Physica A 462 (2016) 341–349

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Flow interaction based propagation model and bursty influence behavior analysis of Internet flows

Xiao-Yu Wu [a,c], Ren-Tao Gu [a,c,*], Yue-Feng Ji [b,c]

[a] Beijing Key Lab of Network System Architecture and Convergence, School of Information and Communication Engineering, Beijing University of Posts and Telecommunications, Beijing, 100876, China

[b] State Key Lab of Information Photonics and Optical Communications, Beijing University of Posts and Telecommunications, Beijing, 100876, China

[c] Beijing Advanced Innovation Center for Future Internet Technology, Beijing, China

HIGHLIGHTS

- Applying flow competition mechanisms, an influence propagation model for Internet bursty flows is proposed.
- The bursty flow has negative and positive effects on its odd and even order neighbors, respectively.
- The influence intensity of the bursty flow shows a sharply decreasing trend in the propagation.
- Network congestion degree affects the influence intensity of the bursty flow.
- WS small-world networks perform well in reducing the influence intensity of bursty flow.

ARTICLE INFO

Article history:
Received 9 January 2016
Received in revised form 23 May 2016
Available online 9 June 2016

Keywords:
Complex system
Internet
Flow interaction
Influence propagation

ABSTRACT

QoS (quality of service) fluctuations caused by Internet bursty flows influence the user experience in the Internet, such as the increment of packet loss and transmission time. In this paper, we establish a mathematical model to study the influence propagation behavior of the bursty flow, which is helpful for developing a deep understanding of the network dynamics in the Internet complex system. To intuitively reflect the propagation process, a data flow interaction network with a hierarchical structure is constructed, where the neighbor order is proposed to indicate the neighborhood relationship between the bursty flow and other flows. The influence spreads from the bursty flow to each order of neighbors through flow interactions. As the influence spreads, the bursty flow has negative effects on the odd order neighbors and positive effects on the even order neighbors. The influence intensity of bursty flow decreases sharply between two adjacent orders and the decreasing degree can reach up to dozens of times in the experimental simulation. Moreover, the influence intensity increases significantly when network congestion situation becomes serious, especially for the 1st order neighbors. Network structural factors are considered to make a further study. Simulation results show that the physical network scale expansion can reduce the influence intensity of bursty flow by decreasing the flow distribution density. Furthermore, with the same network scale, the influence intensity in WS small-world networks is 38.18% and 18.40% lower than that in ER random networks and BA scale-free networks, respectively, due to a lower interaction probability between flows. These

* Corresponding author at: Beijing Key Lab of Network System Architecture and Convergence, School of Information and Communication Engineering, Beijing University of Posts and Telecommunications, Beijing, 100876, China.

E-mail addresses: xiaoyuwu@bupt.edu.cn (X.Y. Wu), jamesgrt@gmail.com (R.T. Gu), jyf@bupt.edu.cn (Y.F. Ji).

http://dx.doi.org/10.1016/j.physa.2016.06.007

results indicate that the macro-structural changes such as network scales and styles will affect the inner propagation behaviors of the bursty flow.

1. Introduction

In recent years, much progress has been made in the field of complex networks [1–5], including social networks [6–9], biological networks [10–12], computer networks [13,14] and citation networks [15–18]. One important research issue in these complex networks is propagation [19–22]. Propagation phenomena sometimes have negative impacts on the network and its users. For example, computer virus propagation [23,24] and failure propagation [25,26] on the Internet will influence people's normal lives. Currently, with the increasing burstiness phenomena of Internet flows, the quality of services (QoS) is seriously affected, which is a more common problem of concern to people. Since there are hundreds of millions of flows transmitted in the network, one bursty flow may lead to large-scale spreading of QoS variations. Therefore, to guarantee the QoS of services, research on the influence propagation mechanism and behavioral characteristics of Internet bursty flows has become more and more important.

Related studies have been conducted over the years, such as causes and effects of bursty flows [27–29] and congestion propagation on the Internet [30–32]. Jiang et al. [29] studied the causes and effects of packet bursts from individual flows. The results showed that such bursts can create scaling on short timescales and increased queueing delays. However, this study mainly focused on the network congestion caused by dynamic flows, but how the influence of bursty flows spreads to the whole network has not yet been considered. In Ref. [31], congestion propagation among routers and the conditions under which congestion propagation occurs have been sufficiently investigated. The results show that the speed of congestion propagation is affected by the bandwidth and the propagation delay of links and that the periodicity of congestion propagation becomes less obvious as the randomness of the network traffic increases. Stéger et al. [32] revealed the mechanism behind congestion propagation that packet losses occur most commonly in computers nearest to the site of the actual congestion. Computers sharing the congested link increase their sending rates and move the site of the congestion downstream. However, these congestion propagation studies focus on the router level of the Internet, which is insufficient to reveal the inner dynamic characteristics at the flow level, i.e., from the perspective of Internet users. Moreover, related researches about traffic dynamics are studied recently. Fekete et al. [33] found that growing scale-free networks, where the scaling properties of the network can be changed with parameter α, will cause traffic performance dynamics. The traffic performance increases as the scaling parameter α increases, and bottlenecks will move to the periphery of the network when network performance is higher. Wang et al. [34] studied the traffic dynamics such as packets distribution and packets traveling time distribution in the scale-free network by proposing a novel routing strategy based on the local structural information. The authors in Ref. [34] inspiringly found that some fundamental relationships exist between the dynamics of synchronization and traffic on the scale-free networks. All of these studies have referential significance to the research of propagation dynamics under network emergency situations in this paper.

In this paper, at the flow level, an influence propagation model of Internet bursty flow is established. To intuitively reflect the influence propagation process, a data flow interaction network with a hierarchical structure is constructed, where vertices and edges represent the flows and interactions between them, respectively. We use the neighbor order to depict the neighborhood relationship between the bursty flow and other flows, and the influence spreads from the bursty flow to each order of neighbors through flow interactions with defined probabilities. Based on the propagation model, the influence propagation behaviors of the bursty flow are investigated under different network conditions. The corresponding research achievements are helpful for developing a deep understanding of the network dynamics caused by Internet bursty flows.

The rest of the paper is organized as follows. In Section 2, we present an influence propagation model based on data flow interaction networks. In Section 3, the propagation behaviors of the bursty flow are investigated. In Section 4, the physical network structural effects on the bursty flow behavior are further studied. Finally, a summary and some conclusions are presented in Section 5.

2. Influence propagation model

2.1. Model establishment

Generally, Internet flows are first processed in the routers and then forwarded to the physical links. However, due to the limitations of the router queue length and the link bandwidth capacity, Internet flows that share the same routers and links often compete for the finite network resources. Because it is common that an Internet flow has shared links or nodes with another flow, a turbulence in one flow will ultimately spread to the whole network through the flow interactions under congestion conditions. To clearly reflect the flow interactions and the influence propagation caused by bursty flows, a data flow interaction network is constructed.