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C. Napoli, G. Pappalardo, and E. Tramontana

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# Improving files availability for BitTorrent using a diffusion model

Christian Napoli, Giuseppe Pappalardo, and Emiliano Tramontana Dipartimento di Matematica e Informatica, University of Catania Viale A. Doria 6, 95125 Catania, Italy Email: {napoli, pappalardo, tramontana}@dmi.unict.it

Abstract—The BitTorrent mechanism effectively spreads file fragments by copying the rarest fragments first. We propose to apply a mathematical model for the diffusion of fragments on a P2P in order to take into account both the effects of peer distances and the changing availability of peers while time goes on. Moreover, we manage to provide a forecast on the availability of a torrent thanks to a neural network that models the behaviour of peers on the P2P system.

The combination of the mathematical model and the neural network provides a solution for choosing file fragments that need to be copied first, in order to ensure their continuous availability, counteracting possible disconnections by some peers.

*Keywords*-Dependability, distributed caching, P2P, neural networks, wavelet analysis.

## I. INTRODUCTION

In peer to peer (P2P) systems using BitTorrent, a shared content (named torrent) becomes split into fragments and the rarest fragments are automatically chosen to be sent first to users requesting the file. Fragments availability is given by the number of peers storing a fragment at a given moment, and periodically computed by a server storing peer ids, fragments held and requested [7]. For computing the priority of fragments to spread, at best availability has been freshly updated, however peers often leave the system hence file fragments availability quickly changes, possibly before the least available fragments have been spread [13]. This occurs so frequently that such a fundamental BitTorrent mechanism may become ineffective, and as a result some fragments can quickly become unavailable. Moreover, when choosing fragments to spread, communication latencies [8], [18] among peers are not considered, therefore fragments spreading will surely occur sooner on peers nearby the one holding the fragment to spread. As a result, the furthest peers could disconnect before receiving the whole fragment.

This paper proposes a model for spreading file fragments that considers both a time-dependent priority for a fragment to spread and latencies among nodes. I.e. the priority of fragments to spread gradually changes according to the passing time and fragments availability. The priority variation is regulated in such a way that the availability of fragments is maximised while time goes.

Fragments to spread are selected according to the results of our proposed diffusion model, developed by analogy to a diffusion model on a porous medium. Moreover, we propose to characterise the typical availability of a torrent observed on the P2P system, by using an appropriate neural network. Then, the selection of fragments to spread aims at counteracting their decreasing availability estimated for a later time. Therefore, the proposed work aims at supporting *Quality of Service* and *dependability* of P2P systems by attributing a priority on both the fragment to spread and the destination peer. This in turn increases *availability* and *performances* [9], [10], [11], as well as consistency [1].

The rest of the paper is organised as follow. Next section provides the mathematical representation for the proposed model. Section III develops the model for the diffusion of contents on a P2P system. Section IV introduces the neural network that predicts the user behavious. Section V describes some experiments based on our proposed model and neural network predictions, as well as the preliminary results. Section VI compares with related work, and finally conclusions are drawn in Section VII.

# II. MATHEMATICAL REPRESENTATION

In order to put forward our analogy between BitTorrent and a physical system, some conventions must be chosen and some extrapolations are needed. We first describe a continuum system using a continuum metric, however later on we will single out a few interesting discrete points of the continuum. Due to the analogy to BitTorrent, we use a distance metric (named  $\delta$ ), which will be assimilated to the network latency among nodes, i.e. the hosts on a network holding seeds, peers or leeches.

