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Perspective of space and time based replica population organizing strategy in unstructured peer-to-peer networks

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ABSTRACT

File replication and replica management are effective strategies to ensure file availability and improve the efficiency of user access in peer-to-peer (P2P) networks. In this paper, inspired by the replica population model in population ecology, we propose a replica population organizing strategy for unstructured P2P networks. We model the activities of a P2P node from a time-and-space perspective, and model a file's availability from the perspective of node accessibility. The strategy automatically adjusts the relationship between the replica population and the environment, as well as the relationship between the replica population and the demand of users. Replica reproduction is well controlled by the strategy to adapt to the dynamic nature of P2P networks. We employ a push–pull approach, which enables replicas to change adaptively, both in their quantity and their distribution. Experimental results show that our strategy is able to adapt to the dynamic P2P environments. It effectively improves file availability, boosts retrieval efficiency, and meanwhile reduces the cost in network bandwidth.

1. Introduction

Peer-to-peer (P2P) is a resource-sharing technique that suits for a dynamic large-scale network. It requires no central-control mechanism. Nodes in such network are functionally equivalent. Each node plays two roles at the same time, a client that receives services and a server that provides services. There are two types of P2P networks. The first is the structured P2P networks represented by DHT. This kind of network maps resources to nodes using hash operations in a rigid manner. It has the advantage of high retrieval efficiency, but autonomy of nodes is jeopardized. As a resulting issue, nodes are difficult to adapt to rapid changes in the network. The second is the unstructured P2P networks. They have advantages over the structured ones in better node autonomy and high fault-tolerant ability, which makes them more popular and more broadly used. For such networks, an important research topic is how to provide data storage service with high availability.

File replication and replica management have been found as effective strategies for ensuring file availability and improving retrieval efficiency by distributing the replicas in different nodes in unstructured P2P networks (Agneeswaran and Janakiram, 2009; Feng et al., 2007). However, existing studies pay little attention to the dynamicity (i.e. the churn) of the network. Instead, many of them seek to optimize the amount and distribution of replicas merely from the perspectives of network bandwidth and response time. Thus, the practical needs of P2P networks are often not satisfied. It has been shown that on P2P networks, as compared to other types of storage systems, the high dynamicity of nodes and high frequency of temporary data unavailability have much greater impacts (Agneeswaran and Janakiram, 2009; Tati and Voelker, 2006). Therefore, it leads to unaddressed problems and challenges to replica management in P2P networks.

In this paper, we focus on the replica management problem in unstructured P2P networks. We propose a replica population organizing strategy from a time-and-space perspective for unstructured P2P networks.

Our contributions are the following:

(1) We model node activities from a time-and-space perspective, and model the availability of a file and its replicas from the perspective of node accessibility. Based on the modeling, replicas are organized and able to better adapt to the dynamicity of P2P networks.
(2) We build an ecological model for replica management. The model is constructed on the basis of the relationship between a replica and its environment, as well as the replica population's self-adaptive adjustment mechanism. In this way, the replica population is optimized and dynamically controlled in

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terms of its size (the amount of replicas in the population) and distribution. In replica reproduction, our strategy uses a push–pull approach to allocate replicas and their indices, which improves the quality of serving shared files and the utilization of storage resources.

(3) We introduce a replica lifecycle management mechanism to manage storage space. The mechanism is designed based on the inspiration that in ecology, every individual has its own growth process. Similarly, in our approach, replicas could be in different lifecycles, and for a replica, its lifecycle can change adaptively. Moreover, there are competitions for resources between replicas. Based on those, our strategy can effectively avoid the bump phenomenon in replica substitution. The needed replicas could survive, and consequently, the utilization of storage space is improved.

In addition, our replica population organizing mechanism does not require any modifications in the routing protocols originally used in the P2P networks. All required information can be obtained incidentally. Therefore, our strategy can be easily applied to any existing unstructured P2P network.

The remainder of the paper is organized as follows: Section 2 introduces related work on the replica management strategy in P2P networks. In Section 3, we describe the characteristics of node activities and the problem of node accessibility, and then we model node activities from the time-and-space perspective. In Section 4, we analyze the characteristics of user requests in dynamic networks, and then model file availability based on node accessibility. In Section 5, we propose the replica population organizing mechanism based on the node time-and-space perspective and a model in population ecology. In Section 6, we evaluate the effectiveness of our strategy by comparing it to existing strategies. In Section 7, we conclude the paper and point out future work.

