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A Comparative Study on Fault-Tolerant Coding Techniques in RAID6 Analyzing the Efficiency and Limitation of EVENODD and RDP Codes

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Abstract:

With the development of computer science, the application of information storage in various fields such as business, military, gaming, and more has been playing a important role in our day-to-day life. This paper provides a systematic analysis of the current academic literature on data storage, offering an overview of RAID storage technology. It discusses the historical development of RAID technology, including real-world application examples, and highlights some researchers' innovative upgrades to the technology. The paper elucidates the details and applications of the EVENODD and RDP algorithms, which are closely related to RAID technology, and analyzes the error correction performance of these two algorithms in scenarios where only a single device fails, supported by relevant calculations. The analysis concludes that the RDP algorithm has an advantage in recovering from single device failures when comparing EVENODD and RDP. Finally, the future prospects and some new application scenarios of RAID data storage technology are discussed.

Keywords:RAID technology,EVENODD,RDP.

1. Introduction

The times are advancing and society is developing. In the current information-based environment, data storage technology is a very important major sector. Data storage is saving digital information on various storage media. Storing data securely and completely in a computer system is a challenging task that requires the utilize of various algorithms and technologies. It is significant for the security of information, the recovery of lost data, and the communication and sharing of information.

Above all, this paper expounds the background of RAID technology. The full name of RAID is "Redundant Arrays of Independent Disk [1]. It was proposed in 1987 by three computer scientists from the University of California. RAID technology enables parallel data access primarily due to its use of striping. Additionally, when disk failure occurs, RAID uses redundancy to recover the data from the failed disk. These advantages of RAID technology result in a high-performance, highly reliable, and large-capacity disk storage system [1]. Moreover, there are many components or details which are related to RAID. This paper simply introduces three important hardware firstly, parity, Storage Controller and I/O. Parity is the redundant information, Its function is to protect and recover data. Storage Controller is a hardware and software component. It is responsible for managing disks and data allocation. I/O means that computer systems or devices establish connections with the external environment, such as data exchange. From the angle of RAID technology, it is not difficult to find that with continuous advancements in technology, RAID technology has undergone multiple upgrades. It is profound that the utilize of double parity checks displaced the single parity check from the angle of storage technology [2]. Obviously, It is the enhancement of RAID 6. Therefore, in practical application, it can be analyzed that RAID 6 architecture excels in fault tolerance compared to other RAID levels. This superiority allows RAID 6 to recover data even when any two disks in the array fail [3].

Then, the relationship between the RAID6 and EVENODD or RDP is simple to be understood. Not only the EVENODD, but also the RDP is a type of algorithm to calculate the two parity of RAID6.By using the algorithm of EVENODD or RDP, RAID6 can deal with the two disks failed and recover it. However, using different algorithm to solve different problems is important. Different algorithm has a large amount of disadvantage and advantage.

Finally, in general, RAID is widely used in normal life. For example, the storage of videos in surveillance systems, medical records in the medical industry, and data in the scientific field all rely on RAID technology.

The section 2 is literature review, it covers the research of RAID. The Section 3 is methodology and theoretical basis, it covers the encoding and decoding of two types of algorithm.

2. literature review

The storage of videos in surveillance systems, medical records in the medical industry, and data in the scientific field all rely on RAID technology. The history of RAID 's development is ordered. After analysis, the evolution from RAID 0 to RAID 6 first achieved data redundancy, then introduced dual parity, and finally combined different RAID techniques to form RAID 10, RAID 50, and RAID 60, significantly enhancing performance and fault tolerance, albeit with increasing costs [2].Researchers have introduced an advanced RAID 6 technology called RAID 6L, which creatively employs a hash list as the key in-memory metadata structure in memory[3]. This innovation not only improves the recovery speed from disk failures but also addresses the write performance issues inherent in the RAID 6 architecture[3]. However, it comes at the cost of reduced reliability and increased log space consumption[3].Through the research of scientists, the combination of RAID and remote storage has led to the development of the dRAID system which accelerates RAID storage and achieves linear scalability within the limits of network bandwidth[4]. However, it also introduces additional network overhead and consumes a certain amount of CPU resources[4].In practical applications, scholars have applied RAID 6 to NAND flash memory, ensuring data integrity in cases where up to two chips fail. This implementation leverages RAID 6's high fault tolerance and maintains chip throughput. However, it also increases the complexity of hardware design[5].RAID technology can also be applied to code review tasks, reducing the workload of manual code reviews and contributing to modern code platforms like GitHub[6]. However, it currently faces challenges such as detection accuracy[6].In brief, RAID technology is continuously being improved and upgraded, and it is widely applied across various fields. Its strong fault tolerance and storage capabilities have always been its strengths, but the increased design complexity and space requirements are also its drawbacks.