For the nodes we use notations  $n^i$  or  $n^i_{\alpha}$ : the first indicates a generic *i*-esime node on the BitTorrent network, the second indicates the  $\alpha$ -esime node as seen from the *i*-esime node. Of course,  $n^i_{\alpha}$  and  $n^j_{\alpha}$  could be different nodes if  $i \neq j$ . Double indexing is needed since when we use something like  $\delta^{ij}$ , it will be representing the distance of the *j*-esime node as measured by the *i*-esime node. Moreover, let us express  $P_k^{ij}$  as the probability of diffusion of the *k*-esime file fragment from the *i*-esime node to the *j*-esime node. Finally, we distinguish between time and time steps: the first will be used for a continuum measure of temporal intervals and we will use for it the latin letter *t*, the second will indicate computational time steps (e.g. the steps of an iterative cycle) and we will use for it the greek letter  $\tau$ . Therefore, while  $\delta^{ij}(t)$  will represent the continuous evolution during time *t*  of the network latency  $\delta$ , which is measured by the *i*-esime node for the distance with the *j*-esime node, the notation  $\delta^{ij}(\tau)$  will represent the latency measured at the  $\tau$ -esime step, i.e. the time taken by a ping from the *i*-esime node to the *j*-esime node, only for a specific time step  $\tau$ . Finally, we will suppose that each node has the fragment  $z_k$  of a file *z* and is interested in sharing or obtaining other portions of the same file, hence we will compute the probabilitylike function that expresses how easily the *k*-esime shared fragment is being copied from the *i*-esime node to the *j*esime node at a certain step  $\tau$  and we will call it  $P_k^{ij}(\tau)$ .

Eventually, we are interested in an analytical computation for the urgency to share a fragment  $z_k$  from  $n^i$  to  $n^j$  during a time set  $\tau$ , and we will call it  $\chi_k^{i,j}(\tau)$ . In the following sections we will distinguish between an actually measured value and a value predicted by a neural network using a tilde for predicted values as in  $\tilde{x}$ .

# III. FRAGMENTS DIFFUSION ON A P2P NETWORK

In our work we compare the file fragments of a shared file to the diffusion of mass through a porous means. To embrace this view, it is mandatory to develop some mathematical tools, which we will explain in the following.

## A. Spaces and metrics

Users in a P2P BitTorrent network can be represented as elements of a space where a metric could be given by the corresponding network communication latency. Therefore, for each node  $n^i \in N$ , set of the nodes, it is possible to define a function

$$\delta: N \times N \to \mathbb{R} \ / \ \delta(n^i, n^j) = \delta^{ij} \quad \forall \ n^i, n^j \in N$$
 (1)

where  $\delta^{ij}$  is the amount of time taken to bring a minimum amount of data (e.g. as for a ping) from  $n^i$  to  $n^j$ . By using the given definition of distance, for each node  $n^i$ , it is also possible to obtain an ordered list  $\Omega^i$  so that

$$\Omega^{i} = \left\{ n_{\alpha}^{i} \in N \right\}_{\alpha=0}^{|N|} : \delta(n^{i}, n_{\alpha}^{i}) \le \delta(n^{i}, n_{\alpha+1}^{i}) \quad (2)$$

In such a way, the first item of the list will be  $n_0^i = n^i$ and the following items will be ordered according to their network latency as measured by  $n^i$ . Using this complete ordering of peers, it is possible to introduce the concept of content permeability and diffusion. Let us consider the files shared by one user of a P2P system: each file consists of fragments that can be diffused. Then, the diffusion of a file fragment can be analysed in terms of Fick's law.

## B. Fick's law and its use for P2P

Fick's second law is commonly used in physics and chemistry to describe the change of concentration per time unit of some element diffusing into another [21]. This work proposes an analogy between a P2P system and a physical system. The key idea is to model the sharing file fragments as the diffusion of a substance into a porous means along one dimension. Different places of the porous means would represent different P2P nodes, whereas distances along such a one-dimension would be proportional to the network latencies. Then, P2P entities would be accommodated into the formalism of equations (1) and (2).

Using both the First and Second Fick's laws, the diffusion of a substance into a means is given as the solution of the following vectorial differential equation

$$\frac{\partial \Phi}{\partial t} = \nabla \cdot (D\nabla \Phi) \tag{3}$$

where  $\Phi$  is the concentration, t the time and D the permeability of the means to the diffusing matter. Since this is a separable equation and we use a 1-dimensional metric based on the distance  $\delta$ , and assuming D as constant among the nodes, equation (3) can be written as a scalar differential equation

$$\frac{\partial \Phi}{\partial t} = D \frac{\partial^2 \Phi}{\partial \delta^2} \tag{4}$$

This partial differential equation, once imposed the initial and boundaries conditions, admits at least Green's Function as a particular solution [2]. Green's Function lets us study the diffusion dynamics of a single substance and can be rewritten as solution of the equation (4) in the form:

$$\Phi(\delta, t) = \Phi_0 \Gamma\left(\frac{\delta}{\sqrt{4Dt}}\right) \quad , \qquad \Phi_0 = \frac{1}{\sqrt{4\pi Dt}} \tag{5}$$

where  $\Gamma$  is the complementary gaussian error function.

