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Reliability Model of RAID-60 Disk Arrays

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Аннотация: The general characteristics of the innovative RAID-60 data storage system, which combines the best aspects of RAID-6 and RAID-0E technologies, as well as the reliability model of this data storage system, are presented. The main purpose of this connection is to provide outstanding performance with maximum data redundancy. The article discusses in detail the structural analysis, advantages and various scenarios for the use of the specified RAID-60 data storage system and the proposed model of its reliability. An important aspect is also the comparison of the RAID-60 system with other widespread variants of data storage systems, such as RAID-0, RAID-1 and RAID-5, as well as with the reliability models of these systems. Particular attention is paid to the formula that allows you to calculate the average operating time to failure of a disk array. Also, for completeness of the analysis, attention is paid to plotting the probability of a RAID-60 failure (P(t)) over time (t). This graph is an important tool for visualizing the dynamics of reliability of data storage systems.

Ключевые слова: 10- RAID-60, reliability, disk array, data redundancy, manufacturer, parity blocks, data storage.

Introduction

Today, information technology plays a key role in the life of organizations and individuals, data security and accessibility are becoming priorities. It is especially important to ensure the reliability and efficiency of data storage systems, and here disk arrays, such as RAID (redundant array of independent disks), become an indispensable tool.

We will analyze various RAID models that are actively used to ensure the reliability and efficiency of data storage.

Let's briefly review the key RAID configurations, including RAID-0, RAID-1, RAID-5, RAID-6 and RAID-50, paying special attention to their unique functions and applications.

Let's consider the advantages and scenarios of using the innovative RAID-60 data storage system, as well as the calculated ratios of the main elements of the proposed model of its reliability.

RAID-0 (Stripping):

- Performance: Optimal (enables simultaneous read and write operations, maximizing speed).
- Data Redundancy: Absent (poses a risk in the event of a single disk failure).
- Application: Well-suited for high-performance applications where data security is not a primary concern.

RAID-1:

- Performance: Average (data duplicated);
- Data redundancy: Full (each disk mirrors the other);
- Application: Ideal for those who care about data security.

RAID-5:

- Performance: Good (combines performance and redundancy);
- Data redundancy: Present but reduced when one disk fails;
- Application: Widely used for medium-sized data stores.

RAID-6:

- Performance: High (similar to RAID-5 but with double parity);
- Data redundancy: High (capable of withstanding failure of two drives);
- Application: Recommended for more reliable data storage.

RAID-50:

- Performance: High (combination of stripping and RAID-5);
- Data redundancy: Depends on the level of RAID-5 within the RAID-

50;

Application: Effective for large-scale, high-performance storage.

Based on the results of a previous study conducted by Rahman P.A. the author's article is devoted to the reliability analysis of redundant disk arrays with alternating RAID-5 data. The study involves the development of a Markov model describing the states of the RAID-5 array de-pending on the functionality of its disks.

The article presents a formula for calculating the average operating time to failure of this disk array. Probably, the author also considers the influence of various parameters, such as disk failure rate, read error rate, information regeneration rate, and critical controller errors, on the overall reliability of the system.

The article concludes by mentioning the additional intensity associated with failures and da-ta regeneration and the possible critical errors of the controller. A formula is presented for estimating the average operating time before failure of the RAID-5 array, taking into account the loss of all data [1].

In this paper, author Rahman P.A. examines the reliability model of dual redundancy RAID-6 disk arrays. The author proposes a Markov model describing the states of operation and failures of the array, as well as a formula for calculating the average operating time to failure.

The basic concepts and parameters of the model include the rate of disk failures, the rate of data read errors to recover information on replaced disks, the rate of disk recovery, the total number of disks in the array, the rate of disk array controller errors, and the additional rate of controller errors when regenerating data after replacing the failed disk [2].

The review also highlights the importance of disk array reliability in today's information technology and warns against the potential for catastrophic consequences of data loss.

The author describes the states of the RAID-6 array, including the health states (where data is available) and the health state in which all data is lost. To estimate the average operating time to failure, a system of Kolmogorov-Chapman differential equations is used [3].