EVENODD, as an important algorithm in RAID, has accumulated a significant amount of research findings. EVENODD is an MDS code composed of a data matrix and a parity matrix that only requires XOR operations[7]. EVENODD is widely used and is particularly popular in data centers and cloud storage. It has the advantages of high encoding efficiency and high decoding efficiency that it can handle two or fewer disk errors[8].However, it does not have strong fault tolerance. It can handle two or fewer disk errors[8].Building on EVENODD, researchers developed EVENODD+, which improves the original computational complexity and reduces the amount of computation required for encoding and decoding[9]. However, this may result in higher hardware requirements[9]. Scholars have unified EVENODD and RDP through research and further proposed the Vandermonde matrix based on EVENODD[10]. This not only increased the algorithm's efficiency but also improved decoding efficiency in special cases[10]. However, in practice, it imposes relatively high demands on hardware[10].In summary. EVENODD is an excellent algorithm, but its high hardware requirements for practical use and upgrades are well recognized.

RDP is also an important algorithm in RAID6, and scientists have accumulated considerable research on this algorithm.RDP is also an MDS code composed of a data matrix and a parity matrix, requiring only XOR operations[7].RDP codes exhibit excellent performance in both encoding and decoding, while also allowing the system to manifest strong adaptability to varying storage requirements[11]. However, when a data block is updated, RDP codes require the updating of three parity blocks, which increases overhead[11].RDP codes can be applied in cloud storage, with the advantage of high reliability, as they can repair multiple node failures[12]. However, the disadvantage is that they can cause increased system recovery latency during data repair[12].Some scholars have also upgraded and modified the RDP code, proposing TRD-RDP, which can repair three disk failures, significantly enhancing fault tolerance[13]. However, the XOR operations have become more complex, and the decoding process now requires two additional XOR operations[13].Overall, RDP has high performance and reliability, with a wide range of applications and low defect levels.

3. Methodology and Theoretical Basis

3.1 Encoding of EVENODD and RDP

First of all, this paper makes the matrix which its size is 4*5,and the matrix is as follow. As shown in Fig 1.Then, it is simple to calculate the parity 1 and parity 2 to get the matrix of 4*7.To perfectly show the specific process of calculation, it is perfect to make a list.As shown in Table 1.

$$\begin{bmatrix} 1 & 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Fig.1 Example Matrix

Table 1. EVENODD Algorithm

disks	0	1	2	3	4	parity1	parity2
0	1	1	0	0	1	1	1
1	0	1	0	1	0	0	1
2	1	0	1	1	1	0	0
3	0	0	0	0	1	1	1

According to the table1,it is suitable to assume the table1 as A to make it more convenient to express the table. At last, the specific data of parity1 and parity2 can be calculated by using the formulates[8].The formulates that can complement the parity 2 are as follow.In this formula, m represents the number of data blocks in each row of the data array. t is an index that varies from 0 to m-1, ensuring that the calculation covers all the data blocks. The value of S is shown in Fig 2. a refers to the value at a specific position in the matrix.

$$S = \sum_{t=1}^{m-1} a_{m-1-t,t}$$
$$a_{l,m+1} = S + \sum_{t=0,t\neq l+1}^{m-1} a < l-t > m,t \qquad (1)$$

The ways to complement the parity 1 is more simple than parity 2. Parity 1 is a simple XOR row-wise parity, it needs to be got the result by summing all the data disks which are in the same row with the specific position of parity 1 in the matrix. We can list specific process of calculations of algorithmic rules to get each target data which are parity 1 and parity 2[8].These works are as shown in Fig 2. After the calculation, the matrix is as follow.As shown in Fig 3.

$$A_7 = S + A_1 + A_5 + A_4 + A_3$$
$$A_2 = S + A_2 + A_1 + A_3 + A_4$$
$$A_3 = S + A_3 + A_2 + A_1 + A_5$$
$$A_4 = S + A_4 + A_3 + A_2 + A_4$$
$$A_6 = S + A_1 + A_2 + A_3 + A_4$$
$$A_6 = S + A_1 + A_2 + A_3 + A_4$$
$$A_3 = S + A_3 + A_2 + A_3 + A_4$$
$$A_4 = S + A_4 + A_2 + A_3 + A_4$$
$$S = A_4 + A_3 + A_4 + A_5$$

