# Performance evaluation of Peer-to-Peer file sharing systems: analytical models and simulation tools

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***Abstract*— Short attention has so far been payed to fundamental performance issues of Peer-to-Peer (P2P) file sharing systems. On one hand, this is probably due to availability of very few analythical and mathematical models which allow to carry out performance evaluation studies. On the other hand, general and reference simulation tools, which assist researchers in exploring P2P file sharing systems from performance evaluation point of view, do not yet exist. In this work we describe our research experience about P2P file sharing system performance evaluation. In particular we show how we have tried to tackle some of the numerous problems related to inclusion of network details in both analytical models and simulation tools.**

## I. Introduction

P2P file sharing systems are nowadays popular in such a way that dominant traffic type observed by Internet Service Providers [1] is associated with this kind of applications. Such popularity has increasingly called scientific community attention. Nevertheless, most of P2P file sharing research has so far been devoted to traffic measurement studies and to system design problems with subsequent proposal of new and different algorithms and solutions.

Our work follows instead the more recent direction of considering some fundamental performance issues. Actually very few works have explored basic performance questions. The first attempt to propose a mathematical abstraction for P2P file sharing systems has been presented in [2]. A multiple class closed queueing network is used to model the different phases following each other during a standard P2P file sharing program session: user connection, content searching and query processing, file transfer, user disconnection. So parameters such as user behavior in terms of connection and disconnection policies, content and query popularity distribution, are taken into account. In [3], service capacity, that is system capacity to serve a given content, is analyzed by means of a branching process and a simple Markovian model respectively in transient regime and in steady state regime. BitTorrent-like file sharing systems represent reference context. In particular, parallel download effect on service capacity has been highlighted. Factors such as number of on line peers, number of requests in progress or queued and number of peers that have finished their download, are shown as factors effecting service capacity. Authors of [4] derive a simple deterministic fluid model from Markovian model proposed in [3], in order to study peer number temporal evolution and average downloading time in BitTorrent-like file sharing systems. Interest parameters are the same than in [4].

In spite of different modelling scenarios described, it is possible to identify a common characteristic for the previous models. They refers only to application level dinamics and they ignore most of the complicated network level dinamics. So, for example, service rate associated with a given file is deemed proportional to peer access link capacity in all previous works; but access link capacities are deemed identical for every peer. Likewise, effect of congestions and round trip delays on transfer times and on service capacity are not considered. This is maybe the most serious limit in the previous models.

In reason of this, we are trying to develop analythical models allowing to study also the effect of network characteristics on P2P file sharing system performance. In particular, we have focused only on access link capacity heterogeneity and in [5] we have proposed a simple fluid model, that is an extention of that one in [4]. Two different classes of peers, associated with two different values of access bandwidth, have been taken in account. As consequence, resulting model exhibits higher complexity due to increase of differential equation number and presence of non linear term. We also had to cope with the need to characterize how potential uploading resources are shared between slow and fast users; assumptions that i) each peer establishes connections with all the available uploaders and ii) bandwidth of each connection is determined according to the max-min fair criteria, have provide us with a reasonable resource sharing criterion. Finally availability of model in [4] has made possible to compare performance indexes we have chosen for heterogeneous scenario with corresponding indexes of homogeneous scenario. Preliminary results so achieved seem to demonstrate that, depending on metrics used to compare bandwidth heterogeneous systems with bandwidth homogeneous systems, file diffusion dynamics can take naturally advantage of access link capacity heterogeneity.

Besides analytical models, generic simulation frameworks may greatly contribute to recent research efforts on P2P file sharing system performance evaluation. First of all, realistic P2P application simulators offer a valid alternative, every time parameters and factors to be modelled are so numerous and complex that relevant analytical model would be impossible to study. As we have experienced in our research work previously described, this always happens when network level dinamics are included in modelling P2P file sharing system functioning. Secondly, reference and generic simulation tools may usefully be used during validation process of analytical model results. We recall that often either model results are not validated or, as in [3], [4], they are validated by means of performance traces generated by trakers. This last kind of validation process is, however, too application-oriented. Thereafter realistic and generic simulator availability seems at this point a strong necessity.

Actually an increasingly large number of P2P simulators has recently emerged as mean to evaluate and test new algorithms and solutions prior to large scale deployment in existing P2P networks. Most of these simulators [6], [7], [8] have been conceived for a specific kind of P2P protocol and are only special-purpose. Moreover, because number of nodes to be simulated is of order of millions, scalability is a fundamental issue; so, in order to avoid overhead related to simulate network level details, many existing simulators [9], [10] focus only on application level details. Ignoring network aspects can lead to heavy inaccuracies and inefficiencies in simulation results; in reason of this, P2P simulators [11], [12] interacting with different packet level simulators have also been developed.

In this scenario, unavailability of general and reference simulation tools being evident, we have decided to implement our own P2P simulator. Its major avdantages are general-purpose scope and network level dinamic inclusion. More in details, simulator functioning revolves around three fundamental objects: *user*, *overlay*, *network*. *User* object is responsible to model peer behavior, that is parameters depending on peer decisions, such as connection and disconnection instants, shared file amount, ingoing and outgoing connection number, etc. *Overlay* object manages overlay topology and overlay interactions among peers. In other words, it handles peer queries on basis of content searching algorithm (centralized, with query flooding, with content hashing, etc) to be simulated. Currently only the centralized searching model is available, so *overlay* acts as central index of the shared resources. *Network* object manages network level topology and relevant connections: in particular, it attends to bandwidth allocation in compliance with max-min fair algorithm. Two simplifying assumptions have been made: graph reproducing network topology is completed, so there is no need to simulate intermediate routers; no bottleneck bandwidth is in the network, so only access link capacities effect download rate. Moreover, parallel downloading, content chunking and query queuing with FIFO processing are supported.

As regards content distribution model, file arrivals are modelled according to a Poisson process, that is in compliance with an exponential distribution of interarrival times. Specifically, when a content arrives into the system, original number of peers receiving it, follows a binomial distribution of parameter $p$ equal to probability that a generic peer owns a copy of that content. Likewise, every time a content arrives into the system, number of peer aiming at obtaining its copy, follows a binomial distribution of parameter $q$ equal to probability that a generic peer is interested in that content; $q$ seems likely to be higher than $p$. Time period that a peer is willing to share a given content, that is file lifetime, is not infinite: an user could in fact erase a file in his hard disk, because it's not more interested in that file, or it could remove it in order to make room for other new interest files. In particular, from the moment a peer receives a given file, it maintains file for a random time period exponentially distributed; as soon as this time elapses, peer does not share file and does not offer it for upload anymore. Moreover, users maintain a given interest for a finite time period; in this way they don't try uselessly to download a file ad infinitum. Like file lifetime, interest lifetime is exponentially distributed; average interest lifetime seems likely to be lower than average file lifetime.

As regards instead implementative details, we have realized our simulator in shape of discrete event simulator and C++ has been chosen as programming language. Events are associated with timestamps and are scheduled by a calendar executing them sequentially. In this way it is possible to simulate time concept and to give simulation time as input parameter. Other significant parameters it is possible to introduce from outside, are peer number, content and interest mean lifetime, probability that a generic peer owns a copy of a given content, probability that a generic peer is interested in a given content, connection interarrival mean time, connection mean duration, content length distribution, chunk length, peer bandwidth distribution.

As for most of existing P2P simulators, performed preliminary tests have revealed scalability problems: using more than thousand nodes requires too long simulation times. In reason of this, expedients and improvements are currently under study and deployment.

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