In the submitted article, authors Mahesh Balakrishnan, Asim Kadav, Vijayan Prabhakaran and Dahlia Malkhi.

Discuss the innovative Diff-RAID storage system designed to effectively manage SSD failures. Diff-RAID architecture includes flexible parity distribution and dynamic parity movement when replacing devices, which contributes to a high degree of system reliability.

The main advantages of Diff-RAID cover several aspects. First, the system promises to provide higher reliability compared to traditional RAID configurations, such as RAID-5 or RAID-4, while maintaining a minimum amount of space consumed [4].

Of particular interest is the possibility of extending the life of the SSD, since Diff-RAID makes it possible to use devices even after exceeding the standard erasure limits.

This is achieved by over-storing data on younger devices, which protects information on devices that are near the end of their lifespan.

The authors evaluate Diff-RAID performance using a software implementation on an array of five Intel X25-M SSDs. The evaluation includes both synthetic tests and analysis of real server traces. Also in the work is an analysis of the reliability of Diff-RAID, which includes the use of real error indicators in the SSD for modeling.

Lastly, our paper aims to complement existing research efforts by conducting a comprehensive review and analysis of the innovative RAID-60 model.

This endeavor underscores our commitment to advancing the knowledge base in storage systems, offering insights that contribute to the ongoing evolution of storage technologies.

This progressive approach not only continues and expands on previous research, but also provides additional practical and theoretical knowledge about the RAID-60 model, which represents a significant step forward in ensuring high performance and storage reliability

Each of these configurations provides a unique balance of performance and reliability, and the optimal choice depends on the specific requirements and goals of the storage system.

The RAID 60 architecture skillfully combines the functionality and benefits of both RAID 6 and RAID 0. This powerful configuration requires at least eight disk drives and provides high fault tolerance and the ability to recover data in the event of a disk failure.

RAID 60 is created by combining multiple RAID 6 sets into one integrated group. Each RAID 6 set consists of at least four drives used to form two parity data bands (P) for error detection and correction.

These RAID 6 [5, 6] groups are then combined using RAID 0. This approach allows you to increase the speed of reading and writing data, since the information is evenly distributed across all disks in the array. It is great that in the event of a failure of one or even two drives, RAID 60 is able to automatically recover data using parity information – an important advantage over RAID 5 and RAID 50.

RAID 60 architecture delivers high resiliency and responsiveness, ideal for large storage and commercial applications where both security and performance are important.

However, the use of a large number of disks also increases the risk of failure of the entire array, so it is recommended to regularly back up data and ensure adequate backup power to the system.

RAID-60 is an innovative model that combines two popular RAID levels: RAID-6 and RAID-0. The RAID-6 approach provides double data redundancy, which means that the system remains operational even if two disks fail. On the other hand, RAID-0 is used to strip data, which leads to increased performance through parallel writing and reading on multiple disks [7].

Features of the RAID-60:

- Data redundancy (RAID-6): One of the main characteristics of the RAID-60 is the ability to keep the array healthy when two disks fail. This is achieved by using a method of allocating redundant information, which allows you to recover data even in case of serious failures.
- Performance (RAID-0): The second important feature is data stripping, which increases write and read speeds. Because data is partitioned and distributed across multiple disks, this allows operations to be performed several times faster than using a separate disk.
- Balanced solution: RAID-60 provides an optimal balance between redundancy and performance. This is especially important in critical systems that require both high reliability and outstanding performance.
- Expandability: RAID-60 provides a certain level of expandability, allowing new drives to be added to the array to increase capacity and performance without significant structural changes.

The use of RAID-60 represents an important step in securing data and optimizing its processing. This innovative model continues the evolution of storage technology, [8] providing state-of-the-art solutions for demanding reliability and performance tasks.

Drawbacks and Use Cases

- Complexity of configuration: RAID-60 [9] requires careful design and configuration, which may require a higher level of expertise. Costs: Additional drives can increase

- Data storage costs.
- Use Cases: RAID-60 is suitable for environments and applications that require both high performance and reliability, such as large data [10] stores or database servers.

