Optimization of the Recovery Time of Pyramid Code in Distributed Storage System

Wei Geng¹, Hang Zhang¹, Longxiang Liu², Rui He², and Dan Tang¹*

¹School of Software Engineering, Chengdu University of Information Technology, Chengdu, Sichuan, 610225, China
²The Software Engineering Technology Research Support Center of Informatization Application of Sichuan.

*Corresponding author’s e-mail: tangdan@foxmail.com

Abstract. In large scale distributed storage systems, erasure code is a basic technology that provides high reliability at low cost. Compared with traditional redundancy technology, erasure coding technology has low redundancy and high flexibility. Therefore, it is a good choice for distributed systems to construct Pyramid codes that are flexible and suitable for a variety of application scenarios, but its disadvantage is that the data recovery time is still long. To address the above problems, in this paper, we propose an Active Fault-Tolerant Pyramid (AFTP) based code, which dynamically adjusts the length of the group in the Pyramid code and the original data block correlation with redundant blocks by using the hard disk fault prediction model based on the decision tree to reduce the length of the group of data blocks in a potentially faulty hard disk, which can be used for multiple hard disk failures. All read and recovery operations are performed within the group, reducing recovery time without adding additional storage overhead. To verify the validity of the AFTP code, we conduct intensive experiments on the distributed storage system based on Ceph. The results show that, compared with Basic-Pyramid (BP), the recovery time of AFTP code is reduced by 8%-64%, and compared with the commonly used classic block codes, the recovery time of AFTP code is reduced by 11%-52%.

1. Introduction

IDC released the latest version of the white paper "Data Age 2025" [1]. The whitepaper has the theme of "Digitalization of the World from Edge to Core". The forecast of the total amount of global data in 2025 has increased from 163ZB to 175ZB. This means that in the current era of science and technology, the growth of information data is explosive, and the explosive growth of data poses a huge challenge to the security and reliability of distributed storage systems.

In order to protect user data, the storage system usually uses a certain redundancy technology to achieve the purpose of data protection. Commonly used redundancy technologies include replication [2] and erasure code[3]. Copy technology directly copies multiple copies of the original data and stores them separately on different nodes of the distributed storage system, using high redundancy rates in exchange for high fault tolerance. Erasure code encodes the original data to obtain redundant data, and stores the original data and redundant data on different nodes to achieve the purpose of fault tolerance. It has the advantages of low redundancy and high flexibility, but the disadvantage is that the recovery time is relatively long.

Faced with the dilemma of passive fault tolerance mode, active fault-tolerant mode can predict hard
disk failure, migrate and protect potentially dangerous data in advance, and fundamentally improve the reliability of the storage system. The hard disks in the storage server now use "Self-Monitoring, Analysis and Reporting Technology" (SMART), which can reflect the various states of the hard disk in real time. The specific research method is to collect SMART data information and system events of a large number of hard disks in advance, and establish a hard disk failure prediction model and then monitor the status of the working hard disk in the storage system in real time, use the prediction model to predict potential hard disk failure, and eliminate potential failures in order to achieve the purpose of improving system reliability.

Combining erasure code technology with hard disk failure prediction technology fundamentally reduces the cost of erasure code repair and improves the reliability of the storage system. At present, there have been relevant studies combining erasure codes with hard disk failure prediction technology. For example, Li et al. copied and backed up data from a potentially faulty hard disk to another healthy hard disk [4]. Although this method effectively reduces the cost of data repair, it greatly increases the extra storage consumption. Zhang et al. combined the LRC code with the hard disk failure prediction model to divide the hard disk that is about to fail into smaller groups. When repairing the data, it reduces the amount of data read from the healthy hard disk, thereby reducing the repair cost [5]. However, this method is only applicable to single hard disk failure, and has no good effect on multiple hard disk failures.

The Pyramid code [6] has a flexible structure and can set different generation rules according to fault tolerance requirements, and has low repair cost, and is suitable for a variety of application scenarios. Therefore, this paper combines active fault tolerance technology with Pyramid code, and proposes a local repair code AFTP based on active fault tolerance, which can dynamically adjust the association between the original data block and the redundant block for multiple hard disk failures, and divide predicted potentially faulty hard disks into the same group, so that all repair and read operations are performed in the group when recovering data, reducing the amount of read data read without increasing additional storage space, shortening recovery time, and maintaining system stability.

