Computer Networks 81 (2015) 1–18

Contents lists available at ScienceDirect

Computer Networks

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

Coercion builds cooperation in dynamic and heterogeneous P2P live streaming networks

Xin Jin [a], Yu-Kwong Kwok [b,*]

[a] Yahoo Inc., Sunnyvale, CA, United States
[b] Department of Electrical and Electronic Engineering, The University of Hong Kong, Pokfulam, Hong Kong Special Administrative Region

ARTICLE INFO

Article history:
Received 9 October 2013
Received in revised form 11 January 2015
Accepted 6 February 2015
Available online 14 February 2015

Keywords:
Peer-to-peer live streaming
Heterogeneous networks
Network dynamics
Selfish topologies
Cooperation
Coercion

ABSTRACT

Sustaining reasonable performance in a peer-to-peer (P2P) network is contingent upon cooperation among peers. As autonomous agents, peers cooperate only when they are incentivized to do so. Typically, incentives are provided through bilateral exchange of useful data, in a tit-for-tat manner. Unfortunately, good for file sharing and video-on-demand systems as they are, such incentive schemes are ineffective in live streaming systems due mainly to the lack of sufficient opportunity to allow such reciprocity to happen, as recently demonstrated in a pioneering quantitative study. The key insight is that with stringent time constraint, good system performance can only be sustained by judicious peer selection.

Despite that some pioneering efforts are done in peer selection, it is as yet a difficult challenge to tackle the inherent non-cooperation of peers in a dynamic and bandwidth-diverse network. In this paper, we meet this challenge by first presenting a novel hierarchical game model, covering strategic interactions among peers, trackers, and the content provider. Based on the analytical insights derived from the repeated game model, we propose a Striker strategy to coerce peers to cooperate, leading to significantly enhanced system performance, as demonstrated by our analytical and simulation results. Most importantly, our proposed incentive schemes are highly practicable in a real-life P2P network.

1. Introduction

Incentive provision [1] is a critical factor for the success of a peer-to-peer (P2P) network that relies heavily on peers' cooperation to sustain reasonable system performance. Indeed, in the past decade, various effective schemes have been proposed and implemented in practical systems [2–7]. However, such schemes, typically based on reciprocity in the form of bilateral data exchange (i.e., tit-for-tat like behaviors) or virtual payments [1], are useful mostly for file sharing and video-on-demand (VoD) systems, but not for the increasingly popular live video streaming systems, e.g., PPLive [8], PPStream [9] and UUSee [10], serving millions of active daily users spread across the globe [11]. The key problem is that with stringent playback deadlines for live streaming, there is a lack of opportunity for timely data exchange.

Specifically, Piatek et al. drew on real measurements of tens of thousands of peers in PPLive [8] and demonstrated the existence of limited trading opportunities among neighboring peers that decisively invalidated the efficiency of bilateral data chunk exchange mechanisms for P2P live streaming [12]. The key insight is that with the stringent time constraint, a more effective strategy is to support more judicious *peer selection*, so as to pair up peers to allow for timely exchange of relevant data chunks. Indeed, peer selection is critical to the effectiveness of the network topology in terms of connectivity, and hence, system performance, by establishing cooperative local connections leading to a high performance global overlay topology.

* Corresponding author. Tel.: +852 2859 8059; fax: +852 2559 8738.
E-mail address: ykwok@eee.hku.hk (Y.-K. Kwok).

http://dx.doi.org/10.1016/j.comnet.2015.02.006
1389-1286/

Broadly speaking, there are two different kinds of efficient peer selection schemes: *capacity aware* [13,12] and *locality aware* [14,15]. The essence of the former is to place high capacity peers closer to the source server so as to better utilize their upload capacity and achieve optimal system streaming quality. On the other hand, the latter promotes network friendliness by matching the overlay topology with the underlying physical networks. For instance, this can be achieved by clustering peers from the same ASes and thus reducing financial cost incurred by inter-AS traffic. For clarity, we focus our analysis on capacity aware peer selection that can be easily extended to locality aware peer selection. The efficiency of our proposed strategies is evaluated in both peer selection scenarios.