Let us move on to the consideration of the Markov model of the reliability of the RAID-60 disk array.

- Status 0 (Fit for Use): All disks are operational and the array is operational.
- State 1 (Waiting for one disk to be replaced): One of the disks failed, but the array continues to operate due to RAID-6 redundancy. The data is awaiting replacement of the failed disk.
- State 2 (Inoperable): Two disks failed. RAID-6 can no longer provide redundancy, and the data becomes inaccessible.

In view of all of the above, the reliability model of the redundant disk array RAID-60 is as follows (Figure1):

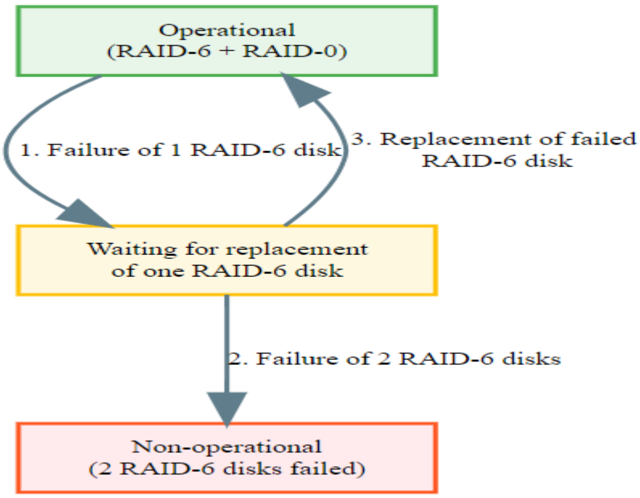

Fig. 1. – The state graph of the disk array reliability model RAID-60

Detailed description of the graph:

- The system is serviceable: Initial state of the system when all disks are functioning normally.

- Waiting for one disk to be replaced: The state that occurs after one disk fails.
- The system is waiting for the failed [11] disk to be replaced. The system is inoperable: The state when two disks failed. The system is inoperable and replacement and restoration are required.

Transitions:

- Failure of 1 disk leads to a transition from "System fit to work" to "Waiting for one disk to be replaced."
- Failure of 2 drives leads to a transition from "Waiting for one disk to be replaced" to "The system is inoperable." Replacement and restoration result in a return from "System inoperable" to "System fit for use."
- Read error, regeneration, critical controller error and additional controller load can cause transitions between "System Fit" and "System Down [12].
- Accordingly, the Kolmogorov-Chapman system of differential sources describes the dynamics of transient probabilities in Markov chains.

The Kolmogorov-Chapman differential method system is as follows:

$$\begin{cases} \dfrac{dp_0}{dt} = -(\lambda_1 + \lambda_2 + \sigma)p_0 + \delta p_2 + \mu p_1; \\ \dfrac{dp_1}{dt} = \lambda_1 p_0 - (\lambda_2 + \sigma + \mu)p_1 + \delta p_2; \\ \dfrac{dp_2}{dt} = \lambda_2 p_1 - (\sigma + \mu)p_2. \end{cases}$$

Here, the terms represent:

- λ_1 and λ_2 failure rates of the first and second disks, respectively;
- μ – regeneration rate;
- σ – critical controller error rate;
- δ – additional controller load during disk failure.

The formula for estimating the average operating time before reflecting the

RAID-60 array can be written as follows:

$$MTF = \int_0^{\infty} T\left(\frac{d}{dt} p_0(t)dt\right).$$

Here:

$p_0(t)$ is the probability of the system being in the "Good" state at time t.

$T(t)$ is a time-to-failure distribution function.

Example of MTTF calculation for the RAID-60 array. To do this, we will use simplified parameters we have the following parameters: in the context of a RAID-60 array with n = 6 disks, the failure rate of disks (λ) is given as 1/120000 $hours^{-1}$, the additional intensity of errors during data reading (ε) is 1/300 $hours^{-1}$, the restoration intensity (μ) is 1/24 $hours^{-1}$, the intensity of critical errors of the controller (σ) is 1/1200000 hours, and the additional intensity of controller errors (δ) is 1/120000 $hours^{-1}$. With these values, the average operational time before data loss is assessed as follows.