 $\Gamma$  function should then be computed by means of a Taylor expansion. However, to avoid such a computationally difficult task, we use an approximation proposed in [6], where a pure exponential approximation for  $\Gamma(x)$  has been obtained, having an error on the order of  $10^{-9}$ . Then, it is possible to have the following equation

$$\begin{cases} \Phi(\delta, t) \approx \Phi_0 \left[ \frac{1}{6} e^{(\Phi_0 \delta)^2} + \frac{1}{2} e^{-\frac{4}{3} (\Phi_0 \delta)^2} \right] \\ \Phi_0 = (4\pi D t)^{-\frac{1}{2}} \end{cases}$$
(6)

for every node at a certain distance  $\delta \in \mathbb{R}^+$  at a time  $t \in \mathbb{R}^+$ .

#### C. From concentration to probability

In equation (6) the scaling factor  $\Phi_0$  is a function of the time t. On the other hand, the used formalism was developed mainly to focus on the distance  $\delta$  and managing t merely as a parameter. The above mathematical formalism is valid as long as the distances  $\delta(n^i, n^j)$  remain time-invariant. The common practice considers the distance between nodes  $\delta$  as time-invariant, however the actual network latencies vary (almost) continuously, with time, and a stationary  $\Omega^i$  ordered set is a very unlikely approximation for the network. In our solution, we make time-dependent the latency embedded into our model. In turn, this makes it possible to choose different fragments to be shared as time goes.

For the P2P system, the equation (6) states that a certain file fragment  $z_k^i$  in a node  $n^i$  at a time  $t_0$  has a probability  $P_k^{ij}(t_0, t)$  to be given (or diffused) to node  $n^j$ , at a distance  $\delta^{ij}(t_0)$  from  $n^i$ , within a time t, which is proportional to the  $\Phi(\delta, t)$  so that

$$P_k^{ij}(t_0,t) = p_k^{ij} \left[ \frac{1}{6} e^{\left( p_k^{ij} \ \delta^{ij} \right)^2} + \frac{1}{2} e^{-\frac{4}{3} \left( p_k^{ij} \ \delta^{ij} \right)^2} \right]$$
(7)

where the function  $p_k^{ij} = p_k^{ij}(t_0, t)$  carries both the diffusion factors and the temporal dynamics. And since we are interested in a simple proportion, not a direct equation, we can also neglect the factor  $4\pi$  and then write  $p_k^{ij}$  in the normalised form

$$p_{k}^{ij}(t,t_{0}) = \frac{1}{\sqrt{4\pi}} \cdot \frac{1}{\sqrt{D_{k}(t_{0})}} \cdot \frac{1}{\sqrt{t}}$$
(8)

It is now important to have a proper redefinition of the coefficient D. Let us say that  $T_k$  is the number of users using file fragment  $z_k$  (whether asking or offering it),  $S_k$  is the number of seeders for the file fragment and  $\rho_k$  is the mean share ratio of the file fragment among peers (and leeches), then it is possible to consider the 'urge' to share the resource as an osmotic pressure which, during time, varies the coefficient of permeability of the network D. In order to take into account the mutable state in a P2P system, D should vary according to the amounts of available nodes and file fragments. We have chosen to define D as

$$D_k(t_0) \triangleq \frac{T_k(t_0)}{S_k(t_0) + [T_k(t_0) - S_k(t_0)] \rho_k(t_0)}$$
(9)

by a formal substitution of D with  $D_k$  in  $\Phi_0$ , we obtain the analytical form of the term  $p_k^{ij}$ .

