Convergence of all finite-dimensional distributions
δ^2	-	Central second difference operator
$\overset{d}{\rightarrow}$	-	Convergence in law of random variables
$\gamma(\bullet)$	-	Covariance
$\overset{d}{\sim}$	-	Equality in law
$\overset{d}{=}$	-	Equivalent in distribution
$\hat{H}$	-	Estimated Hurst parameter
Γ	-	Gamma function
$\Lambda(X)$	-	Law of random variable X
$\overline{X}(n)$	-	Sample mean
σ^2	-	Variance
ΔH	-	Relative inaccuracy
$\lfloor z \rfloor$	-	The greatest integer smaller than or equal to z
a	-	Peakedness factor
$B_H(t)$	-	Ordinary Gaussian process with zero mean and unit variance
E	-	Expectation
H	-	Hurst parameter
$I(\bullet)$	-	Periodogram
K_L	-	Maximum value of the linear trend
K_{LS}	-	Maximum value of the level shift trend
K_P	-	Maximum value of the Parabolic trtend
m	-	Mean traffic rate
$r(k)$	-	Autocorrelation function
S $(\bullet)$	-	Power spectrum

$S^2(n)$	-	Sample variance
t	-	Time
$X(t)$	-	Amount of traffic arrived in $(0, t)$
Y_n	-	Discrete sample
$Z(t)$	-	Normalized fractional Brownian motion characterized by H

LIST OF ABBREVIATIONS

ACF	-	Autocorrelation Function
AR	-	Autoregressive
ARD	-	Abbreviation for “Arbeitsgemeinschaft der offentlich rechtlichen Rundfunkanstalten der Bundesrepublik Deutschland”. This translates as the “Association of Public Broadcasting Corporations in the Federal Republic of Germany”.
ARIMA	-	Autoregressive Integrated Moving Average
ARMA	-	Autoregressive Moving Average
ATM	-	Asynchronous Transfer Mode
Bell Lab	-	Bellcore Laboratory
B-Frame	-	Bi-directional-Frame
B-ISDN	-	Broadband-Integrated Service Digital Network
BMAP	-	Batch Markovian Arrival Process
CBR	-	Constant Bit Rate
CDF	-	Cumulative Distribution Function
CDMA	-	Code Division Multiple Access
CD-ROM	-	Compact Disc-Read Only Memory
D-BMAP	-	Discrete-Time Batch Markovian Arrival Process
DCA	-	Dynamic Channel Allocation
DI	-	Double Intermittency
DVD	-	Digital Video Disc –or – Digital Versatile Disc
E-Commerce	-	Electric Commerce
FARIMA	-	Fractional Autoregressive Integrated Moving Average
FGN	-	Fractional Gaussian Noise
FIR	-	Finite Impulse Response

FPDI	-	Fixed Point Double Intermittency
FPI	-	Fixed Point Intermittency
FTP	-	File Transfer Protocol
GoP	-	Group of Pictures
GRN	-	Gaussian Random Number
GSPP	-	Generalized Switched Poisson Process
HDTV	-	High Definition Television
IEC	-	International Electrotechnical Commission
I-Frame	-	Intra-Frame
IIR	-	Infinite Impulse Response
IP	-	Internet Protocol
IPP	-	Interrupted Poisson Process
ISO	-	International Organization of Standardization
K-S Statistic	-	Kolmogorov-Smirnov Statistic
LAN	-	Local Area Network
LFSM	-	Linear Fractional Stable Motion
LFSN	-	Linear Fractional Stable Noise
LRD	-	Long-Range Dependent
MAP	-	Markovian Arrival Process
Mbps	-	Megabytes per second
MLE	-	Maximum Likelihood Estimation
MMPP	-	Markov Modulated Poisson Process
MPEG	-	Moving Picture Experts Group
MTU	-	Maximum Transfer Unit
MWM	-	Multifractal Wavelet Model
NCSA	-	National Centre for Super-computing Applications
OTcl	-	Object Tool Command Language
PARC	-	Palo Ato Research Center
PDF	-	Probability Density Function
P-Frame	-	Predicted-Frame
PLR	-	Packet Loss Rate
QoS	-	Quality of Service
QQ	-	Quantile-Quantile

