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A Novel Replication Model with Enhanced Data Availability in P2P Platforms

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Abstract

With the development of P2P technology, more and more distributed systems are applying it for deploying large-scale storage infrastructure. However, maintaining desirable data availability in P2P environments is still an opening issue because of the vulnerability of participated peers. In this paper, a novel replication model is proposed to improving the data availability of P2P storage platforms. In the proposed replication model, the probability of peer's failure is estimated by semi-Markov chain, which enables us to significantly improving the prediction accuracy of peer's failure in a given period. Massive experiments are conducted in a real-world P2P platform to examining the performance of the proposed replication model, and the results indicate that it can achieve better tradeoffs between performance and data availability comparing with other replication schemes.

Keywords: *Peer-to-Peer; Distributed Storage; Data Replication; Peer Availability*

1. Introduction

In the past few years, peer-to-peer (P2P) technology has rapidly developed as an effective paradigm for sharing various resources over the Internet [1]. The P2P networks usually organize peers in a decentralized way to enhance reliability in resource sharing. Resources can be arbitrarily distributed into peer nodes without a structure, or they can be distributed following certain structures such as Distributed Hash Tables (DHTs). Although, P2P platforms are famous for the accommodation and utilization of numerous unstable peers, their core services rely heavily on stable peers which have a large session time length [2, 3]. As a result, most of existing P2P storage platforms are still facing a challenging issue, which is how to maintain the data availability in such a volunteer-participating environments [4, 5]. Typically, P2P storage service often relies on data replication technique which maintains multiple data replicas on each peer [6]. By this way, even if some replicas become unavailable because of network failing or peers leaving, the target data can still be obtained by accessing other online replicas. However, existing data replicating techniques have many shortcomings that need to be addressed. For example, when a P2P platform runs over a long period, it must produce more and more replicas so as to compensate for others lost to peer failures, which in turn consume a large amount of resources including bandwidth, CPU and disk space [7, 8]. Meanwhile, many recent studies indicated that the most of peers (also called participants) in real-world P2P platforms are quite unstable. For example, the session time of many peers are often less than one hour [9]. Therefore, the P2P storage platforms have to deal with the dilemma that how to provide satisfactory quality of service (QoS) through those unstable peers. Existing works on this issue have proposed several techniques, including *Super Nodes* [10], *Stable Neighbour* [11] and *Flat Peers* [12]. So, how to achieve optimal

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tradeoffs between performance and data availability becomes the most key issue in P2P storage platforms.

In order to overcome the problem of data availability, we proposed a novel technique which can figure out the probability of peer's failure during a given period. In this way, we can estimate the failure probability of any groups of peers so as to estimate the optimal number of replicas that can achieve better tradeoffs between performance and data availability in P2P platforms. In addition, our technique applies several approximate methods to reduce the computation costs so as to obtain better tradeoffs between complexity and accuracy. To test the effectiveness of the proposed technique, we implement it in a real-world P2P storage platform and use various traces to evaluate its performance. The rest of this paper is organized as following: In Section2, related work is discussed; The many ideology of the proposed replication model is described in section 3; In Section 4, massive experiments are conducted to investigate the effectiveness of the proposed method; Finally, Section 5 concludes the paper with a brief discussion of our future work on this study.

2. Related Work

Like the other distributed processing paradigm, the quality of service (QoS) of P2P platforms becomes an important issue as soon as its application in business and commercial areas. As a result, many studies on P2P's QoS have been presented in recent years. For instance, In [13], the authors presented a probability-based technique to study the quality of data delivery service in P2P platforms. In addition, they also proposed a novel model which incorporates both bandwidth and data availability of P2P network for evaluating the QoS of P2P video streaming platforms. In [14], the authors studied the dependability of peers with aiming to improving the QoS of service selection in P2P environments. The most significance of this work is that the authors found that node trust, available capacity, and lifetime positively will affect peer's reputation. Based on this, they proposed a manual trust model and an automatic trust model that remove the influence of additional factors on reputation to truly reflect node trust. In [15], the authors proposed a QoS-aware service discovery method which can be applied in P2P-based cloud environments. In their method, peer nodes engaged in P2P network are firstly registered to its neighbours in a flooding way, and then the QoS-aware service discovery is promoted in a probabilistic flooding way according to the network traffic.