# D. Discrete time evolution on each node

Indeed, the physical nature of the adopted law works in the entire variable space, however for the problem at hand discrete-time simplifications are needed. Let us suppose that for a given discrete time step  $\tau = 0$  node  $n^i$  effectively measures the network latencies of a set of nodes  $\{n^j\}$ , then an ordered set  $\Omega^i$  as in equation (2) is computed. Now, every node  $n^i$  computes probability  $P_k^{ij}$  for each of its own file fragment  $z_k$  and for every node  $n^j$ . This probability corresponds to a statistical *prevision* of the *possible* file fragments spreading onto other nodes.

Suppose that for a while no more measures for  $\delta$  have been taken, and at a later discrete time step  $\tau$  file fragment  $z_k^i$  be copied to the first node to be served, which is chosen according to the minimum probability of diffusion, latencies and time since last measures were taken (see following subsection and equation (12)).

Moreover, such a file fragment is reaching other nodes if the latency for such nodes is less than time  $t^i$ , computed as

$$t_k^i(\tau) = \sum_{\alpha_k=0}^{\tau} \delta(n^i, n_\alpha^i)$$
(10)

Index k is used in equation (10) to refer to file fragment  $z_k^i$ .

Indeed, since nodes need and offer their own file fragments, the ordered set of nodes referred by a given node depend on resource  $z_k$ , i.e.  $\Omega_k^i = \{n_{\alpha_k}^i\}$ .

It is now possible to have a complete mapping of the probability of diffusion by reducing the time dependence from  $(t_0, t)$  to a single variable dependence from the discrete time-step  $\tau$ . For each resource  $z_k$  as  $P_k^{ij}(\tau)$  stated that it is possible to reduce  $D_k(t_0, t)$  to a one-variable function  $D_k(\tau)$  by assuming that at  $t_0$  we have  $\tau = 0$  and considering only the values of  $D_k(t_0, t)$  when t is the execution moment of a computational step  $\tau$ .

### E. Assigning priorities and corrections

Once all the  $P_k^{ij}(\tau)$  have been computed, and values stored to a proper data structure, it is actually simple to determine the most urgent file fragment to share, which is the resource that has the least probability to be spread, i.e. the k for which  $P_k^{ij}(\tau)$  is minimum.

Furthermore, we consider that while time goes on an old measured  $\delta$  differs from the actual value, hence the measure becomes less reliable. To take into account the staleness of  $\delta$  values, we gradually consider less bound to  $\delta$  the choice of a fragment, and this behaviour is provided by the negative exponential in equation (11). Given enough time, the choice will be based only on the number of available fragments. However, we consider that by that time a new value for  $\delta$  would have been measured and incorporated again into the model choosing the fragment.

Generally, for nodes having the highest latencies with respect to a given node  $n^i$ , more time will be needed to receive a fragment from the node  $n^i$ . We aim at compensating such a delay by incorporating into our model the inescapable latencies of a P2P network. Therefore, the node that will receive a fragment first will be chosen according to its distance.

In order to model the fact that distant nodes, having the highest values for  $\delta$ , will take more time to send or receive file fragments, we have chosen a decay law. Now it is possible to obtain a complete time-variant analytical form of the spreading of file fragments

$$\chi_k^{ij}(\tau) = \frac{e^{-c\tau\delta^{ij}}}{P_k^{ij}(\tau)} \tag{11}$$

where the decay constant c can be chosen heuristically, without harming the said law, and tuned according to other parameters. If k indicates a file fragment and  $k^*$  the index of the most urgent file fragment to share, this latter is trivially found as the solution of a maximum problem so that

$$k^* : \chi_{k^*}^{ij}(\tau) = \max_k \left\{ \chi_k^{ij}(\tau) \right\}$$
(12)

Of course, all the priorities depend on the value of the bidimensional matrix of values of  $P_k^{ij}$  (we mark that the index

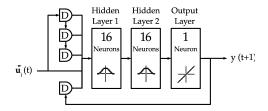


Figure 1. Topology of the WRNN

*i* does not variate within the same node  $n^i$ ). Among these values, there is no need to compute elements where j = i and for those elements where the node  $n^j$  is not in the queue for resource  $z_k$ . In both these cases it is assumed  $P_k^{ij} = 1$ . Moreover, after  $n^i$  having completed to transfer  $z_k$  to the node  $n^j$ , the element of indexes (j, k) is set to 1. In a similar fashion, each peer is able to identify a possible resource to ask for in order to maximize the diffusion of rare ones instead of common ones.