R&TV ARD	-	Radio and Television ARD
R/S	-	Rescaled-Adjusted Range
RFC	-	Request For Comments
RMD	-	Random Midpoint Displacement
RNG	-	Random Number Generator
RTCP	-	Real-Time Control Protocol
RTP	-	Real-Time Transport Protocol
SIC	-	Sensitive Dependence on Initial Conditions
SK	-	Pearsonian Coefficient of Skewness
SPP	-	Switched Poisson Process
SRD	-	Short-Range Dependent
SS7	-	Signaling System Number 7 Protocol
SSQ	-	Switched Scalar Quantizer
Tcl	-	Tool Command Language
TCP	-	Transmission Control Protocol
TDMA	-	Time Division Multiple Access
TES	-	Transform Expand Sample
TKN	-	Telecommunication Networks Group
TV	-	Television
UDP	-	User Datagram Protocol
VBR	-	Variable Bit Rate
VHS	-	Video Home System
VINT	-	Virtual InterNet Testbed
WAN	-	Wide Area Network
WWW	-	World Wide Web

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CHAPTER 1

INTRODUCTION

1.1 Prelude

Variable Bit Rate Moving Pictures Expert Group (VBR MPEG) video is one of the major applications used on current networks. Video traffic can range form relatively low bandwidth applications like video phone and video conference, to high bandwidth applications like full-motion entertainment video. In order to design networks that can meet the demands of these applications, a solid understanding of video traffic behavior is required.

Effective design and performance analysis of such networks thus depends on accurate modeling of video traffic. Among bursty traffic types, MPEG-4 video traffic flows are the most important and demanding to model, due to their bandwidth requirements, their complex correlation structures, and the difficulties in obtaining, storing and analyzing empirical video data.

MPEG-4 is the one that is most suitable for the Internet. It is targeted for low bit rates. It allows real images to co-exist with computer-generated counterparts and also allows their separation and their receiving different treatment due to interaction with the user. The main feature of importance to the network is MPEG-4's capability of real-time adaptive encoding. This enhances network utilization and enables MPEG-4 senders to be more responsive to changes in network conditions. It generates video in three different frame types (I, P, and B) that serve to encode different portions of the video signal in different levels of quality.

Traditional (conventional) models have been used for VBR video traffic [135, 147, 151, 154]. These models exhibit short-range dependence (SRD), i.e., have an autocorrelation function that decays exponentially. Various studies [25, 60, 85, 86, 96] have shown that network traffic exhibit ubiquitous properties of self-similarity and long-range dependence (LRD). Intuitively, self-similar means the traffic has similar statistical properties at a range of time scales: milliseconds, second, minutes, and even hours. In other words, network traffic exhibits correlation across many time scales. LRD is characterizes by a slowly decaying autocorrelation function (i.e., it decays less than exponentially fast).

These observations of self-similarity in network traffic apply to both data traffic and to video traffic. Leland and his colleagues [191] analyzed an extensive set of Ethernet LAN (Local Area Network) traffic. The result indicated that Ethernet LAN traffic is long-range dependent. A paper by Paxson [193] shows that WAN (Wide Area Network) traffic cannot be modeled by Poisson processes and instead need long-range dependent models. Also measurement based on video traffic shows that VBR video traffic possesses self-similar characteristics [10].

An important feature of video traffic at the packet level that has a significant impact on performance is traffic correlation. Specially, (bursty) traffic patterns generated by VBR compressed video and audio tend to exhibit certain degrees of correlation between arrivals, and how long-range dependence in time (self-similar traffic) [19, 22].

As the network traffic is expected to carry more and more video streams, the correct characterization of this type of sources is increasing its importance. The MPEG family of video coding standards achieves high compression ratios by exploiting the reduction of both spatial correlation in intra-frame coding, using spatial transforms, and reduction of temporal correlation in intra-frame coding by means of motion compensation. This produces a high variability in the offered load as Intra frames usually need from 2 to 5 times the number of bits necessary for inter frame coded frame (P and B frames in MPEG terminology). Video distribution is furthermore to be seen as an aggregate of video streams coming out of a single server for multicasting over network and a high quality of service (QoS) must be maintained for such services as video on demand since the user expecting to receive the same quality signal he is used to receive from broadcaster or conventional cable.

