Modeling and Analysis of Large Scale Interconnected Unstructured P2P Networks

Rossano Gaeta, Riccardo Loti, Vincenzo Ciancaglini, Luigi Liquori

▶ To cite this version:

HAL Id: hal-00908800
https://inria.hal.science/hal-00908800

Submitted on 26 Nov 2013

Modeling and Analysis of Large Scale Interconnected Unstructured P2P Networks

Rossano Gaeta, Riccardo Loti
Dipartimento di Informatica
Università di Torino
Torino, Italy
Email: first.last@di.unito.it

Vincenzo Ciancaglini, Luigi Liquori
LogNet Team
INRIA Sophia Antipolis Méditerranée
Sophia Antipolis, France
Email: first.last@inria.fr

I. INTRODUCTION

Interconnection of multiple P2P networks has recently emerged as a viable solution to increase system reliability and fault-tolerance as well as to increase resource availability. In this paper we consider interconnection of large scale unstructured P2P networks by means of special nodes (called *synapses*) [1] that are co-located in more than one overlay. Synapses act as *trait d'union* by sending/forwarding a query to all the P2P networks they belong to. Modeling and analysis of the resulting interconnected system is crucial to design efficient and effective search algorithms and to control the cost of interconnection. Yet, simulation and/or prototype deployment based analysis can be very difficult - if not impossible - due to the size of each component (we consider large scale systems that can be composed of millions of nodes) and to the complexity arising from the interconnection of several such complex systems. To overcome this strong limitation, we developed a generalized random graph based model that is validated against simulations and it is used to investigate the performance of search algorithms for different interconnection costs and to provide some insight in the characteristics of the interconnection of a large number of P2P networks.

II. SYSTEM DESCRIPTION

We describe an overlay by means of its degree distribution $\{p_k\}$, i.e., the probability that a randomly chosen peer has k connections in the overlay ($\sum_{k=1}^{\infty} p_k = 1$). We consider a set of X unstructured P2P networks that are interconnected thanks to a subset of peers that belong to multiple overlays (*synapses*). Any peer may then belong to $i \in \{1, \ldots, X\}$ overlays (i is the *synapse degree*). The interconnected system is then described by $\{s_i\}$ ($i \in \{1, \ldots, X\}$) where s_i is the probability a peer belongs to i overlays ($\sum_{i=1}^{X} s_i = 1$).

The search algorithm we consider is probabilistic flooding: a peer starting a search sends *queries* to a randomly chosen subset of its one-hop neighbors. These nodes forward the queries to a randomly chosen subset of their one-hop neighbors, excluding the query originator, and so on until the maximum number of allowed hops, i.e. the query time-to-live (TTL). Each peer sends/forwards the query to one of its neighbors by tossing a coin whose weight is $0 < p_f \leq 1$.

Table I: Paper notation.

Parameter	Description
X	Number of interconnected P2P networks
$\{p_k\}$	Probability a randomly chosen peer has k connections (p.g.f. is $G_0(z) = \sum_{k=0}^{\infty} p_k z^k$) [2]
$\{r_k\}$	Probability a peer reached by choosing a random edge has k connections excluding the chosen edge (p.g.f. is $G_1(z) = G_0'(z)/G_0'(1)$) [2]
$\{s_i\}$	Probability a peer belongs to i overlays (p.g.f. is $F(z) = \sum_{i=0}^{\infty} s_i z^i$)
p_f	Probability to send a query to a neighbor
α	Resource popularity
TTL	Query time-to-live.

The goal of a search is to localize at least one copy of a resource. We represent resource popularity by $0 < \alpha \leq 1$, i.e., the probability that a randomly chosen peer owns a copy.

All the notation is summarized in Table I.

III. SYSTEM MODEL

If we consider one of the X P2P networks including the Synapse nodes then the p.g.f. for the number of connections of a randomly chosen peer can be written as $M(z) = s_1 G_0(z) + s_2 G_0^2(z) + \ldots + s_X G_0^X(z) = F(G_0(z))$, that is, if the chosen node is a degree 1 synapse (which happens with probability s_1) then the number of connections is represented by $G_0(z)$. If the node is a degree 2 synapse (which happens with probability s_2), then the number of connections is represented by the sum of two independent random variables whose p.g.f. is $G_0(z)$; a well-known property of generating function states that the generating function of the sum of two independent random variables is equal to the product of the respective generating functions yielding the $G_0^2(z)$ factor in the expression for $M(z)$. The same reasoning is valid for synapses whose degree is greater than 2.

A similar expression can be written for the neighborhood of a node reached by following one randomly chosen edge *excluding the selected edge*: $N(z) = \frac{G_1(z)}{G_0(z)} F(G_0(z))$.

A. Search algorithm

We denote as q_h the probability that h first hop neighbors received a query from the peer that started the search. This peer sends a query to one of its neighbors with probability p_f. Therefore, the number of neighbors that receive the

query follows a binomial distribution with parameter p_f. It is well known [2] that the probability distribution $\{q_h\}$ has p.g.f. given by $Q(z) = M(1 + p_f(z-1))$. Similarly, for the p.g.f. of the probability distribution describing the number of queries sent by a node reached by following a randomly chosen edge, we obtain $R(z) = N(1 + p_f(z-1))$.

