Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 50-2 (2017) 221–226

Dynamical Analysis of an Internet-Based Video System

Oluwafolake E. Ojo * **Ayodeji O. Oluwatope** ** **Suraju O. Ajadi** ***

* *Department of Computer Science, Federal University of Agriculture, Abeokuta, Nigeria. (e-mail: ojoeo@funaab.edu.ng).*
** *Department of Computer Science and Engineering, Obafemi Awolowo University,Ile-Ife, Nigeria (e-mail: aoluwato@oauife.edu.ng)*
*** *Department of Mathematics, Obafemi Awolowo University, Ile-Ife, Nigeria, (e-mail: sajadi@oauife.edu.ng)*

Abstract: The dissemination of video applications across the Internet still remains the driving force for Internet traffic growth. Generally, video streaming systems are characterized with irregular transmitting pattern and fluctuation which usually leads to transmission delay and frame loss. Furthermore, the democratic platform created by peer-to-peer (P2P) network for video streaming suggests complex dynamical behaviour with difficult predictable performance. The existence of flash crowd and peer churn situations in P2P streaming systems obtained from random arrival and departure of peers exhibits chaotic attributes. In this paper, a P2P streaming system(UStream) was modelled using a system of first order differential equations. The dynamics of UStream were analysed using equilibrium points and eigenvalues structure. Instability region was tracked through numerical investigation. The numerical simulation conducted using the Mathematica package software showed that UStream exhibits spiral fixed point and strange attractors with certain initial conditions which confirms experimental measurement and observations. Also, the system responds exponentially with time and reflects instability pattern for the first 20 seconds and 500 seconds when investigated with client-to-server(CS)and P2P network models respectively.

Keywords: Chaos theory, peer-to-peer network, video streaming and attractors..

1. INTRODUCTION

Research in complex non-linear dynamic system has rapidly developed and diversified as concepts of chaos and attractors have become applicable to nearly all disciplines such as physics, mathematics, economics, geomorphology, medicine, computer science e.t.c. Andrievskii and Fradkov (2004); Baas (2002); Chen et al. (2006); Adewumi et al. (2016). Lorenz was one of the originators of chaos theory with its unique discovery on the paradox of initial conditions, its equations and attractors became the epitome for chaos theory Lorenz (1963). Several researches had also been conducted on application of chaos theory. Chaotic behaviour were deeply explored in optical system Illing et al. (2007), nervous system Korn and Faure (2003), transportation systems Shang et al. (2005) and signal theory Hayes (2005). Furthermore, research revealed chaotic pattern in computing. For example; chaotic behaviours were recognized in cryptography Alvarez and Li (2006), TCP/IP networks Veres and Boda (2000) and many more.

In this study, we demonstrated that P2P streaming system(P2PSS) exhibits some chaos features like nonlinearity, sensitivity to initial conditions and sustained irregularity in the behaviour of the system Boccaletti et al. (2000). The remainder of the paper is organized as follows-the background information on P2PSS was given in section two. Section three presents the mathematical modelling and the dynamic behaviours of the UStream chaotic system. The results from the numerical simulation were presented and discussed in section four and conclusion is given in section five.

2. BACKGROUND STUDY ON P2P STREAMING SYSTEMS

In most distributed systems, peer-to-peer (P2P) networks are gradually becoming a substitute for the conventional client-server networks based on the democratic feature displayed by individual peer. Research showed that 70% of the global Internet traffic is produced by P2P applications Dai et al. (2011). In P2P network paradigm, peers operate hand and glove to form a self-organizing, self-maintaining network and share resources (like computing power, memory and network bandwidth) in the absence of central server Feldman and Chuang (2005); Liu et al. (2009). The evolution of P2P technology has experienced tremendous success in offering a variety of Internet services, ranging from traditional file sharing to media streaming systems Wang et al. (2010). Generally, file sharing system can still accommodate inter-packet delay. However, timely delivering of media content plays a crucial role in streaming services Hefeeda et al. (2004). The main cost in P2PSS is focused on dedicated streaming servers because the system

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2017.12.040

relies on participating peers upload bandwidth Zhou et al. (2007, 2011). P2PSS are usually deployed to provide either live streaming or video-on-demand(VoD) Wang et al. (2013). VoD manage bandwidth variation and peer churn effectively by buffering specific chunks beyond playback range Liang et al. (2010). In P2P live streaming systems, peers choose neighbouring peers with high inter-peer bandwidth to ensure timely delivery of chunks Tu et al. (2005); Wu et al. (2007) and also ensure that peer receives each packet only once Zhang and Hassanein (2012).