Since the data availability is always a critical problem in P2P storage platforms, many studies have taken efforts on improving the data availability so as to provide better QoS for end-users. For instance, In [16], the authors proposed a P2P desktop grid framework which utilizes resource availability prediction technique to improve the execution performance of upper-level applications. In [17], an epidemic protocol is proposed to improving the file-sharing in eDonkey network. By performing extensive experiments (about 27 days) in a real-world P2P system, Le-Blond *et al*. indicated that the proposed epidemic protocol is effective to quickly choosing optimal peers when sharing files in P2P environments. In [18], Tu *et al*. proposed a model which combines data replication and data partition to assure data availability, confidentiality, accessing efficiency for data-intensive grid applications. The proposed model is described as a multi-objective problem and a genetic algorithm is also developed to obtain the Pareto-optimal solutions.

As noted above, data replication is a well-known technology to improving the dependability of P2P platforms. As a result, it also been extensively studied in the past few years. For instance, Mondal *et al*. proposed an *Economic scheme for Adaptive Revenue-Load-based dynamic replication scheme* (namely E-ARL) in mobile P2P platforms [19]. E-ARL uses an economic scheme for efficiently managing mobile P2P resources in a context-aware manner by facilitating effective replica hosting and message relaying by peers. In addition, it collaboratively performs bid-based replica allocation to facilitate better quality of service. In [20], the authors developed a proactive data replication mechanism and incorporated it into GirdCast system. Based on the new mechanism, a peer can proactively replicate data chunks to stable cache servers for future sharing, when it has high possibility to leave the overlay. In [21], the authors addressed the issue of optimal replication ratio in P2P-VoD systems. The most important result in this study is that the conventional *proportional replacement policy* is 'sub-optimal', and they also proved that *passive replacement policy* can achieve the optimal replication ratios under certain conditions.

3. Data Replication Model

3.1 Theoretical Analysis on Replication Schemes

When applying replication scheme in a P2P storage platform, raw data item will be broken into m equal-sized linear chunks, and then n-m additional parity chunks will be generated. So, data replication technology can be generally described as an m/n scheme [22]. Generally speaking, there are two operations (erasure and bucket) in an m/n scheme. Erasure operation must retrieve data from at least m different peers to maintain data integrality, while bucket operation only needs to access a single peer if that copy is complete. So, there are several approaches to implementing the m/n scheme, such as Replication Coding (RC), Erasure Coding (EC), Erasure Coding with Primary Copy (EC/1P), Erasure Coding with mirrored Primary Copy (EC/2P), Bucket Coding with Mirrored Copy (BC/1R), Bucket Coding with two Mirrored Copies (BC/2R). Assuming that the availability probability of all peers is constant noted as p, the replication degree is noted as r, then it is easy to theoretically derive the formulations of data item availability with different m/n schemes, which is summarized in Table 1.

Table 1. Data Availability with Different Replication Scheme

Replication Scheme	Availability of Data Item
RC	$1-(1-p)^n$
EC	$\sum_{i=m}^{n}\binom{n}{i}p^i(1-p)^{n-i}$
EC/1P, 2P	$1-(1-p)^r\left[1-\sum_{i=m}^{n}\binom{n}{i}p^i(1-p)^{n-i}\right]$
BC/1R, 2R	$1-(1-p)\left[1-\sum_{i=m}^{n-1}\binom{n-1}{i}p^i(1-p)^{n-i-1}\right]$

The other critical issue on data replication scheme is the data accessing costs. Typically, the data accessing cost in a P2P platform can be measured by the number of active connections in P2P network. By using the above formulations shown in Table 1, we can further derive their corresponding data accessing costs as Shown in Table 2.