1.2 Problem Formulation

Modeling the sources traffic is as important as modeling the network which carries the traffic source. Thus, it is important to carefully characterize any traffic under study to ensure that the models used do lead to useful network performance results. Measurement-based traffic characterization has come to acquire a great deal of importance in networks. This is particularly so when dealing with relatively new sources such as video, imaging, and multimedia traffic. Traffic characterization is not only important when designing buffers for multiplexers, for example, but also in studying admission, access, and network control. In all these areas and others related to network performance management, the main objective is to ensure all traffic types receive the appropriate QoS. One can then use these models to study traffic control into, and across, the network.

Traditional Markovian traffic models [135] have played a significant role in the design and engineering of networks. In particular, Poisson arrival [116, 129] and exponential holding time statistics have served as earlier models in carrying out both the engineering and performance evaluation of networks, because they are mathematically tractable. However, it has become increasingly clear that these models are not adequate for carrying out the design and evaluation of modern networks. The integration of packetized voice, video and imaging, and file transfer data traffic, each with its own multiobjective QoS, requires the development of improved traffic models, in order to carry out accurate design and performance evaluation.

In the current research, the underlying assumption in existing traffic models is that of self-similarity. In very simple terms, self-similarity means the object appears the same regardless of the time scale at which it is viewed. One of the implications of the self-similarity finding for traffic modeling is that it suggests an appealing alternative to the popular belief that since actual network traffic is extremely complex in nature, only complicated and highly parameterized models are likely to result in an accurate approximation of reality. By accepting the self-similarity hypothesis, the principle of parsimony can be applied and results in simple models that exhibit the same features as the actual network traffic.

1.3 Objectives

Due to the growing complexity of modern telecommunication networks, simulation has become the only feasible paradigm for their performance evaluation. In order to study the performance either by means of analysis or simulation, there is a need for video traffic models. Statistical video traffic models are required for generating synthetic video streams for network performance studies. With synthetic video streams, performance study can be carried out without requiring the actual traces. Furthermore, a video traffic model can generate many realizations which represent "structurally similar", but not identical synthetic streams. Moreover, with video traffic models there is a more controllability of video traffic characteristics e.g., on the autocorrelation of frame sizes and on the mean frame sizes.

Motivated by the above discussion, the objectives of the thesis are:

- To evaluate three video source traffic generators in terms of their statistical characteristics and to compare the output of these models with the empirical traces to validate the effectiveness of the models (Hurst parameter, frequency histogram and probability density function PDF). The Hosking's model, the random midpoint displacement model and the chaotic model are the three video traffic generators that will be evaluated in this thesis.
- To evaluate the quality of the synthetic video traces generated using the random midpoint displacement method and chaotic-based method. The quality of a video synthetic trace is measured by how well the results of simulations using the synthetic trace as input agree with those of simulations using the actual video trace.

1.4 Scope of Study

In this thesis we mostly concentrate on analytical modeling and simulation, based on measured network traffic. This project is broken into four phases; data collection and representation; data analysis, network traffic modeling and models validation. Figure 1.1 depicts the proposed modular methodology that use bottom up design to simplify the system.

