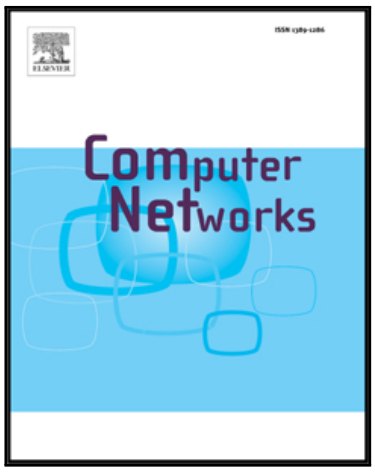

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Masahiro Sasabe

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Analysis of Optimal Piece Flow in Tit-for-Tat-Based P2P Streaming

Masahiro Sasabe*

Graduate School of Science and Technology, Nara Institute of Science and Technology,
8916-5 Takayama-cho, Ikoma, Nara 630-0192, Japan

Abstract

BitTorrent, which is one of the successful Peer-to-Peer (P2P) file distribution systems, adopts the tit-for-tat (TFT) strategy in game theory to encourage cooperation among peers, i.e., each peer has to provide fragments of the original file, called pieces, to others so as to retrieve its demanding pieces from them. Because the TFT strategy can restrict free riding behavior of peers, there are also several TFT-based P2P streaming systems and the performance of such existing systems has been analyzed. However, optimal piece flow in TFT-based P2P streaming has not been revealed yet. In this paper, a discrete-time model of TFT-based P2P streaming is first developed and integer linear programming (ILP) is formulated to determine the optimal piece flow where the average play-out delay is minimized. By solving the ILP using existing solver, i.e., CPLEX, we can obtain numerical examples of optimal piece flow. The analysis of obtained optimal piece flow reveals that (1) optimal piece selection is based on the balance between in-order piece retrieving and the rarest-first piece retrieving, (2) optimal peer selection depends on the upload capacities of peers and the stage of streaming, (3) the number of pieces does not affect the system performance, (4) the maximum play-out delay can be bounded by the ratio of the number of peers to the server's upload capacity, and (5) how the relaxation of TFT constraint can improve the system performance.

Keywords: P2P streaming, optimal piece flow, tit-for-tat strategy, integer linear programming (ILP)

1. Introduction

With the proliferation of the Internet streaming services, e.g., YouTube [1], Hulu [2], and NetFlix [3], IP video traffic will be 82% of all IP traffic (both business and consumer) by 2020, up from 70% in 2015 [4]. Most of the current streaming services adopt client-server architectures by taking account of the simplicity of managing user information and contents. Such client-server architectures, however, have potential drawbacks of load concentration and single point of failure at the server(s).

Peer-to-Peer (P2P) streaming has been expected to overcome such drawbacks of client-server architectures by utilizing the upload capacities of peers joining the streaming services [5]. There are some P2P streaming services, e.g., BitTorrent Live [6], PPTV [7], and GridCast [8], where, in the P2P architectures, contents are divided into fragments called pieces. Clients called peers can retrieve the pieces not only from the server(s) but also from other peers. As a result, the streaming system can dynamically and autonomously increase/decrease the scale depending on the number of peers [9]. Such scalability, however, requires peers' altruistic behavior, i.e., uploading pieces to others. In case of streaming services, users tend to hesitate in uploading pieces to others and become free riders, due to high and long-term bandwidth consumption [10, 11].

To alleviate such free-riding problems, Tit-for-Tat (TFT) strategy in game theory has been expected to encourage peers to willingly exchange pieces with others [9, 10, 12, 13, 14]. Note that BitTorrent [15] first applied the TFT strategy to P2P file distribution systems. The TFT strategy in P2P content distribution means that each peer has to upload pieces to others so as to retrieve his/her demanding pieces from them. To exchange pieces between two peers, they have to possess different pieces. As a result, in case of file distribution, it is rational and optimal for peers to follow a *rarest-first* strategy, where they preferentially retrieve the rarest piece(s) in the system.

In case of streaming distribution, however, such a rarest-first strategy is not necessarily optimal because *in-order* strategy is also important, where pieces are prioritized in play-out order. There are several studies on performance evaluation of TFT-based P2P streaming [16, 17, 18, 19]. However, most of them have been focusing on the piece retrieving strategies that seem to be rational, e.g., the rarest-first strategy and in-order strategy. As a result, the optimal piece flow in TFT-based P2P streaming has not been revealed yet.

In this paper, the optimal piece flow in TFT-based P2P streaming is analyzed with the help of integer linear programming (ILP). Although our problem is NP-hard, it can be solved by existing solver, e.g., CPLEX [20], in case of small-scale systems. The analysis of the obtained optimal solution will show fundamental characteristics of the optimal piece flow.

The main contributions of this paper are as follows:

1. A discrete-time model of TFT-based P2P streaming is developed and ILP is formulated to determine the optimal piece flow where the average play-out delay is minimized.

*Corresponding author
Email address: sasabe@is.naist.jp (Masahiro Sasabe)