Table 2. Data Accessing Costs with Different Replication Scheme

Replication Scheme	Data Accessing Cost
RC	$p+2p(1-p)+\cdots+(n-1)(1-p)^{n-2}p+n(1-p)^{n-1}$

EC	$\sum_{i=m}^{n-1} i \binom{i-1}{m-1} p^m (1-p)^{i-m} + n\left[1-\sum_{i=m}^{n-1}\binom{n-1}{i} p^i (1-p)^{n-i-1}\right]$
EC/1P	$p+(1-p)(1+Cost_{EC})$
EC/2P	$p+2p(1-p)+(2+Cost_{EC})(1-p)^2$
BC/1R, 2R	$p+(1+Cost_{EC})(1-p)$

Based on the theoretical analysis in Table 1 and Table, most of the previous studies concentrate on achieving a balancing tradeoff between data availability and the corresponding costs. However, the assumption that the availability probability of all peers is constant and identical is not true in real-world environments. More importantly, assuming the data availability is equal to the peer availability might result in overestimation of the former since other types of failures will also lead to lose of data item. To overcoming these problems, we firstly present a more accurate failure model to evaluate the data availability, and then design novel replication model which can estimate the failure probability of any groups of peers so as to estimate the optimal number of replicas that can achieve better tradeoffs between performance and data availability in P2P platforms.

3.2 Markov-Chain based Failure Model for Peers

Let $W_i(X_i>t)$ be the conditional probability that peer i fails permanently if it has been unavailable for t time units, where X_i is the random variable representing the duration between its failure and the following recovery. To obtain the formulation of $W_i(X_i>t)$, we define three states for any peers, including ACTIVE, INACTIVE, FAILED. Let p_i be the probability that peer i changed from ACTIVE to FAILED, 1-p_i be the probability that peer i changed from ACTIVE to INACTIVE. Therefore, the life cycle of a peer can be characterized as a continuous Markov chain. Let T_i^f be the mean failure duration, T_i^r be the mean recovery time, T_i^l be mean life duration. As the life cycle of a peer is characterized as a continuous Markov model, the peer's lifetime is the absorption time of the chain in FAILED state. If the peer generates N transient failures before it fails permanently, we can obtain the following equation:

$$N = \frac{T_i^l - T_i^r}{T_i^f + T_i^r} \tag{1}$$

If N follows a geometric distribution, then it also satisfies $\tilde{N} = (1-p_i)/p_i$. In many real-world systems, T_i^l is often sufficiently larger than T_i^l. So, it is easy to obtain that $p_i = (T_i^f + T_i^r)/T_i^l$. Using Bayesian theory on the Markov model of peer life cycle, we can obtain that

$$W_i(X_i > t) = \frac{p_i}{(1-\Pr\{X_i > t\})p_i + \Pr\{X_i > t\}} \tag{2}$$

where $\Pr\{X_i>t\}$ is the cumulative distribution function of random variable X_i, which can be obtained by analyzing the logs of the given P2P platform.

3.3 Data Replication Model

Considering a replication scheme with replication degree *r*, it is well known that larger *r* will increase the data availability, while also resulting in more resource costs including bandwidth, disk space and *etc*. In this work, we try to find an approach to obtain an optimal *r* which can lead to better tradeoff between availability and costs. As noted above, assuming the data availability is equal to the peer availability might result in overestimation of the former since other types of failures will also lead to lose of data item. When using a replication scheme, the system needs to maintain *r* replicas for all data items at any time.