The organization of this paper is as follows: Section 2 introduces the relevant concepts of the technology used in the paper. Section 3 gives a detailed description of the specific method of the AFTP code proposed in this article, and gives specific examples. Section 4 conducts experiments related to the recovery time and update penalty of the AFTP code, and compares it with typical erasure codes. Finally, the summary of the full text is given.

2. Related Overview and Problem Definition

2.1. Related concepts of hard disk failure prediction technology
The active fault tolerance technology was built on the SMART technology hard disk failure prediction model from the beginning. When the model predicts that the hard disk will fail [7], an alarm will be issued. If the data is backed up in time, the fault tolerance mechanism can ensure the stability of the system. The hard disk failure prediction model is based on a large amount of hard disk data for analysis and prediction. Each piece of hard disk data collected contains multiple attributes. Even if the data attributes collected by hard disks produced by different manufacturers are different, most of the attributes are the same. Such as, spin up time, reallocated sector count, high fly writes, and current pending sector count. In order to make the prediction result more accurate and reduce the algorithm complexity of the model, some redundant attributes are usually deleted, and only the basic attributes are retained as the input characteristics of the model. The representative attributes are shown in the following table:

| Attribute ID | Attribute     |
|-------------|---------------|
| 1           | Spin Up Time  |

Table 1. Representative SMART Attribute
2.2. Problem definition

2.2.1. Recovery time.
The time consumed by erasure codes in data recovery. Data recovery will occupy the storage server's computing and memory resources. If the recovery time is too long, the resources will be occupied for a long time, and the system's operating load is too heavy, which may cause the data on the remaining healthy hard disks to fail. Therefore, for erasure codes in distributed storage systems, the shorter the recovery time, the better.

2.2.2. Update penalty.
After the erasure code is encoded, the amount of data to be read by the erasure code group is adjusted according to the results given by the hard disk failure prediction model. The smaller the update penalty, the smaller the impact on the system and ensure the stable operation of the storage system.

3. The design of AFTP code

3.1. Selection of hard disk failure prediction model algorithm
SMART technology judges the quality of a hard disk by setting a threshold in advance. The technology is simple, but it cannot effectively predict hard disk failure. In the experimental data, the fault false alarm rate of SMART technology can reach 0.1%, but it can predict that the hard disk failure is only up to 10%, and the prediction accuracy rate is very limited.

In order to improve the detection rate of hard disk failures, a lot of research work uses statistics or machine learning algorithms to establish hard disk failure prediction models. For example, Elkan[8] used Bayesian classification algorithm to reduce the false alarm rate of hard disk failure prediction to 1% based on SMART attributes, and the accuracy rate reached 55%. Hughes [7] used the statistical method and the rank sum test method to achieve a false alarm rate of 0.5% and an accuracy rate of 60%. Zhu et al. adopted algorithms of artificial neural network[9] and decision tree[10] which can achieve a false alarm rate of 0.1% and an accuracy rate of 95%.

An excellent hard disk failure prediction model should have a high accuracy rate and a low false alarm rate. In this paper, the SMART data open sourced by Hughes et al. is used in the experiment. The data contains 178 healthy hard drives and 191 faulted hard drives. The two most common artificial neural networks and decision trees in the current hard drive failure technology are used to measure the false alarm rate and accuracy.

In the test, 10 features were sampled on the SMART dataset. The 10 features are shown in Table 1. The sampled data set was randomly split into a training data set and validate the data set to test the data set. They account for 70%, 20% and 10% of the total data, respectively. The test performance is shown in the following table:

| Algorithm               | FDR/% | FAR/% |
|-------------------------|-------|-------|
| BP Neural Network       | 94    | 2.64  |

### Table 2 Performance Comparison BP Neural Network and Decision Tree
It can be seen from Table 2 that the artificial neural network and decision tree can achieve higher FDR and lower FAR. The rules generated by the hard disk failure prediction model based on the decision tree are easier to understand and can clearly reflect the cause of the hard disk failure. Therefore, the hard disk failure prediction model based on the decision tree was selected.

3.2. The algorithm of AFTP code
The algorithm design process of AFTP code is as follows:

Step 1: Divide the original data blocks into several groups, calculate and generate global redundant blocks and local redundant blocks, and store them in different hard disks.