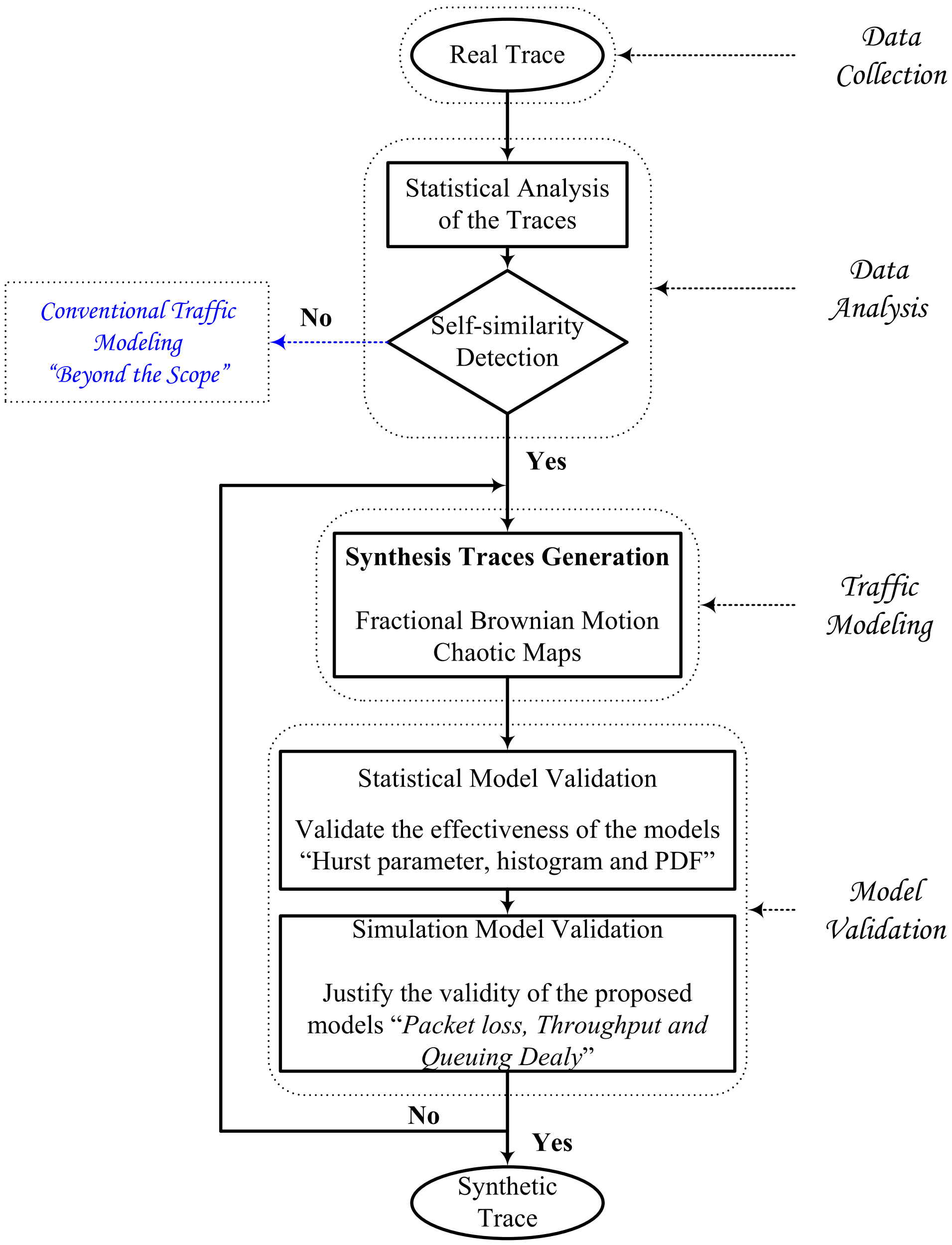

Figure 1.1 Research methodology system architecture

Understanding the problem is gained through literature review. Chaos theory and the probability theory of self-similarity and long-range dependence are discussed. Traditional modeling approaches are also surveyed. The tools of system implementation such as C, and MATLAB have been used. The scope and objective of the study is then defined to solve the critical part of the research problem. Detailed system architecture is shown in Figure 1.2.