As soon as the replication degree of a data item falls below *r*, it is responsible for creating new replicas so as to maintain desirable availability. As any data item has *r* replicas, the data availability is the probability that at least one of the *r* replicas of the data item is available, which means that it can noted as $1-(1-W_i(X_i > t))^r$. If a P2P storage platform is required to maintain the data availability above ψ for all data items, then we can easily have $r \geq \ln(1-W_i(X_i > t))/\ln(1-\psi)$. This is the lower-bound of replication degree with constraints to data and peer availability. To improving the predication accuracy of data availability, the peer group that holding the target replica should be taken into consideration. So, we must figure out that how many replicas still available during the runtime. Let *W* be a random variable representing the number of remaining replicas at a given time. Therefore, we can have

$$\Pr\{W \leq k\} = \sum_{i=1}^{n} \prod_{i \notin G} \left(\frac{p_i}{(1-\Pr\{X_i > t\})p_i + \Pr\{X_i > t\}} \right) \cdot (1-\Pr\{W = k\}) \tag{3}$$

$$\Pr\{W = k\} = \sum_{i=1}^{n} \prod_{i \in G} \left(\frac{\Pr\{X_i > t\}(1-p_i)}{(1-\Pr\{X_i > t\})p_i + \Pr\{X_i > t\}} \right) \tag{4}$$

where *G* is the peer group that holding the replica of the given data item.

To figure out the number of required replicas during runtime, we can directly compare the actual alive replicas with the lower-bound of replication degree. However, such an approach may lead to lower data availability in real-world systems. So, we presented to a novel technique, namely *Prediction-based Replication Schem*e (PRS), to direct the operation of replication scheme. The goal of RPS is to achieve better tradeoffs between data availability and system performance. To do this, we use the condition max(Pr{$W \leq k$}) to estimate the number of alive replicas of any given data item. Therefore, the problem of obtain optimal replication degree can be formulated as following:

$$\begin{aligned} &\arg\max_{0<k\leq n}(\Pr\{W \leq k\}) \\ &s.t.\ r \geq \ln(1-W_i(X_i > t))/\ln(1-\psi) \\ &\quad\ r \leq n-m \end{aligned} \tag{5}$$

To solve this constrained optimization problem, the time complexity is O(2^n), since we must try all the possible combinations among the peer groups that holding the data replica. Fortunately, we can use approximation method to simplify the computation since the most of the variables in (5) should be integer. More importantly, the constrained conditions have directly limited the searching range of the optimal solution. So, the practical computation cost is very low.

4. Experiments and Performance Evaluation

4.1 Experiment Settings

In the experiments, a P2P test-bed is deployed in our HP Networking Center to examine the performance of the proposed PRS. The underlying networking resources consist of eleven high-performance clusters, which are organized as volunteer computing system by using OmniRPC middleware [23]. In this test-bed, there are about 1400 PCs and 100 servers. As we only need to test the P2P storage service, the disks of all the PCs and half of the servers are configured as storage peers, and the total storage space is about 225 TB. In each cluster, one of the servers is configured as master peer which is responsible for monitoring the other peers in this cluster and maintaining the global DHT. The two traces are used in our experiments to simulate the real-world availability. The first is Farsite which logs the availability of about 50,000 PCs within Microsoft for 35 days. The average availability in Farsite trace is about 85%, and there are about 10% peers are always available during the whole trace. The other trace is Overnet which consists of the availability logs from about 2500 peers over a week. Unlike the Farsite trace, the availability of peers is much lower than that in Farsite. According to our analysis, the overall online time of the peers is approximately 15%. At the beginning of each experiment, over 5000 files with average size 135 MB are randomly scattered among 800 peers. During the experiments, the master peers will issue file download operations among different peers in their own cluster through OmniRPC. In addition, all the experimental logs are recorded by the mast peers grouped by different clusters.

4.2 Comparison on Data Availability

In the first experiment, we examine the data availability with different replication schemes. To compare the experimental results, four replication schemes are selected, including RC, EC, EC/1P and BC/1R. In each test, we use different traces (Farsite and Overnet) to simulate the peer availability in the tested P2P platform. For clearly representation, the data availability are categorized by 11 groups each coming from different storage clusters, and the results are shown in Figure 1 and Figure 2.

