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Queueing analysis of peer-to-peer swarms: stationary distributions and their scaling limits

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Abstract

In this paper we analyze the dynamics of a P2P file exchange swarm from a queueing standpoint. In such systems, the service rate a peer receives depends on one mostly fixed component (servers or seeders), and another that scales with the number of peers present. We analyze a class of M/G Processor Sharing queues that describe populations and residual workloads in this situation, characterizing its stationary regime in the case of a fixed population of servers; the result behaves like a combination of $M/G/1$ and $M/G/\infty$ queues. We apply scaling limits to this queue and identify two limiting regimes, depending on whether the server or peer contribution becomes dominant. For the latter, more important case we refine the fluid limit description of the download profile with a suitable functional Gaussian approximation. We also analyze the case of a slowly varying population of servers, extending the fixed case through a quasi-stationary analysis. For practical validation we offer comparisons with detailed packet simulations.

Keywords: P2P, Processor-sharing queues, General job sizes, Fluid limits.

1. Introduction

In recent years, peer-to-peer (P2P) file sharing systems such as BitTorrent [1] have become widespread, representing an important portion of Internet traffic. Content is disseminated by subdividing it into small pieces (*chunks*), and enabling peers to exchange such units bidirectionally. The power of P2P as a means of content distribution lies on the fact that downloading peers simultaneously contribute by uploading pieces to others, so the supply of service capacity for a certain content scales with the corresponding demand.

The set of peers exchanging a given content file is often referred to as a *swarm*, in which one distinguishes two classes: some peers (*seeders* in BitTorrent parlance) already own the entire file and act like servers to others, while the downloading peers (*leechers*) act simultaneously as clients and servers. Such swarms evolve in time subject to peer arrivals and departures, and thus it is natural to analyze their population dynamics with tools of queueing theory.

A first queueing model of this nature was the seminal paper [2], where the authors proposed a continuous-time Markov chain with two M/M queues in tandem, respectively representing leecher and seeder populations. Poisson arrivals feed the leecher queue; upon service completion peers transit to a seeder queue, stay some exponential time and eventually leave the system. The defining feature of P2P is that the service capacity that controls the inner transition is state-dependent, growing with the total peer population. This Markovian model assumes implicitly that download requirements for individual peers are independent exponentials, a coarse assumption since peers are sharing the same content file. Despite this simplification, the resulting chain does not admit an analytic solution: [2] studies it numerically. This work and other relevant references are reviewed in Section 2.

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