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Using a Volterra system model to analyze nonlinear response in video-packet transmission over IP networks

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Abstract

This paper presents a Volterra system-based nonlinear analysis of video-packet transmission over IP networks. With the Volterra system, which is applicable to the modeling of nonlinear dynamic systems from sets of input and output data, we applied a time-series analysis of measured data for network response evaluation. In a test-bed connected to the Internet, we measured two parameters: the time intervals between consecutive packets from a video server at the originating side, and the transmission time of packets between originating and terminating sides. We used these as input and output data for the Volterra system and confirmed that the relative error of this model changed with conditions of network systems, which suggested that the packet transmission process affected the degree of nonlinearity of the system. The proposed method can reproduce the time-series responses observed in video-packet transmission over the Internet, reflecting nonlinear dynamic behaviors such that the obtained results provided us with an effective depiction of network conditions at different times.
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1. Introduction

With the growing size and diversity of computer networks, network traffic including real-time applications has increased in recent years. Due to the shared nature of current IP-network structures, real network traffic shows complex dynamical characteristics in the time domain. To comprehend the properties of IP-network traffic and system conditions, many kinds of reports that are based on measured network traffic data have been presented.

Firstly, recent studies have revealed that the traffic patterns seen in actual IP networks are in fact self-similar, that is, they show fractal-like behaviors [1–5]. The results of these studies demonstrated that aggregated traffic in real world networks has long-range dependence (LRD), and thus indicated the insufficiency of the models (e.g. Poisson-related models) that have been widely used so far. Further studies about network traffic analysis have also drawn attention to the phase transition patterns in real network systems. For example, Takayasu et al. have pointed out that the behaviors of network traffic change with phase transition patterns, and that the fractal-like behaviors of the traffic can be affected by patterns of packet density in the time domain [6,7]. These studies have contributed to the analysis by demonstrating that phase transitions and power laws apply to changes in real network traffic density.

Furthermore, to express the complex behaviors of dynamical network systems, various kinds of network traffic modeling have been reported [8–13]. In [10], for example, Akritas et al. applied nonlinear time-series analysis approach to traffic measurements, and evaluated the applicability of identifying the features of measured traffic. In this study, they used the Grassberger–Procaccia algorithm to estimate embedding dimension of measured traffic, and confirmed that the statistical properties of measured traffic could be obtained by using a neural network-based method. In addition, the applicability of fluid-flow modeling of the Internet traffic has been also discussed in mobile networks [12]. However, there are many kinds of IP applications and network systems in the real world, so that further studies associated with identification of network traffic properties will have to be undertaken to cover various conditions.

This paper describes a nonlinear analysis of video-packet transmission over the IP network for network response evaluation. Using the Volterra system [14–17], which is capable of identifying nonlinear responses from given sets of input and output data, we applied a time-series analysis of measured data in the real environment. Section 2 of this paper presents the basic flow of the Volterra system and how we applied this model to the analysis of measured data. In Section 3, we show a case study performed on a test-bed with terminals connected via the Internet. Through the measurement-based evaluation, this paper shows that the proposed method is effective in the analysis of nonlinear time-series properties of IP-based video streams.

2. Method of analyzing measured video traffic

2.1. Discrete time-domain Volterra system model

The Volterra system [14–17], also known as a polynomial filter, is now widely used as a tool for modeling of nonlinear phenomena. This method is effective because it provides us with a nonparametric modeling approach to describe the nonlinear dynamic system. The modeling operation is

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