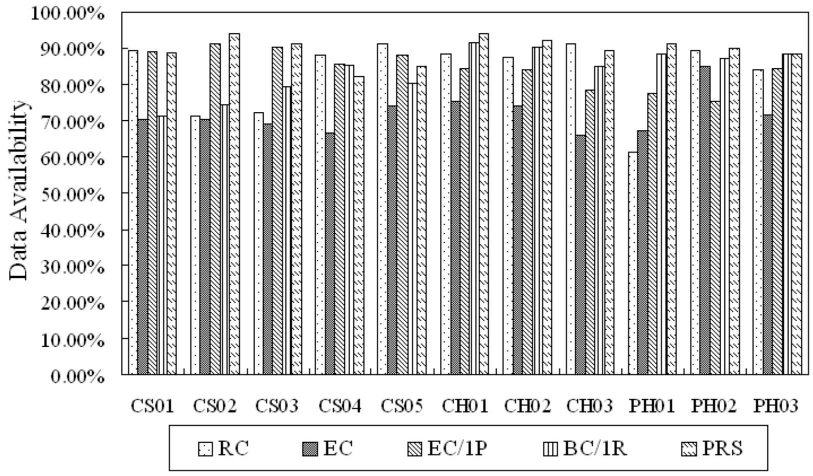


Figure 1. Comparison on Data Availability with Farsite

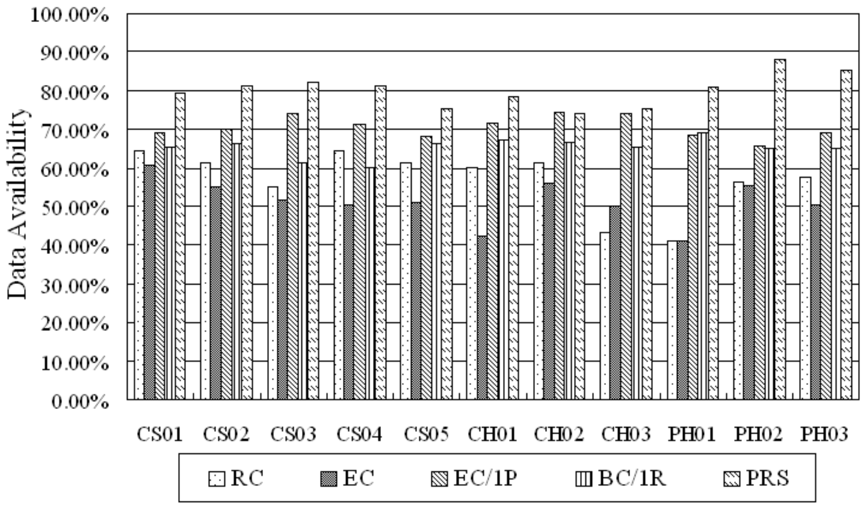


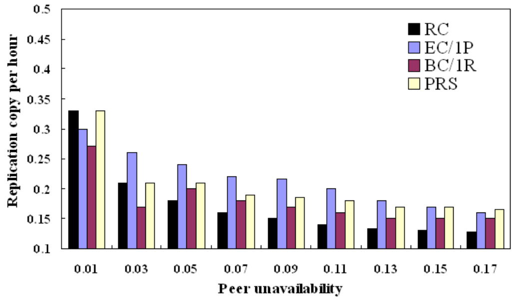
Figure 2. Comparison on Data Availability with Overnet

According to the results in Figure 1 and Figure 2, we can see that different traces have significant effect on the data availability. As noted in above, the peer availability in Overnet is much lower than that in Farsite. As a result, we can see that such a difference on peer availability will directly lead to lower data availability in all cases. Fortunately, the relationship between the two measurements is not linear. By our experimental results, although the overall peer availability of Overnet is lower than that of Farsite by about 50%, it seems that the overall data availability under Overnet trace is about 15% lower than that under Farsite. Such a result clearly indicates that using replication scheme in P2P platform is quite important for improving the data availability.