Fig. 2 Specific Calculation

$$\begin{bmatrix} 1 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 \end{bmatrix}$$

Fig. 3 Result Matrix

Moreover, it can also utilize the approach of RDP to implement both parity 1 and parity 2. According to RDP, the process of calculating parity 1 is similar to the EVENODD code. However, the process to complement parity 2 differs from the methods used in the EVENODD code. The formulas are as follow[12].In this formula, p refers to the column in the diagonal parity blocks. i and j represent the indices used to traverse the elements in the matrix to calculate the parity value, and d represents the value of the element at a specific position.

$$\mathrm{d}_{i,p-1} = \bigoplus_{j=0}^{p-2} d_{i,j}$$
$$d_{i,p} = \bigoplus_{j=0}^{p=1} d_{<i-j>p,j} \quad (2)$$

Therefore, this paper uses the matrix which size is 4*5 again to show how to utilize the RDP to make a calculation, the matrix is as follow.As shown in Fig 4. Firstly, to distinguish it from the previous matrix, it is obvious to assume the matrix as B. As shown in Fig 4.Then, it is easy to list the specific calculations to complement Parity 1 and Parity 2[12]. These works are as follows.As shown in Fig 5.

$$\begin{bmatrix} 1 & 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Fig 4. Example Matrix

$$\begin{aligned} B_6 &= B_1 + B_2 + B_3 + B_4 + B_5 \\ B_2 &= B_1 + B_2 + B_2 + B_4 + B_3 \\ B_3 &= B_3 + B_2 + B_3 + B_4 + B_3 \\ B_4 &= B_4 + B_2 + B_3 + B_4 + B_5 \\ B_7 &= B_1 + B_3 + B_4 + B_5 + B_6 \\ B_7 &= B_2 + B_1 + B_4 + B_5 + B_6 \\ B_7 &= B_3 + B_1 + B_3 + B_5 + B_6 \\ B_7 &= B_4 + B_3 + B_3 + B_4 + B_6 \end{aligned}$$

Fig 5. Specific Calculation

Last but not least, this paper utilize a table to show the result. The table is as follow.As shown in Table 2. Furthermore, the matrix which gotten with RPD is as follow.As shown in Fig 6.

$$\begin{bmatrix} 1 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 \end{bmatrix}$$

Fig 6. Result Matrix

Table 2. RDP Algorithm

disks	0	1	2	3	4	parity1	parity2
0	1	1	0	0	1	1	1
1	0	1	0	1	0	0	0
2	1	0	1	1	1	0	1
3	0	0	0	0	1	1	1

3.2 Decoding of EVENODD and RDP

From the perspective of decoding, both of EVENODD and RPD is similar. There are 5 conditions about the erasures in the matrix of the two types of code. For the one failures case, it have 1 information failed or 1 parity failed. For the two failures case we have ether 2 parity disks failed, or 2 information disks failed, or 1 information and parity 1 failed, or 1 information and parity 2 failed. However, if there are 3 failed, it is impossible to recover the data[13]. Because the coding matrix no longer possesses the property of having a unique solution.

First, if it have only one failed, we can recover the matrix simply, it is not a complex work to utilize the linear equation with one unknown to calculate the data. It is quick to recover this type of single disk of erasure when the basic algorithm rules are not listed incorrectly. Second ,If there are two disks failed, we can solve it using binary quadratic equations based on two encoding calculation rules.

4.Experiment and Model Evaluation

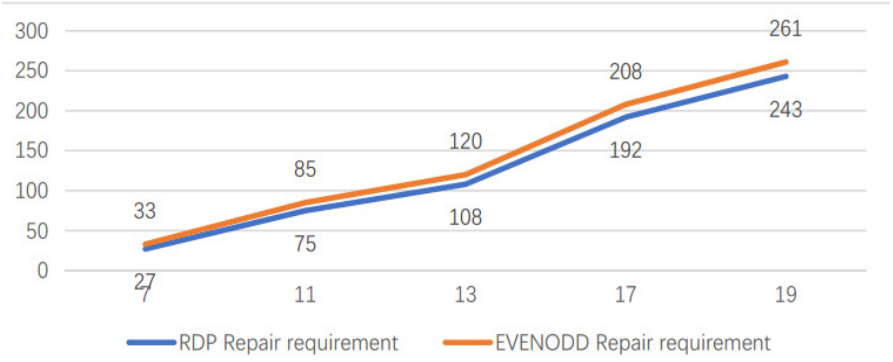

Fig 7. Comparison in Experiment[7]