- **Calculate Total Failure Rate (λ_{total}):**

$$\lambda_{total} = n \times_{disk} + \sigma + \delta = 6 \times \frac{1}{120000} + \frac{1}{120000} + \frac{1}{120000} = \frac{8}{120000}\ hours.$$

- **Calculate MTTF:** $MTTF = \dfrac{1}{\lambda_{total}} = 150.000\ \ hours$.

- **Reliability Characteristics:**

  ✓ Probability of failure: $P(t) = e^{-\lambda_{total} \times t}$,

  ✓ Reliability: $R(t) = 1 - e^{-\lambda_{total} \times t}$.

- **Additional Time Points:**

t_1 =5000 hours, t_2 =10000 hours, t_3 =20000 hours, t_4 =50000 hours.

Results for Various Time Intervals:

1. Time t=5000 hours:
   - Probability of failure $P(5000) \approx 0.967$;
   - Reliability $R(5000) \approx 0.033$.
2. Time =10000 hours:
   - Probability of failure $P(10000) \approx 0.935$;
   - Reliability $R(10000) \approx 0.065$.
3. Time t =20000 hours:
   - Probability of failure $P(20000) \approx 0.868$;
   - Reliability $R(20000) \approx 0.132$.
4. Time t =50000 hours:
   - Probability of failure $P(50000) \approx 0.716$;
   - Reliability $R(50000) \approx 0.284$.

However, when interpreting the results, especially when operating at large time intervals, the failure probability values (P (t)) decrease while the reliability values (R (t)) increase.

The results of the reliability study of the RAID-60 storage system are presented in the form of graphs of the probability of failure and reliability depending on the time presented in Figure 2.

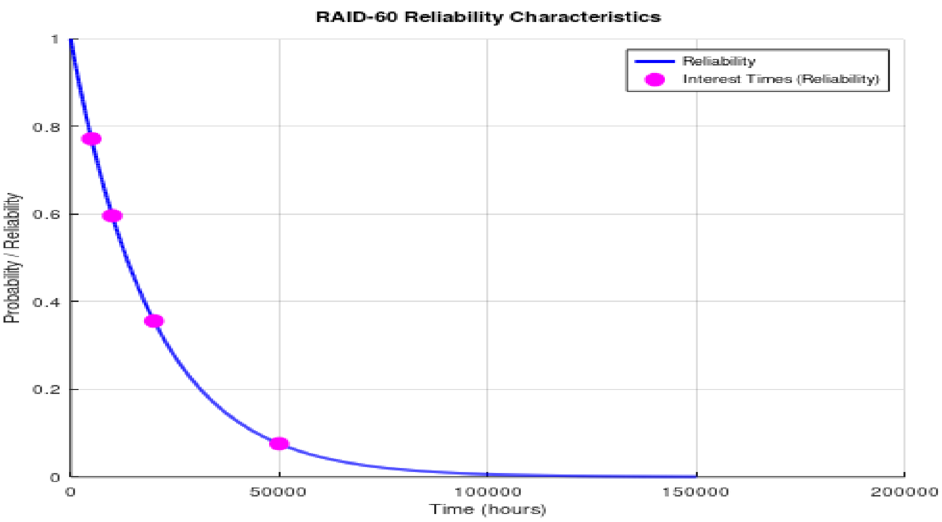

Fig. 2. – Graph of probability of failure and reliability of the system

The analysis makes it possible to highlight key points in the life cycle of the system, which can be very useful in making decisions on its management and maintenance.

Conclusion

The analysis of the innovative RAID-60 data storage system and its comparison with other systems confirm its performance with maximum data redundancy.

The proposed reliability model and a graph of the probability of failure over time provides visualization of the dynamics of the system, confirming its stability and efficiency in different periods.

The results of the study convincingly confirm the potential of RAID-60 as an advanced data storage system for modern requirements of the present time.

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