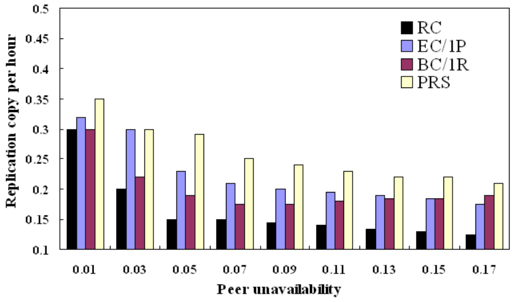
In most cases of this experiment, the data availability of PRS is the highest among the tested schemes. As to other schemes, the data availability of EC/1P is very close to the proposed PRS, and EC scheme performs worst in a term of data availability in all the schemes. As noted in Section 3.1, the only difference between EC and EC/1P is that the latter keeps a primary copy for each data item. So, this result indicates that the primary copy is of significant importance for improving the data availability. As to BC/1R and RC schemes, their data availability decreased very quickly with lower peer availability trace which can be found by comparing the results. So, although replication scheme can mitigate the negative effects of peer failure, different replication schemes still have different adaptiveness. In our test-bed, the clusters can be categorized into three groups. CS01 ~ CS05 are deployed in the School of Computer Science, CH01 ~ CH03 belong to School of Chemistry, and the left belong to School of Physics. According to our logs from the HP Networking Center, the average workloads on CS01 ~ CS05 are relatively stable comparing with the others. On the other hand, the clusters in School of Chemistry and Physics often need to execute some large-scale data-intensive simulations, which require large volumes of storage space. As a result, we can see that the data availability on CS01 ~ CS05 is overall higher than that on other clusters.

4.2 Comparison on Replication Performance

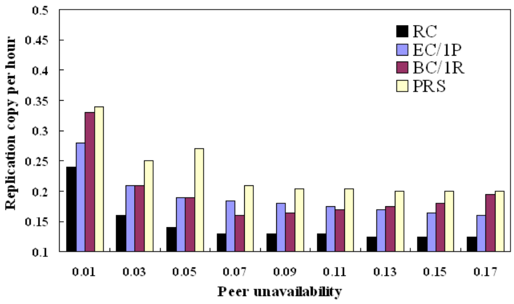
In the second group of experiments, we want to test the performance of various replication schemes. Generally, for a replication scheme its performance often involves various measurements, including average number of replicas, average utilization of replicas, average utilization of bandwidth and *etc*. In this paper, we introduce a novel metric, namely replication copy per hour (RC/h), to evaluate the performance of a replication scheme. The advantage of the RC/h metric is that it takes into account both efficiency-related measurement and cost-related one. Unlike the first experiments, in this experiment we need to test the RC/h metric under various peer availability. So, we generate synthetic traces based on the original Farsite trace, and the peer unavailability is gradually increased from 0.01 to 0.17. As our test-bed is based on OmniRPC platform which is designed for volunteer computing, we need to take the peer's local workloads into consideration. So, we designed a simple benchmark which can occupy the peer's local resources (including CPU, memory, and I/O) according to pre-defined ratio that noted as β. In the experiment, we change β from 0.2 to 0.5 and the experimental results are shown in Figure 3(a)~(d).