As a pioneering effort, Piatek et al. proposed *Contracts* [12] to provide incentives against free-riding through capacity aware peer selection. To the best of our knowledge, *Contracts* is the only study to provide practical incentives by structuring topologies via judicious peer selection, instead of bilateral chunk exchanges [12]. Unfortunately, the success of *Contracts* is contingent on the presumed cooperation of peers in the peer selection process. To further aggravate the problem, it is as yet a difficult challenge to tackle the non-cooperative issue in a dynamic and heterogeneous network (i.e., peers are equipped with diverse upload/download bandwidth). With this motivation, this paper aims to propose practical incentive schemes for P2P live streaming, by fully exploring strategic peer selection.

Our contributions in this paper are as follows. We first demonstrate quantitatively that peer non-cooperation is highly likely in strategic peer selection. We then model strategic peer selection as a repeated game, based on which we propose a Striker strategy for coercing peers to cooperate in P2P live streaming systems. Our Striker strategy works well in both centralized and fully distributed network environments. The key idea of the Striker strategy is to provide enough threat to selfish peers to thwart them from deviating from cooperation. The most important feature of our scheme is that it provides peers with no incentive to falsify their upload capacities. We are also among the first to study quantitatively the *hidden effects* of ineffective incentive protocols (i.e., crowding out of low bandwidth peers).

Contrary to previous studies [13,12], both our empirical simulations and rigorous analytical modeling show that, due to the inevitable peer non-cooperation, prescribed protocols induced by capacity aware peer selection significantly deteriorate system social welfare, let alone provide sharing incentives in Nash equilibria (N.E.). In particular, such performance degradation is incurred by clustering among peers with similar upload capacities that is different from file sharing and VoD systems [16,17], due to different system requirements, such as stringent playback deadlines.

The remainder of this paper is organized as follows. In Section 2, we present the system model of the interactions between the content provider and selfish peers, and a solution concept to quantify any peer selection protocol. Extensive simulation results show that noncooperation of peers in strategic peer selection is a general problem not limited to capacity aware peer selection. Formal game theoretic analysis is then provided to model iterative peer selection in Section 3. Section 4 presents our Striker strategy for coercing selfish peers to cooperate in establishing effective topologies, followed by practical algorithms in Section 5. Section 6 validates the efficiency of our Striker strategy with extensive simulations. Recent advances in P2P networks are surveyed in detail in Section 7. Finally, we present conclusions and future work in Section 8.

2. System architecture and model

In this section, we first present the system architecture and model. Before delving into our detailed rationality analysis and incentive scheme design, we quantitatively scrutinize implications of strategic peer selection for P2P live video streaming based on extensive simulation results, augmented with preliminary modeling efforts. Indeed, such preliminary analysis shows that existing overlay construction protocols based on capacity aware peer selection deteriorate social welfare in Nash equilibria because high capacity peers simply do not have the incentives to follow the prescribed protocols. This offers us valuable insights for more accurate system modeling leading to useful theoretical analysis.

2.1. System architecture

We consider a practical P2P live streaming system (e.g., PPLive) that is based on a mesh topology or unstructured overlay [8,18]. A general architecture of live streaming overlays consists of: (a) content servers, (b) trackers, and (c) peers. Content servers, the streaming source, upload the video content to a small number of peers. Each video is divided into equal-sized pieces called chunks. Trackers maintain a list of all concurrently online peers. In a practical system such as PPLive, trackers are under centralized control to serve in the interest of the content provider [11].

The maintenance and functioning of P2P streaming overlays can be hierarchically decomposed into peer selection for efficient *overlay construction*, and chunk scheduling for distributed *resource sharing* [11,18]. Before the start of streaming, each peer first retrieves a list of concurrently online peers by gossiping with each other or querying trackers. A peer then selects a set of peers to connect with as neighbors. This peer selection process is also known as *overlay construction* [1]. Peers then periodically exchange buffer maps with neighbors to indicate chunk availability, and request unavailable chunks from neighboring chunk holders. This process is commonly referred to as *chunk scheduling* [1].

With such delineation, we can then conceive a hierarchical game model that provides a clearly-defined boundary between selfishness for chunk scheduling and peer selection.

- **Resource Sharing Game.** Peers are reluctant to share. This game concerns motivating them to contribute in chunk scheduling with rewards of virtual payments or relevant video packets [2–7].