2. Related work

Many replica management strategies have been proposed for P2P networks.

Based on when a file is replicated, the strategies can be classified into two categories: the static replication strategy and the dynamic replication strategy. In the static replication strategy, the amount and locations of the replicas are already determined in the initialization phase of the network, such as CFS (Dabek et al., 2001). This type of strategy is easy to implement, but cannot adapt to the dynamic environment of P2P networks. On the contrary, the dynamic replication strategy creates replicas dynamically and allocates them automatically, and thus it better fits a dynamic environment.

Based on where a file is replicated, the replication strategies can be classified into three categories: the owner replication, the path replication and the random replication. The owner replication is that after a node successfully retrieves a file, the node becomes the owner of the file, and it shares the file and provides retrieval services for the file. For a single file, the number of its replicas is positively correlated to how often the file gets requested. The path replication is that after a successful retrieval, the replicas of the file are replicated on all nodes in the path through which the response message was forwarded. This replication strategy suffers from the problems of large bandwidth and storage consumption. The random replication distributes replicas on the nodes which are selected according to some probability. The effectiveness of this strategy is not guaranteed under a network with an unknown structure.

HFOCC (Li et al., 2008) is a hotspots-free overlay cooperative caching scheme. It targets at heterogeneous nodes and unbalanced workload. It adopts a proactive replication strategy for hotspot files, which improves throughput, resource utilization, and balances workload. However, this approach does not take user request behaviors (Wu and John, 2012) into account, nor could it guarantee the availability of those non-hotspot resources.

SADDRES (Hai-yan et al., 2005) is a dynamic replica creation strategy that suits for enterprise data grid applications. When a user requests some data, this strategy considers the spatial locality of the data. In particular, it treats the nodes which have a data transfer rate higher than a certain threshold as a storage alliance. The strategy replicates files across alliances, and distributes the replicas to appropriate locations within an alliance. In these two ways, the strategy makes a spatially-reasonable data distribution. Jianjin and Guangwen (2009) studied the relationships between the distribution of user requests and the distribution of the requested replicas. Based on the study, they built an optimized model on access latency, so that the amount of the replicas is optimized. The two above studies are similar in both focusing on the spatial locality of user requests, further standing on this point, to optimize the distribution of replicas. However, neither considers the over-time changes in user requests and node availability. In consequence, they cannot adapt to the P2P networks with high dynamicity and heterogeneity.

Research in Feng et al. (2007) proposed a proactive replication strategy on the basis of the overlay network topology. This strategy considers the impacts on the retrieval success rate from node connectivity and replica sparseness. Based on how popular the requested data is, the strategy presents the optimal distribution model for node connectivity. Specifically, the strategy distributes the more-frequently-requested files to those high-connectivity nodes so as to improve the hit rate. The strategy makes several assumptions. First, all nodes in the network have the same frequency of sending requests. Second, the frequency of requesting certain data is stable. However, based on the measures to a real network environment (Klemm et al., 2004), it has been found that different users have different frequencies of requesting resources, and the frequencies are changing over time. In addition, in a P2P network, there are limited bandwidth and storage space, which can result in an expensive overhead if data are too frequently migrated (Klemm et al., 2004).

EDRS (Xing et al., 2009) is a dynamic replica creation strategy that works for the hierarchical education resource grid. It considers the impacts from network bandwidth and file sizes. It decides to replace a replica based on the result of a comparison, in which it compares the benefit brought by creating a new replica against the cost caused by deleting an existing replica. Meanwhile, if a node cannot make a replica for a file, it hands the task over to its neighbor. Having the same issue, this strategy also fails to consider nodes being dynamic. Besides that, in the study, no approaches were proposed in terms of replica distribution and storage management. As a result, this strategy does not work for a P2P environment where nodes have high dynamicity and the frequency of requests changes in a large amount.

As we introduced above, existing strategies optimize replica management merely by adjusting the number of replicas or the locations of them (Feng et al., 2007; Jianjin and Guangwen, 2009). Few considerations have been given to the over-time changes in nodes, users and replicas. However, these changes characterize the dynamicity of a P2P network, and appropriately handling those changes is the key to improve data availability in a P2P network. Other existing strategies (Hai-yan et al., 2005; Xing et al., 2009) focus more on the network structures, while pay less attentions to node dynamicity and the characteristics of user requests.