Furthermore, the two mostly used overlay topology in P2PSS are tree-based and mesh-based Liu et al. (2008). The tree-based topology distribute resources using tree hierarchy pattern and organize peers in a single tree or multiple multicast trees. Mesh-based approach is an improved version of tree-based topology with unstructured peers arrangement, formed by peers connecting to neighbours, which may be randomly selected. Although, the mesh overlays topology have proven to handle peer churn situation than tree-based overlays Biskupski et al. (2008); Silverston et al. (2009) but flash crowd, churn-induced instability and bandwidth variation are problems still associated with P2P streaming technology. These conditions have a serious impact in the quality of service (QoS) and consequently in the quality of experience (QoE) Efthymiopoulos et al. (2015). Hence, a more robust hybrid P2P streaming system (UStream) was presented in our previous work Ojo et al. (2015). The mathematical modelling of UStream and its dynamic behaviours were studied in this paper.

3. USTREAM ANALYSIS

A three compartment model of the UStream overlay topology in Ojo et al. (2015) is depicted in Figure 1. S represents the streaming server, R stands for all the root peers, P represents all the parent peers and C represents all the children peers. a represents the link capacity from the streaming server to the root peer, b represents the link capacity from the root peer to the parent peer, c represents the link capacity from the parent peer to the children peer, d and e represent the alternate route from the streaming server to the parent peer and children peer respectively. Also, f represents the link capacity from the root peer to the children peer. The unique attribute of P2P network was also incorporated in this scheme (i.e. the ability of peers to act as servers and clients simultaneously). Therefore, transmission can occur from the children peers holding the necessary video chunks required by incoming parent peers. Similarly, the parent peers can also feed new peers at the root peers with the desired video chunks. Hence, at each layer, backward routes were also considered; b_- represents link capacity transmission from the parent peer to root peer, c_- is the transmission from the children peer to the parent peer and f_- represents transmission from the children peer directly to the root peer. For simplicity, it was assumed that peers with the same upload bandwidth are grouped at the same level. Furthermore, peers with highest upload bandwidth are classified as root peers followed by the parent peers. The peers with lowest upload bandwidth are classified as children peers. Several scenarios were considered in this modelling varying the constant parameters. The default path creates a typical client-to-server network; in this

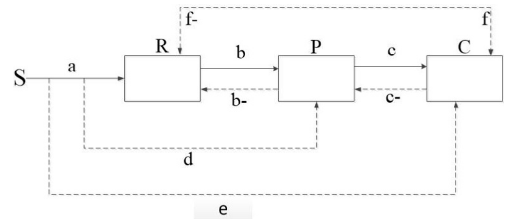

Fig. 1. Schematic Diagram of UStream Model

case, the root peers access video chunks directly from the streaming server and forward it to the parent peers based on request. Subsequently, the parent peers transfer video chunks to the children peers. Also, in P2P scenario, peers at each layer dynamically distribute video chunks both in forward and backward direction. The straight lines in Figure 1 indicate the default communication between peers while the unbroken lines indicate alternative route between peers when there is total failure or partial failure in the network.

3.1 UStream Mathematical Model

The non-linear three dimensional autonomous equation of UStream is given as:

$$\begin{aligned} R' &= a - bRP + b_-RP + f_-RC - fRC \\ P' &= bRP - b_-RP - cPC + c_-PC + dP \\ C' &= cPC - c_-PC + eC + fRC - f_-RC \end{aligned} \tag{1}$$

Let R, P, C in (1) represent upload bandwidth of peers at the root, parent and children levels respectively, Also, $a, b, c, d, e, f, b_-, c_-, f_-$ stand for link capacities which are constant parameters.
For simplicity, let $b_- = g$, $c_- = h$ and $f_- = i$, then (1) becomes:

$$\begin{aligned} R' &= a - bRP + gRP + iRC - fRC \\ P' &= bRP - gRP - cPC + hPC + dP \\ C' &= cPC - hPC + eC + fRC - iRC \end{aligned} \tag{2}$$

The state space of system in (2) is three dimensional and the vector field on the right hand sides of the system is defined by:

$$V(R,P,C) = \begin{bmatrix} V(R) \\ V(P) \\ V(C) \end{bmatrix} = \begin{bmatrix} a - bRP + gRP + iRC - fRC \\ bRP - gRP - cPC + hPC + dP \\ cPC - hPC + eC + fRC - iRC \end{bmatrix}$$

The divergence of the vector field V is easily calculated as :

$$divV(R,P,C) = \frac{\partial V_1}{\partial R} + \frac{\partial V_2}{\partial P} + \frac{\partial V_3}{\partial C}$$

$$= -bP + gP + iC - fC + bR - gR - cC + hC + d + cP - hP + e + fR - iR$$

$$= bR + fR - gR - iR + gP + cP - bP - hP + iC + hC - fC - cC + d + e$$

$$= R(b + f - i - g) + P(g + c - b - h) + C(i + h - f - c) + d + e$$

$$= b + f < i + g \ , \ g + c < b + h \ , \ i + h < f + c \ , \ d + e < 0$$

Hence,