Step 2: According to the results of the hard disk failure prediction model, the block data contained in all hard disks of the system is divided into two states, healthy blocks and bad blocks. Bad blocks are the block data in the hard disks about to fail.

Step 3: Adjust the position of the bad block. Select the group with the largest number of bad blocks, and exchange the healthy blocks in the group with the bad blocks of other groups. When the number of bad blocks in a group is equal to the number of local redundant blocks, the group with the second largest number of bad blocks is to be found. The second group and the third group contain the same number of bad blocks, so the second group is randomly selected.

Step 4: All adjusted groups regenerate locally redundant blocks.

Step 5: When the bad block fails, read the block data in the group to repair the lost block data of the failed disk.

Step 6: After repairing the lost block data, restore the bad blocks and healthy blocks that were previously adjusted to their original positions.

Suppose that as shown in Fig. 1, D1, D2, D6, and D9 are derived from the hard disk failure prediction model as bad blocks in the stripe.

As shown in Fig. 2, first, selecting the group with the largest number of bad blocks is needed, and the first group is selected. Since the number of bad blocks in this group is equal to the number of locally redundant blocks, the group with the second largest number of bad blocks is to be found. The second group and the third group contain the same number of bad blocks, so the second group is randomly selected. The next step is to replace bad block D9 in the third group with healthy blocks D5 in the second group, so that the remaining bad blocks are all in the second group.

Since the data blocks of the two groups have changed, the two groups regenerate local redundancy Q22, Q23, Q32, Q33. When bad blocks of the two groups fail due to hard disk failure, only a total of 4 blocks of data are needed to repair the two lost blocks D1, D2 read the D3, D4 data blocks and P11, P12 local redundant blocks in the first group. Read the D7, D8 data blocks and Q22, Q32 local redundant blocks in the second group. Only 4 blocks of data are needed to repair the two missing blocks D6 and D9. The BP code to repair the four missing blocks needs to read 4 blocks of data in each of the three
5

groups, and a total of 12 blocks of data can be repaired. Compared with BP code, the AFTP code can reduce the repair cost by 33.3%.

4. Evaluation

4.1. Experimental environment
In order to test all aspects of AFTP code in a real distributed environment, an erasure code test platform was built based on the Ceph distributed storage system. The erasure code test platform used in the experiment contains a total of 20 nodes, 2 clients, and 2 Monitor nodes, and the remaining nodes are used as OSD storage nodes. Each node is equipped with a Core processor of i5-4200U 1.6GHz, memory size 8G, solid state hard disk size 500G, and 1GBps Ethernet card. Each node runs on the Centos 7.0 system, and all have Python 2.7 and Ceph 10 installed.

4.2. Experimental comparison indicators and methods
The experiment is divided into two parts in total. The first experiment compares recovery time of AFTP code and other erasure codes. First, we compare the recovery time of AFTP code and BP code. Secondly, we compared the recovery time between the AFTP code and the pLRC code using hard disk failure prediction technology. Finally, we compare the recovery time of the AFTP code with the SHEC[11], DLRC[12], and LRC code commonly used in distributed storage systems. The second experiment tests the update penalty of the AFTP code. The update cost refers to the amount of data to be read when adjusting the erasure code group according to the results given by the hard disk failure prediction model. In the above experiment, the file upload data size is 1GB, and the default data block size is 8MB.

4.3. Average recovery time

4.3.1. Comparison of the average recovery time between AFTP code and BP code

![Fig.3 Comparison of the average recovery time of AFTP code and BP code](image_url)

Fig. 3 shows the comparison of the average recovery time of the multi-node hard disk failure of (13,8) AFTP code and BP code. The abscissa in the figure represents the number of failed hard disks, and the ordinate represents the time it takes to recover. Since most of the repairs of the AFTP code can be repaired within the group, the amount of data read is small, and the recovery time is less than the BP code. When the number of multi-node hard disk failures of AFTP code is 2 or 3, the recovery time is about 6%-35% less than that of BP code.
4.3.2. Comparison of recovery time between AFTP code and pLRC code

Fig. 4 is the comparison of the average recovery time of the multi-node hard disk failure of (13,8) AFTP code and pLRC code. The abscissa in the figure represents the number of hard disk failures, and the ordinate represents the time it takes to repair. It can be seen from the following figure that when the multi-node hard disk failure is repaired, the recovery time of the AFTP code is shorter than that of the pLRC code by approximately 38%-52%.