## IV. WRNN PREDICTORS AND USERS BEHAVIOR

In order to make the P2P system able to properly react to peaks of requests, as well as very fast changes of fragments availability and/or share ratio, we propose an innovative solution based on Wavelet Recurrent Neural Networks (WRNN) to characterise the user behaviour and producing a short-term forecast. For a given torrent, the wavelet analysis provides compression and denoising on the observed time series of the amount of users prividing or requesting fragments; a proper recurrent neural network (RNN), trained with the said observed time series, provides well-timed estimations of future data. The ensamble of the said wavelet analysis and RNN is called WRNN [5], [15]. [16] and provides forecasts for the number of users that will share a fragment. Several neural networks have been employed to find polaritons propagation and metal thickness correspondence [3]; to predict the behaviour of users requesting resources [17], to perform wavelet transform in a recursive lifting procedure [4], [20].

# A. WRNN setup

For this work, the initial datasets consists of a time series representing requests for a torrent, coming from peers, or given declaration of availability for the torrent coming from both peers and seeds. Independently of the specificities of such data, let us call this series  $x(\tau)$ , where  $\tau$  is the discrete time step of data, sampled with intervals of one hour. A biorthogonal wavelet decomposition of the time series has been computed to obtain the correct input set for the WRNN as required by the devised architecture shown in Figure 1. This decomposition can be achieved by applying the wavelet transform as a recursive couple of conjugate filters in such a way that the *i*-esime recursion  $\hat{W}_i$  produces, for any time step of the series, a set of coefficients  $d_i$  and residuals  $a_i$ , and so that

$$\hat{W}_i[a_{i-1}(\tau)] = [d_i(\tau), a_i(\tau)] \qquad \forall \ i \in [1, M] \cap \mathbb{N} \quad (13)$$

where we intend  $a_0(\tau) = x(\tau)$ . The input set can then be represented as an  $N \times (M + 1)$  matrix of N time steps of a M level wavelet decomposition, where the  $\tau$ -esime row represents the  $\tau$ -esime time step as the decomposition

$$\mathbf{u}(\tau) = [d_1(\tau), d_2(\tau), \dots, d_M(\tau), a_M(\tau)]$$
(14)

Each row of this dataset is given as input value to the M input neurons of the proposed WRNN (Figure 1). The properties of this network make it possible, starting from an input at a time step  $\tau_n$ , to predict the effective number of requests (or offers) at a time step  $\tau_{n+r}$ . In this way the WRNN acts like a functional

$$\tilde{N}[\mathbf{u}(\tau_n)] = \tilde{x}(\tau_{n+r}) \tag{15}$$

where r is the number of time steps of forecast in the future and  $\tilde{x}$  the predicted serie.

#### B. Predicted user behaviour

As described by equation (15), it is then possible to obtain a future prediction of the number of requests for a specific torrent, as well as its availability in the future. In fact, by considering both the predicted  $\tilde{x}_k(\tau_{n+r})$  and the modeled  $\chi_k(\tau_{n+r})$ , it is possible, at a time step  $\tau_n$ , to take counteracting actions and improve the probability of diffusion for a rare torrent. This is achieved, in practice, by using altered values for  $D_k(\tau_{n+r})$ , which account for the forecast of future time steps. Such modified values are computed by our WRNN, e.g. in a computing node of a cloud. Therefore, predicted values for  $T_k(\tau_{n+r})$ ,  $S_k(\tau_{n+r})$  and  $\rho_k(\tau_{n+r})$  are sent to each node acting as a peer.

Each time a new torrent becomes shared on the P2P network, then a new WRNN is created and trained on a server, e.g. requested from a cloud system, to provide predictions related to the availability and peers of the novel set of shared fragments for that torrent. The predictions will be sent to the peers periodically, and allow peers to update the values of  $D_k(\tau)$ . The update frequency can be tuned in order to correctly match the dynamic of hosts.

