International Journal of Software Science and Computational Intelligence
Volume 12 • Issue 1 • January-March 2020

An Incentive Compatible Mechanism for Replica Placement in Peer-Assisted Content Distribution

Prabir Bhattacharya, Concordia University, Montreal, Canada
Minzhe Guo, University of Cincinnati, USA

ABSTRACT

Content delivery is a key technology on the Internet to achieve large scale, low-latency, reliable, and intelligent data delivery. Replica placement (RP) is a key machinery in content delivery systems to achieve efficient and effective content delivery. This work proposes a novel decentralized algorithm for the replica placement in peer-assisted content delivery networks with simultaneous considerations for peer incentives. By applying techniques from the algorithmic mechanism design theory, the authors show the incentive compatibility of the proposed algorithm. Experiments were conducted to validate the properties of the proposed method and comparisons were made with the state-of-the-art RP algorithms.

KEYWORDS

Algorithmic Mechanism Design, Content Delivery, Peer Assistance, Replica Placement, Strategy-Proof Mechanism

1. INTRODUCTION

Content delivery is one of the key technologies in the Internet computing paradigm to achieve large scale, low-latency, reliable, and intelligent data delivery, enabling higher-level value-added applications, such as the video-on-demand streaming. Content delivery networks (CDNs) and peer-to-peer (P2P) networks are two alternative technologies for delivering the contents by the Internet. Both these approaches have some advantages and some disadvantages. With huge sets of servers deployed around the world, the CDN companies, such as Akamai, are serving geo-distributed data consumers with a higher throughput and better quality of service (QoS). However, the maintenance and management of a large number of server clusters scattered around the globe is challenging and expensive. On the other hand, the P2P networks can achieve a high scalability by leveraging the resources of the participating peers while keeping the server requirements low. For example, the *PPLive* used less than 10Mbps of server bandwidth to simultaneously serve a 400 kbps video stream to roughly 1.5 million end users (Huang & Ross, 2007). Nevertheless, the decentralized and uncoordinated operation in the P2P systems implies that this scaling comes with undesirable side effects, such as the high startup delay (Yin et al., 2010) and potential asynchronicity in the peer arrival times (Karamshuk et al., 2015). Given the complementary advantages of both the approaches, researchers proposed some hybrid CDN-P2P systems (Jiang et al., 2008; Xu et al., 2006), aiming to incorporate the best of both approaches and offset each other's disadvantages. Based on the coupling model, the hybrid system can be classified into two categories (Lu et al., 2012): the peer-assisted CDN (PCDN) and

DOI: 10.4018/IJSSCI.2020010104

the CDN-assisted P2P. Most of the existing approaches (Yin et al., 2010; Jian et al., 2008; Xu et al., 2006; Zhao et al., 2013; Jian et al., 2008; Huang et al., 2008) fall into the first category, in which the P2P network is designed as a complement component for the regular CDN-based content delivery. Large-scale measurements revealed that substantial savings could be obtained from such approaches, e.g., a reported 70% of server traffic offload in Akamai's *NetSession* (Zhao et al., 2013), and over 87% savings for a video-on-demand workload from *Conviva* (Balachandran et al., 2013), suggesting that peer assistance can greatly decrease the cost of content delivery. Nevertheless, the gains from peer assistance can be limited due to a number of obstacle factors. Karamshuk et al. (2015) identified three obstacle factors, including ISP-friendliness – requiring peers to be within the same Internet service provider (ISP), bit rate stratification – the need to match peers with others needing similar bit rate, and partial participation – some peers choosing not to redistribute the content.

Although a large number of replica placement (RP) algorithms have been proposed for traditional CDNs (Zaman & Grosu 2011; Neves et al., 2009; Benoit et al., 2008; Vicari et al., 2007; Wauters et al., 2006; Bakiras & Loukopoulos 2005; Tang & Xu 2005; Karlsson & Karamanolis 2004; Khan & Ahmad 2004; Loukopoulos & Ahmad 2004; Bartolini et al., 2003; Karlsson et al., 2002; Karlsson & Mahalingam 2002; Chen et al., 2002; Kangasharju et al., 2002; Dilley et al., 2002; Jamin et al., 2001; Qiu et al., 2001; Kalpakis et al., 2001; Wolfson et al., 1997), they may not work efficiently in the PCDN environment where the P2P technology is incorporated to achieve the cost-efficiency in a two-level hybrid architecture. In PCDNs, the increase in user requests also means a higher probability that the requests can be served by nearby peers (Jiang et al., 2009), reducing the traffic overload in the nearby CDN servers. The RP algorithms for the PCDN need to take the peer contributions into consideration.

In this paper, we have investigated the replica placement problem in PCDNs with the simultaneous considerations of the peer incentives. Following the design of the PCDN architecture in (Jiang et al., 2008), we have considered the use of BitTorrent-like protocols for the P2P level content distribution in the PCDN and focus on improving the peer contributions in the PCDN by designing a mechanism that incentivizes the contribution of self-interested seeders.

The main contributions of the paper are summarized as follows. We present a system model for the RP in PCDNs, introduce an economic model that consolidates the delivery cost of the PCDN and the incentives for the peer participation, and formulate the RP problem with seeding incentives in PCDN systems. We propose the DPRP-IC, a decentralized algorithm for the replica placement in PCDN, to derive RP schemes that improve the upload contribution of self-interested seeders while controlling the payments for seeding incentives, and reduce the cost of the content delivery in the system. By applying techniques from algorithmic mechanism design (a sub-field of game theory), we prove the incentive compatibility and the computational efficiency of the proposed algorithm. Experiments were conducted to validate the properties of the proposed method and we compared the results with some state-of-the-art RP algorithms. Our results suggested that the RP algorithms that consider peer contributions have a better performance in the PCDN. Also, our approach incentivizes the contributions of the self-interested peers and improves the performance of the replica placement.

The remainder of this paper is organized as follows. Some related works are described in Section 2. In Section 3, we present the system model for the RP in PCDN, introduce an economic model for measuring the quality of RP schemes, and formulate the RP problem that underlies the necessary system-related assumptions. In Section 4 we present our incentive compatible mechanisms and the analysis of its properties. Comparative evaluations are presented in Section 5. Finally, we conclude the paper in Section 6.

2. RELATED WORKS

Some of the earliest works on the CDN-P2P delivery model are described in (Xu et al., 2006) and (Lu et al., 2012). Besides the efforts on designing specific hybrid CDN-P2P systems, a line of work (Huang et al., 2007; Karamshuk et al., 2015; Xu et al., 2006; Zhao et al., 2013; Jiang et al., 2008;