4.3.3. Comparison of Recovery time between AFTP code and several classic block codes

Fig. 5 shows the recovery time comparison of (15,10) AFTP code, (15,10) LRC code, (16,10) SHEC code, and (16,10) DLRC code. The abscissa in the figure represents the number of hard disk failures, and the ordinate represents the time it takes to recover. When two or three nodes fail, the recovery time of AFTP code is about 26%-48% shorter than that of LRC code, and the recovery time of AFTP code is about 11%-13% shorter than that of SHEC code. The recovery time of the AFTP code is shorter than that of the DLRC code by approximately 22%-25%.

4.4. Average update penalty

Fig. 6 Average update penalty
Fig. 6 shows the update penalty of AFTP code. It can be seen from the figure that its update penalty is proportional to the number of bad blocks that need to be moved. The more bad blocks that need to be moved, the greater the update penalty. Although it will bring a certain update penalty when adjusting the position of the bad block, but compared with its shortened data recovery time, it is still within the acceptable range.

5. Conclusion
In this paper, the hard disk failure prediction model based on the decision tree is applied to the Pyramid code, and the group length of the Pyramid code is dynamically adjusted. A local repair code AFTP based on active fault tolerance is proposed. This scheme can effectively shorten recovery time without adding additional storage overhead.

Acknowledgments
This work was financially supported by two projects of Sichuan Province Science and Technology Department Artificial Intelligence Major Project(2019YFG0398) and Sichuan Province Science and Technology Department Artificial Intelligence Major Project(2018GZDZX0030).

References
[1] David Reinsel, John Gantz, John Rydning. (2018) Data Age 2025. https://www.seagate.com/cn/zh/our-story/data-age-2025/
[2] Li Jing, Wang Gang, Liu Xiaoguang, et al. Review of reliability prediction for storage system [J] .Journal of Frontiers of Computer Science and Technology, 2017,11(3):341-345(in Chinese)
[3] Wang Y, Sun W, Zhou S et al. Key technologies of distributed storage in cloud computing environment [J]. Journal of Software, 2012(04):232-256.(in Chinese)
[4] Peng Li, Jing Li, Rebecca J Stones, et al. ProCode: A Proactive Erasure Coding Scheme for Cloud Storage Systems[C]// IEEE Symposium on Reliable Distributed Systems (SRDS 2016). IEEE, 2016.
[5] Zhang X Y, Xu J, Hu Y. Predictive Local Repair Codes in Cloud Storage Systems [J]. Journal of Computer Research and Development, 2019, 56 (9).
[6] Huang C, Chen M, Li J. Pyramid codes: Flexible schemes to trade space for access efficiency in reliable data storage systems[C]//Sixth IEEE International Symposium on Network Computing and Applications (NCA 2007). IEEE, 2007: 79-86.
[7] Hughes, G. F., Murray, J. F., Kreutz-Delgado, K., & Elkan, C. (2002). Improved disk-drive failure warnings. IEEE transactions on reliability, 51(3), 350-357.
[8] Hamerly G, Elkan C. Bayesian approaches to failure prediction for disk drives[C]//ICML. 2001, 1: 202-209.
[9] Bingpeng Zhu, Gang Wang, Xiaoguang Liu. Proactive drive failure prediction for large scale storage systems[C]// IEEE Symposium on Mass Storage Systems & Technologies. IEEE, 2013.
[10] Murray J F, Hughes G F, Kreutz-Delgado K. Hard drive failure prediction using non-parametric statistical methods[C]//Proceedings of ICANN/ICONIP. 2003.
[11] Miyamae T, Nakao T, Shiozawa K. Erasure code with shingled local parity groups for efficient recovery from multiple disk failures[C]//10th Workshop on Hot Topics in System Dependability (HotDep 14). 2014.
[12] Meng Y, Zhang L, Xu D, et al. A Dynamic Erasure Code Based on Block Code[C]//Proceedings of the 2019 International Conference on Embedded Wireless Systems and Networks. Junction Publishing, 2019: 379-383.