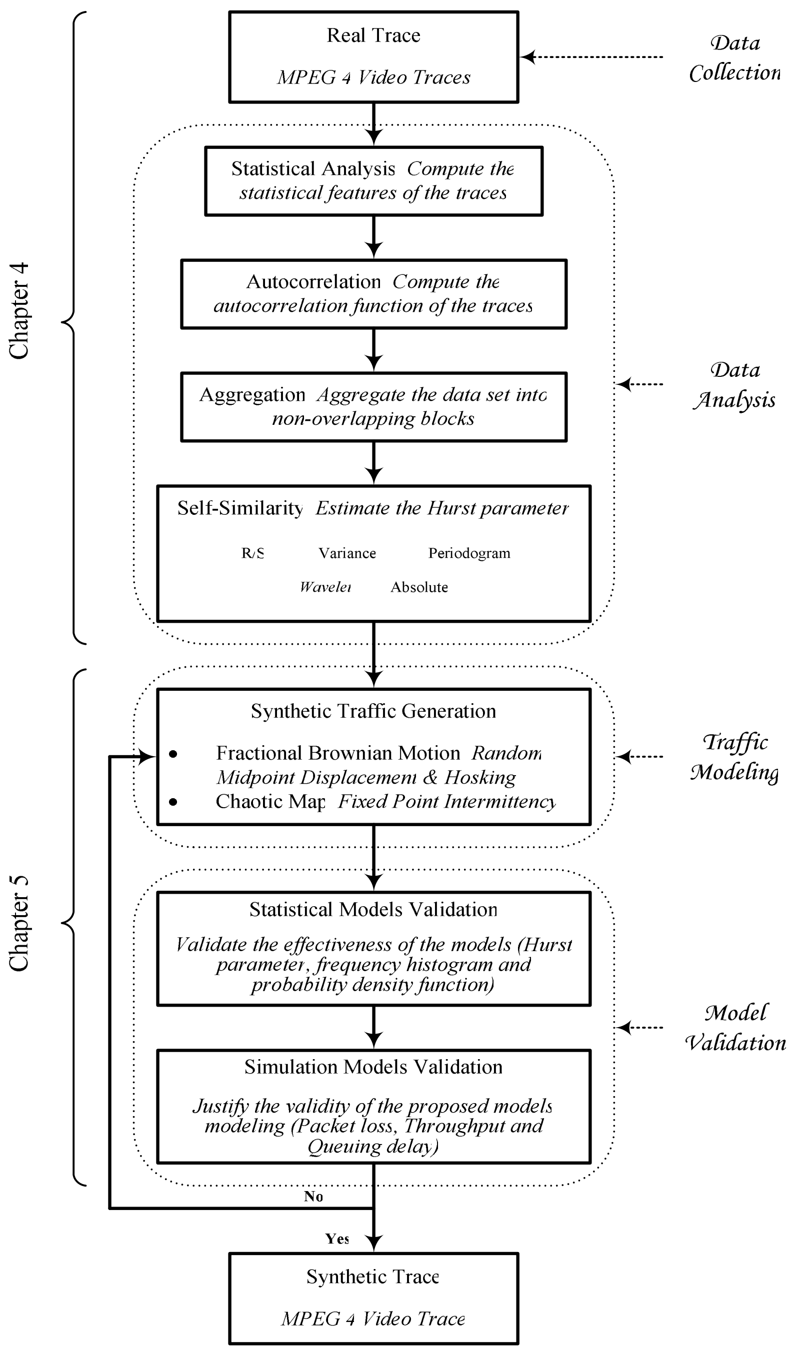

Figure 1.2 Detailed methodology system architecture

1.5 Importance of the Study

The knowledge of the characteristics of the traffic flowing in the network plays one of the most important roles in the design of communication/computer networks. It enables us:

1. To simulate, analyze, and predict the behavior of the networks under different conditions and to take appropriate measures in case of undesirable problem.

2. To optimize the performance of the network, to guarantee a specific quality of services to user.

3. To avoid congestion in network components and links resulting from variation of the rate flow of information.

1.6 Original Research Contributions

There is still a considerable debate about how to model the VBR video traffic and about its impact on network performance. The objective of this thesis is to evaluate three self-similar video traffic models, Hosking-based model, RMD-based model and chaotic maps and compare their output with the empirical traces to validate their effectiveness. The following is the list of main contributions of this thesis to the field of the modeling of self-similar traffic for simulation.

- A comparative study is conducted to determine the minimal length of a sequence used as a sample for estimating the Hurst parameter using the H-based estimators. The estimators considered include the wavelet-based H estimator, R/S statistic analysis, variance-time analysis, absolute-based analysis and Periodogram-based estimator

- Comparative analysis and evaluation of estimators of self-similarity parameter H. Their properties were assessed on the basis of estimates and other statistical tests to statistically prove which of the estimators should be recommended in practice.