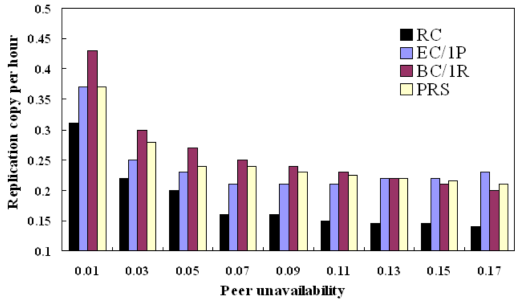
(a) β=0.2



(b) β=0.3



(c) β=0.4



(d) β=0.5

Figure 3. Comparison on RC/h Metric with Different Background Workloads

According to the above experimental results, RC/h metric will be decreased with the increasing of peer unavailability. This is because that higher peer unavailability will depress replication copy operations so as to maintain desirable performance for the P2P storage platform. An important result shown in this experiment is that when peer unavailability increases from 0.01 to 0.05, the RC/h metric will be decreased quickly, while such a decreasing becomes quite slow when peer unavailability is in higher level. Such a finding indicates that all the tested replication schemes are fault-tolerance in the term of peer availability. When β=0.1 (which means the local workload on peers is very light), the RC/h of EC/1P is the highest in all replication schemes. This means that EC/1P is able to achieve better tradeoffs between replication performance and costs.

As noted in Section 3.1, EC/1P needs to keep a primary copy of all the data items. So, to keep the data availability desirable, more replication copy operations are necessary. Since the β value is very lower, peer's local workload will not have too many effects on the replication copy operations. When β=0.3 and 0.4, we can see that the RC/h metric of PRS is generally higher than that of other schemes. By examining the logs, we find that the average load intensiveness on the peers in normal working time is about 30% ~ 40%. So, the real-world background workload in peers can be exactly simulated by setting β in [0.3, 0.4]. As shown in Figure 3(b) and (c), even the peer unavailability is over 17%, our PRS still can keep the RC/h value above 0.25. Among the tested schemes, the RC scheme performs worst in all cases in the term of RC/h metric. To further investigate the performance of our PRS, we record the response time of the test-bed when the file size and available peers are dynamically changed, and the results are shown in Figure 4.

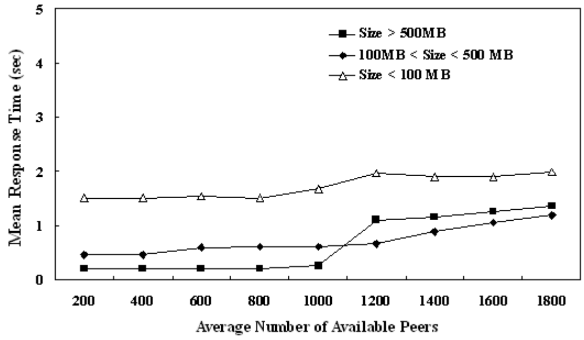


Figure 4. Mean Response Time of PRS on Various File Sizes and Availability Peers

As shown in Figure 4, the mean response time for transferring large files is much less and small files when using PRS. Such a result indicates the PRS tends to keep more replicas for large files among peers, especially when the available peers are sufficient. This feature is very effective for those non-dedicated distributed system, such as volunteering computing platforms. As noted in Section 4.1, our experimental test-bed is based on OmniRPC which is designed for providing service for remote users only when local nodes are in idling state. So, we can conclude that the PRS can be easily to deployed on such kind of P2P storage platforms.

6. Conclusion

To improving the data availability in P2P storage platforms, we designed a prediction-based replication scheme (PRS) in P2P storage platforms. By modeling the probability of peer's failure during a given period, our PRS is enabled to evaluate the failure probability of any groups of peers so as to estimate the optimal number of replicas. In a real-world P2P platform, we conducted extensive experiments to investigate the effectiveness and performance of PRS. According to the experimental results, the PRS can achieve better tradeoffs between performance and data availability comparing with many existing replication schemes. Currently, the PRS is implemented as standalone model which relies on OmniRPC platform for execution. In the future, we are planning to incorporate it into other P2P middleware and conduct more experiments to test its performance. In addition, we also plan to apply the PRS in mobile-P2P environment, in which energy-efficiency optimization will be our primary objective.

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