If we denote as $Q_t(z)$ the p.g.f. for the probability distribution of the number of neighbors t hops away from a randomly chosen peer that received a query, we have that: $Q_1(z) = Q(z)$, $Q_2(z) = Q(R(z))$, and $Q_3(z) = Q(R(R(z)))$, etc. Since the p.g.f. of the sum of independent random variables is given by the product of the corresponding p.g.f., the total number of queries generated by a search issued by a randomly chosen peer is described by $T(z) = \prod_{t=1}^{TTL} Q_t(z)$ yielding the *average number of queries* $m = T'(1)$.

If we denote as w_h the probability that h first hop neighbors hold a copy of the requested resource *and* received a query from a peer that belongs to i overlays we note that the number of such neighbors follows a binomial distribution with parameter αp_f. If we denote as $H_t(z)$ the p.g.f. for the probability distribution of the number of neighbors t hops away from a randomly chosen peer that received a query *and* hold a copy of the requested resource then we have that: $H_1(z) = Q_1(1 + \alpha(z-1))$, $H_2(z) = Q_2(1 + \alpha(z-1))$, $H_3(z) = Q_3(1 + \alpha(z-1))$, and so on. Therefore, the total number of search hits is described by a probability distribution whose p.g.f. is given by $H(z) = \prod_{t=1}^{TTL} H_t(z)$ yielding the search *hit probability* $p_{hit} = 1 - H(0)$.

IV. Results

We show an example of the results we can obtain by solving our model for a very large scale system. Please note that it would be too computationally inefficient to use simulations or deployments to study the same system.

We consider a search algorithm with $p_f = 0.5$ and $TTL = 3$ in a system where $\alpha = 0.0001$. We analyze the values of p_{hit} and m for an increasing number of overlays (X) and four different configurations, with an increasing number of degree one synapse nodes in the system. In these evaluations the individual overlays have been modeled following the neighbors degree distribution measured in [3] and exploited in [4].

Figures 1 and 2 show results for four different configurations where the parameter s_1 indicates the share of degree one synapses nodes, while the remaining part $(1 - s_1)$ is equally distributed among the remaining $X - 1$ values, i.e., $s_i = \frac{1-s_1}{X-1}$ for $1 < i \leq X$. It can be noted that as s_1 decreases the p_{hit} and m values increase for all considered values of X. Furthermore, the effectiveness of the search algorithm (p_{hit}) is correlated with the average number of query messages (m). Finally, the probability of locating at least one copy of the resource can be increased by interconnecting more overlays.
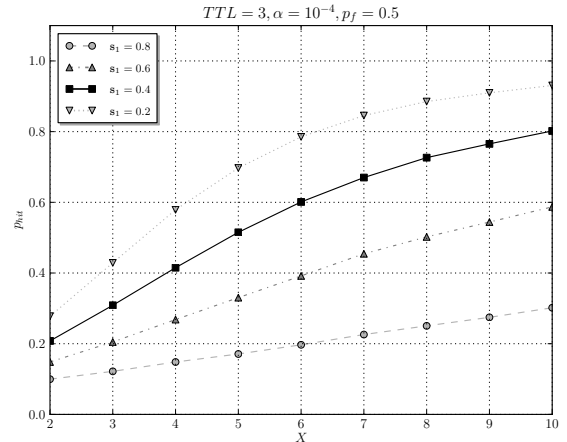

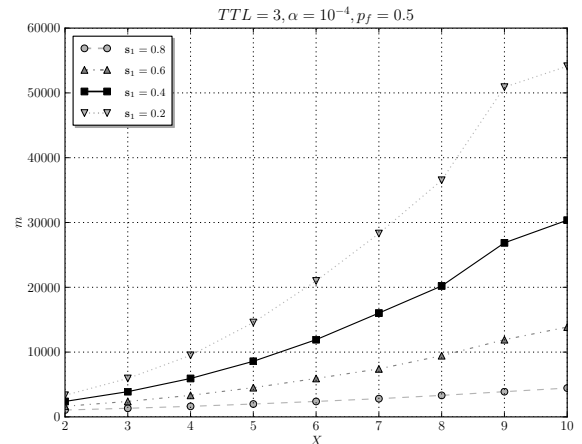Figure 1: p_{hit} for increasing number of overlays X.

Figure 2: m for increasing number of overlays X.

References

[1] L. Liquori, C. Tedeschi, L. Vanni, F. Bongiovanni, V. Ciancaglini, and B. Marinkovic, "Synapse: A scalable protocol for interconnecting heterogeneous overlay networks," in *Proc. of Networking '10*, 2010.

[2] M. E. J. Newman, S. H. Strogatz, and D. J. Watts, "Random graphs with arbitrary degree distributions and their applications," *Phys. Rev. E*, vol. 64, p. 026118, Jul 2001.

[3] R. Bolla, R. Gaeta, A. Magnetto, M. Sciuto, and M. Sereno, "A measurement study supporting p2p file-sharing community models," *Computer Networks*, vol. 53, no. 4, pp. 485–500, 2009.

[4] R. Gaeta and M. Sereno, "Generalized probabilistic flooding in unstructured peer-to-peer networks," *IEEE Transactions on Parallel and Distributed Systems*, vol. 22, pp. 2055–2062, 2011.