## V. EXPERIMENTS

As shown in Figure 2, for the initial condition of the P2P system some file fragments for a torrent happen to be heterogeneously spread among peers (e.g. no one shares fragment n. 2, and very few nodes have fragment n. 5). We report a simulation comprising 11 peers and 5 file fragments, and an evolution in only 5 time steps. In the order, step after step, peer  $n^0$  selects file fragment  $z_4$  and sends this to peer  $n^{10}$ . Both the fragment to spread and the destination peer have been chosen according to equation (12).

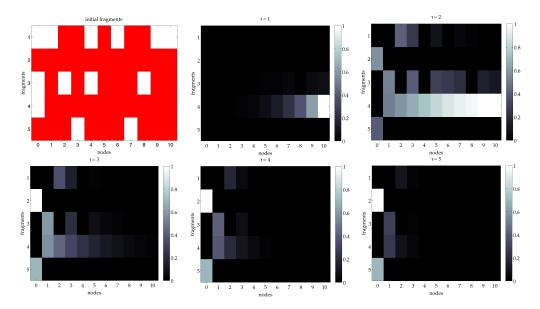


Figure 2. In order: the initial condition (white cells represent the fragments), the normalised  $\chi_k^{ij}(\tau)$  for a certain node  $n^i$  at different time steps  $\tau$ 

Later on, as soon as possible, peer  $n^0$  selects another fragment, i.e.  $z_3$  to spread. Such a fragment could be send just after the transfer of the previous fragment has been completed, or concurrently to the first transmission. The shown evolution does not consider that the file fragment could have been passed, e.g., to node  $n^{10}$ , and so that for the next time step the value of  $\chi$  for  $n^{10}$  would drop to zero. Note that the highest values of  $\chi$  are an indication of the urgency of receiving a fragment.

The described model and formula allow subsequent sharing activities, after the initial time steps, to be determined, in terms of which fragments should be sent. Figure 2 shows that after the first time steps it becomes more and more urgent for node  $n^0$  to obtain the missing fragments  $z_2$  and  $z_5$ . It is possible to see that the highest priority is for fragment  $z_2$ since its share ratio and the relative availability are very low with respect to fragment  $z_5$ . This was the expected behaviour of the developed model. For the simulation shown in Figure 2, all fragments, except  $z_2$  since it is actually unavailable, would be spread to peers in a very low number of time steps. Figure 3 shows the decay of several computed  $\chi$  for different peers requiring fragment number 3. On the long run, this law will benefit nearby nodes, while on the short term, distant nodes are given the highest priority.

# VI. RELATED WORK

Several studies have analysed the behaviour of BitTorrent systems from the point of view of fairness, i.e. how to have users contribute with contents that can be uploaded by other users, levelling the amount of downloads with that of upload. Fewer works have studied the problem of unavailability of contents in P2P BitTorrent networks. In [19], authors proposed to order peers according to their

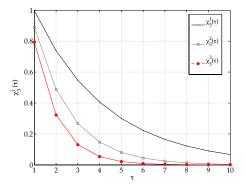


Figure 3. Time decay of normalised  $\chi^j_k(\tau)$  for increasing time steps  $\tau$ 

uploading bandwidth, hence when providing contents the selection of peers is performed accordingly. One of the mechanism proposed to increase files availability has been to use multi-torrent, i.e. for ensuring fairness, instead of forcing users stay longer, they provide their contribution to uploaders for fragments belonging to different files [12]. Similarly, in [13] authors show that by using multi-torrent availability can be easily increased, and confirm that fast replication of rare fragments is essential. Furthermore, bundling, i.e. the dissemination of a number of related files together, has been proposed to increase availability [14].

The above proposed mechanisms differ from our proposal, since we take into account several novel factors: the dynamic of data exchange between distant peers, a decay for the availability of peers, and the forecast of contents availability. Such factors have been related into a proposed model that manages to select the rarest content to be spread taking into account the future availability, and the peers that should provide and take such a content.

# VII. CONCLUSIONS

This paper proposed to improve availability of fragments on a P2P system by adopting a mathematical model and a neural network. The former describes the fragments diffusion and the urgency to share fragments, whereas the latter provides an estimation of the availability of peers, and hence fragments, at later time. By using the estimate of future availability into the diffusion model, we can select the fragments that need to be spread to counteract their disappearance due to users disconnections.

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