To better compare the performance of EVENODD and RDP codes in recovering from a single device failure, an experiment was conducted. In the corresponding figure, the horizontal axis represents the P value, which indicates the size of the coding matrix for both codes. For EVENODD, the matrix has dimensions of (P-1)*(P+2), while for RDP, the matrix has dimensions of P*(P-1)[7]. The vertical axis in the figure represents the number of data elements required for error recovery by the two codes. These data elements include both data blocks and parity blocks, which are essential for recovering from disk failures. It is through these data elements that the failed disk can be restored. Additionally, the results for the number of required data elements in the figure are derived using two functions corresponding to the two codes. By observing how these values change as the prime number P increases, one can compare the values at each point and analyze the trend of the functions for further insights. The function for EVENODD is labeled as $\frac{(3P+1)(P-1)}{4}$, while the function for RDP is labeled as $\frac{3(P-1)^2}{4}$ [7]. From the image as shown in Fig 7, we can first observe that, when examining the required data elements at each node for the prime number PPP across the two functions, there are fluctuations and variations in the growth of data element values between adjacent prime numbers. Secondly, in cases where the number of P is less than 20, the number of data elements required for data recovery using EVENODD is consistently lower than that required by RDP. Additionally, when the number of P is greater than 20, it becomes challenging to compare all the data values directly. Therefore, a mathematical derivation is performed to provide proof for the observations. First, we calculate the difference between the two functions representing the required data elements for EVENODD and RDP codes, denoted as the difference function P-1. As the number of P increases, the difference in the number of data elements required to recover from a single device failure between the two codes will become increasingly significant. Therefore, in the experiment for recovering from a single device failure, the number of data elements required by EVENODD is always greater than that required by RDP. This demonstrates that RDP has superior recovery performance compared to EVENODD. The results are shown in the figure.As shown in Fig 8.

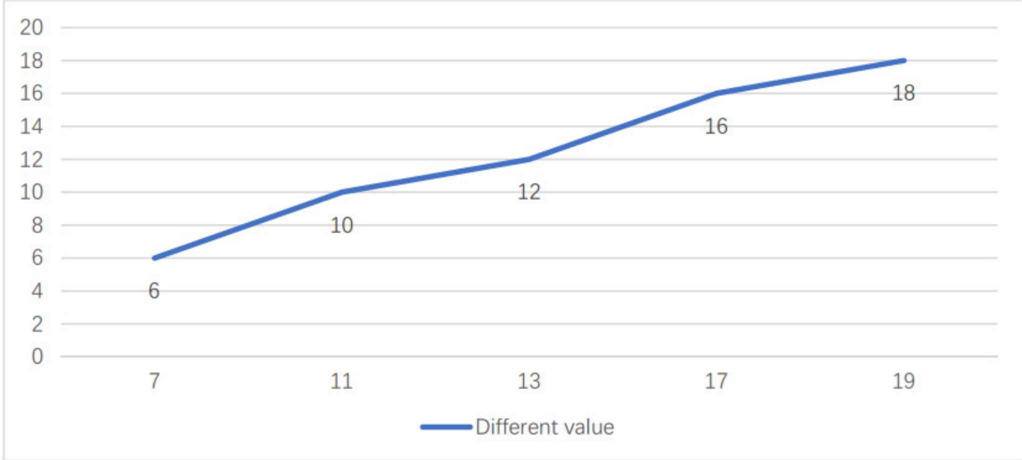

Fig 8. Different value [7]

5. Conclusion

This paper first explores and analyzes the practical applications of EVENODD and RDP, as well as the improvements and upgrades made to each. Secondly, the paper discusses the encoding and decoding procedures of EVENODD and RDP under the XOR rules. Finally, through experimentation, the paper compares the recovery performance of EVENODD and RDP in the event of a single device failure, determining a clear winner. Based on the results, RDP is recommended for single device failure recovery. However, there are many factors not considered in this experiment, such as a comparison of the hardware requirements for the two codes. In the future research directions, this paper also proposes several recommendations. With the advancement of technology, the demand for low-latency data storage in large-scale online games is increasing, and the requirements for I/O performance are also continually rising. This calls for further development and research on RAID technology. Additionally, the growing emphasis on encrypted data storage and network security is becoming increasingly important, not only for personal privacy and financial security but also for national interests. Therefore, it is essential to continue in-depth research on data encryption in storage.

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