- We analytically investigate the effect and implication of non-stationary in the LRD estimators, namely the R/S statistic analysis and variance-time analysis.

- Evaluate and compare the operational properties of the random midpoint RMD self-similar generator and the chaotic map one. The statistical accuracy and time required to produce long sequence are studied experimentally. The evaluation of the generators concentrated on two aspects: (i) how accurately self-similar process can be generated (assuming a given mean, variance and self-similarity parameter), and (ii) how quickly the generators can generate long self-similar sequence.

- We present a detailed statistical analysis of three video traffic models namely, Hosking-based model, RMD-based model and chaotic model in terms of how well synthetically generated traces match the characteristics of the empirical traces.

- To justify the validation of our models, we valuate the quality of the synthetic video traces generated using the random midpoint displacement method and chaotic-based method. The quality of a video synthetic trace is measured by how well the results of simulations using the synthetic trace as input agree with those of simulations using the actual video trace.

1.7 Organization of this Thesis

This thesis is organized into six chapters. In this chapter, the problem formulation and objectives of this research thesis are clearly defined. Firstly, a prelude of self-similar traffic modeling in network is presented. This is followed by a brief discussion of the research problem formulation. Subsequently, the thesis objectives are stated. The scope of work and the importance of this study are defined. The main contributions of this thesis to the field of the modeling of self-similar traffic for simulation are stated, and at the end of the chapter the thesis organization is outlined.

In Chapter Two, the first part of this chapter mainly covers a literature review of network traffic modeling. This part contains an extensive literature review of current traffic modeling approaches for video traffic, reviews the recent measurements studies, and motivates the application of self-similar to describe and analyze the traffic flow in networks. The second of the chapter presents a detailed survey of self-similar generators proposed for generating a self-similar sequence. Two approaches were proposed to deal with self-similar properties of packet traffic; (1) stochastic models related to self-similar processes and (2) deterministic models using nonlinear chaotic maps. Note that the motivation for both approaches is the desire for a relatively simple description of the complex packet traffic generation process. Three different modeling techniques are examined in more detail. The first one is based on exactly self-similar stochastic fractional Brownian motion process called Hosking method. The second approach based on approximation self-similar stochastic fractional Brownian motion process called random midpoint displacement, and the final method is based on deterministic chaotic maps.

Chapter Three gives the mathematical background of self-similar stochastic process. First, the mathematical definitions for the notion of self-similarity, long-range dependence, and some mathematical concepts associated with chaos which are relevant to our study are given. The second part of this chapter summarizes the properties of self-similar process. Finally, the third part to gives an overview of the statistical method used for testing and estimating the degree of self-similarity. Four different graphical statistical tests are discussed, the so-called wavelet estimator, R/S statistic, the variance-time plot, the absolute method, and an analysis based on Periodogram.

In Chapter Four, the first part of this chapter exhaustively evaluates the most commonly used methods for estimating the self-similarity Parameter H. The RMD-based algorithm is used to generate self-similar sequences. Values of estimated H were used to statistically prove which of the Hurst parameter estimators is more accurate than the other. In the second part the implications of some typical non-stationary effects, which can be observed in measured network traffic, were investigated in R/S-based H estimator and variance-time H estimator. Mathematical analysis of the Fixed Point Intermittency map and operational properties comparison of the Random Midpoint Displacement generator and chaotic generator are presented in the third part of the chapter. Finally, the third part presents statistical analysis of MPEG4 video traces encoding over 9 sequences of 60 minutes length each since they are used as a benchmark sequences to validate our synthetic traffic generators.

In Chapter Five, the first part of this chapter detailed statistical analysis of two empirical MPEG video traces, as well as an assessment of the three video traffic models in terms of how well synthetically generated video traces match the characteristics of empirical video traces. The second part of the chapter presented how simulation supports model selection processes. This part described the experimental methodology for simulation evaluation of two video traffic generators, chaotic-based and RMD-based models, and presented their simulation results.

The final chapter summarizes the research findings and suggests the direction of the future work. In particular, summary of the main contributions achieved and the research limitation that suggests the direction for future work are stated.

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