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Self similarity analysis via fractional Fourier transform

Cebrail Çiflikli, Ali Gezer *

Erciyes University, Kayseri Vocational High School, 38020 Kayseri, Turkey

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ABSTRACT

Self similarity has taken great interest in computer networks since modeling of Ethernet traffic via self similarity. Recent studies have shown that network traffic exhibits long range dependency which could not be modeled with Poisson distribution. Time and frequency domain representations are frequently utilized to better visualize and characterize self similar stochastic processes.

Fractional Fourier transform is a generalization of ordinary Fourier transform and find applications in many areas that ordinary Fourier transform has found. In this study, a network traffic analysis via fractional Fourier transform is performed. This study aims to better evaluate self similarity of network traffic via using fractional Fourier transform. Due to their high self similarity degrees, real IPv6 packet traffic is used for the analysis. We also perform analysis with an exact self similar process, fractional Gaussian noise to compare the results.

1. Introduction

Self-similar processes are emerging as a powerful representation of a great variety of physical phenomena [1]. Self similarity has been discovered and exploited in many areas such as biology, econometrics, turbulence, natural images, fluctuations of the stock market and traffic modeling in broadband Networks [2–4]. It is not that simple phenomenon related with correlation. It has changed the way of looking at some basic artifacts in many disciplines. As an example, previously modeling of network traffic used to be realized with Poisson like models [5]. Performance evaluations were performed considering this acceptation. But after modeling of Ethernet traffic via self similarity, performance-related calculations for networks such as resource sharing, queue management and routing management have changed, substantially [4]. Nowadays, self similarity artifacts have occurred in most of the broadband network traffic [6–10]. Therefore, its robust analysis is significant.

Displaying a stochastic process in frequency or time domain might give beneficiary information about it. How the process differs in frequency or time domain with respect to Hurst degree is a significant step to make comment about the dependency of the process. For instance, Ethernet data traffic represents bursty behavior in time domain representation [4]. The bursty nature of Ethernet traffic does not vanish as time scale increases many times. Rescaled way of looking at network data traffic in time domain provides new perspectives about the analysis of it. Detailed time domain analyses of network traffic obviously show that its traffic could not be modeled with Poison or Markovian distributions [5]. Self similar models best suit to this structure. Time domain analysis of self similar stochastic processes has paved the way of time based Hurst estimation methods. The Rescaled Range (R/S) statistics [3], Variance Time [11], Absolute Moment [12] and Variance of Residuals [13] are commonly used time based Hurst estimation methods. Displaying of network traffic in frequency domain obviously show that it has $1/f$ type power spectrum. Frequency based Hurst estimation methods mostly exploit the power law behavior

* Corresponding author.
E-mail addresses: cebrailc@erciyes.edu.tr (C. Çiflikli), aligezerr@hotmail.com (A. Gezer).

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of power spectral density. Daniel PB estimator [11], Whittle Maximum Likelihood [3] and Local Whittle ML [14] are commonly used frequency based estimators.

The fractional Fourier transform has found many applications in several areas including signal and image processing, communications, optics and wave propagation, mathematics, and physics [17–26]. The transform is likely to have something to offer in every area in which the conventional Fourier transform and related concepts are used. In this study, we propose self similarity analysis of network traffic via fractional Fourier transform. Self similarity causes serious performance degradations in computer networks. If self similar structure of traffic does not take into account, an efficient network management would be impossible with wrong traffic models.

A Hurst parameter estimator based on fractional Fourier transform has been proposed in [15,16]. In mentioned studies, by making some acceptations, fractional Fourier transform has been compared with wavelet transform. According to those acceptations and using similarities with wavelet formula, a Hurst based estimator has been proposed via some processing of wavelet coefficients. There is no use of pure fractional Fourier transform for self similarity analysis in [15,16]. In our study, we perform analyses of network traffic via fractional Fourier domain to reveal in what ways changes occur with respect to different transform orders and whether it gives any insights about the robust evaluation of self similarity. Displaying of network traffic in a different domain might give beneficiary information about it. If performed transforms give significant details about self similarity, better Hurst estimation methods might be found.

Network traffic is mostly modeled with fractional Gaussian noise and Fractional Brownian motion [27,28]. We also perform fractional Fourier transform of fractional Gaussian noise. Comparison of fractional Gaussian noise and real network traffic in fractional Fourier domain might also give beneficiary information about the analysis of self similarity via fractional Fourier transform.

This paper is organized as follows. Section 2 provides detailed information about analyzed Internet traffic traces. Afterwards, we give background information about fractional Fourier transform, self similarity and fractional Gaussian noise. Section 3 presents fractional Fourier transform analysis of network traffic and fractional Gaussian noise, elaborately. Then we conclude the paper.

2. Internet traces

We analyze packet-level Internet traces of May 2008 obtained on an IPv6 line connected to WIDE-6Bone in Japan. The traffic traces are taken from MAWI Working Group archive [29]. All traces consist of different kinds of application traffic including p2p, http, ftp, smtp, etc. Protocol breakdown of analyzed traces is given in Table 1.

A packet sniffer application is used to filter packet inter-arrival time and packet size from the traces. Traces were captured on daily basis. Capturing starts at 18:00 in each day and lasts until 300,000 packets were captured. Totally, over 1.8 million IPv6 packets are used for the analyses.

2.1. Fractional Fourier transform

The fractional Fourier transform (FRFT) is a generalization of the conventional Fourier transform. Fractional Fourier domains could be interpreted as oblique axes in time-frequency plane [20]. Mathematical representation of the transform is given below.

Table 1
Packet breakdown of May 2008 IPv6 packet traffic.

Protocol	Packets (%)
tcp6	74.89
http(s)	17.26
http(c)	36.3
squid	0.043
smtp	0.042
nntp	0.69
ftp	0.1
pop3	0.08
ssh	0.255
dns	0.0075
bgp	0.17
other	18.87
udp6	20.21
dns	18.785
other	1.43
icmp6	4.35
ospf6	0.5
other6	0.02