

# Dynamic load balancing of SCSI WRITE and WRITE SAME commands

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## **Abstract**

Load balancing is a technique to distribute workload evenly, which allows performing the same tasks with faster speed. Application of load balancing methods can help to fulfill the same task using less resources. This methodology is very important in any computational system because it can improve the speed.

The thesis describes the communication model between a SCSI controller and SCSI disks. The application system sends SCSI WRITE and WRITE SAME commands to the disks through the controller to realize the complete erasure of the disks. The aim of the research is to figure out if the parallel strategy of overwriting of the disks is optimal. The thesis discusses the parameters, which impact the speed of erasure, and how we can avoid the bottlenecks.

The results of the thesis show that disk speed is the limiting factor for the erasure if we perform it by WRITE SAME command. Using the WRITE command, the bus is the bottleneck, but by varying transfer length of the buffer it is possible to find the optimal way of sending the commands depending on the amount of disks.

### **Keywords:**

Load balancing, RAID, SCSI, pass through commands.

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# List of abbreviations

|       |  |
|-------|--|
| ATA   | Serial ATA (AT Attachment)                         |
| HP    | Hewlett Packard                                    |
| IDE   | Integrated Drive Electronics                       |
| IT    | Information Technology                             |
| JBOD  | Just a Bunch of Disks                              |
| RAID  | Redundant Array of Independent Disks               |
| SAS   | Serial attached SCSI                               |
| SCA   | Single Connector Attachment                        |
| SCSI  | Small Computer System Interface                    |
| SMART | Self-Monitoring, Analysis and Reporting Technology |
| VHDCI | Very-High-Density Cable Interconnect               |

# Chapter 1

## Introduction

Information technology (IT) is growing up so fast nowadays that we can not even compare what was 10 years ago and what is now. Current situation shows that every month, every day, every minute IT-community goes forward and the steps are so huge that some products, which were popular couple years ago, are already outdated and not supported. All over the world people start using more mobile phones, laptops, electronic books and so on. This is the reason why the amount of information is increasing so fast.

All the time user expects that the device will work without any errors and delays. Moreover, user wants that it will be easy to use and the information will keep privacy that nobody can get the access to it. From technical side the systems start to be very complicated, because the processes start to take more memory and the commands start to mix up, that is why for the device it started to be more difficult to handle all these things.

Every computation system has the limits of speed, memory or some other parameters. However, if the program even works correct the speed can be

decreased by some reason that can be not because of software. It is also possible to happen that the application would start taking too much memory. That is why IT-community started to focus on these problems a lot. In this research we will consider the optimization, which is a general technique of finding the solutions for this topic. In mathematics and computer science, optimization is the selection of a best element from some set of available alternatives with regard to some criteria. In current work we will try to find the optimal speed for the erasure process, which depends on a lot of parameters. Load balancing methodology, which is part of optimization theory, will help us to find the right solution.

The methodology called *Load balancing* was invented almost 40 years ago and serves for making the computation system faster with less usage of the resources [19]. Mostly this technology is using for the Internet services [8], for example, one of the most used common applications of load balancing is to provide a single Internet service from multiple servers. In this paper we will consider load balancing methodology on the example of communication between Small Computer System Interface (SCSI) controller and different amount of SCSI disks.

Lets imagine that some program sends the SCSI WRITE and SCSI WRITE SAME commands from the computer though the controller to the disks to perform the complete erasure. There are a lot of parameters, which can prevent the communication speed between the computer program and the disks. Moreover, some more parameters appear for consideration because we have a SCSI controller in the middle. In the thesis we will apply several load balancing strategies and test the communication model with different parameters. The task is to find out the fastest technique of erasure.

The thesis discusses the parameters, which are more important for the speed of the erasure. Tests with HP Smart Array 642 controller show how the speed depends on such parameters as transfer length, disk cache, disk capacity, amount of the disks and others. Moreover, the thesis suggests applying special dynamic load balancing system to perform the erasure faster. The aim of this system is to find the optimal transfer length for the buffer, which allows to send the data in optimal way.

Current thesis has 6 chapters, including concurrent parts as introduction and conclusion. The second chapter gives an open view to the basic concepts of the thesis. Chapter 3 discusses the mathematical way of the problem and considers all parameters, which can influence on the communication process between the devices. The fourth chapter is one of the most important ones, because we describe there the main idea of application the dynamic load balancing system. The principal concepts of new system are based on the Chapter 5, where we present different results from testing. Chapter 6 concludes all work and sum up the ideas from the thesis.



## Chapter 2

# Introduction to load balancing and RAID controllers

In this chapter, we will focus on basic information for understanding the topic of the paper. We will discuss different types of load balancing systems and consider the things, which programmer should take into attention during implementation this kind of systems. This chapter also describes different types of RAID, which is very important topic, when we speak about the controllers. Finally, the last section tells about different write commands, which we use for the erasure of the disks. This section gives the information about the structure of the commands and opens many parameters in details. This chapter gives the basic knowledge for understanding the results of the thesis.

## 2.1 Load balancing

In general, load balancing is the methodology that increases the speed by balancing the resources. This part of computer science is not new, because the scientists started to focus on that already in the previous century [16]. The main idea is to do as much as possible with least amount of resources. Mostly it depends on the processes, which we can divide by threads and launch them in parallel. Sometimes load balancing divides to the four types: static, dynamic, combined, and preemptive. In scientific articles, combined and preemptive load balancing systems are mentioned very rarely because of their specificity and usefulness only in some certain cases. That is why in this research we will consider two main different types: static and dynamic.

Static load balancing system makes the analysis before the application starts to work. That is why the programmer should know some information for creating good load balancing system via static methods. Firstly, he should know the amount of distributed resources before starting the implementation of the program. Secondly, the programmer should divide the time in such a way that the duration of the tasks would be approximately the same. There are several methods to hand out the tasks such as Round Robin algorithm, Random algorithm, Recursive Bisection algorithm and some others [14], [18]. Scientists frequently take the initial parameters from the previous launch results and genetic algorithms are used. We can take an example of load balancing system from image processing. Let consider  $16 \times 16$  segmented image and 16 processors. With that image, each processor would work on the segment  $4 \times 4$ . The most important piece of all this division of work is that each processor determines this information and which segments it will work on.

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Dynamic load balancing systems have more possibilities than static systems because the balancing process can be done during the application running [5]. This fact gives the advantage of resource movement from busy part to less busy. Thus, we will achieve that all parts of the application will be in average busy condition, which is the ideal solution. The disadvantage of this method is that the system should also collect the information about the status of application, which increases the resources. The programmer should follow on three general criteria during implementation the dynamic load balancing system:

1. Which process is busy or free
2. Priority of the task to be done
3. Length and/or duration of the task

The program, which performs the dynamic load balancing system, should check the loading of computation units, connection possibility, and frequency of sending commands. Dynamic load balancing technique has many methods, such as Bidding algorithm, Drafting algorithm [13], Recursive Coordinate Bisection (RCB) and some others. In this paper, we will call these methods as strategies, but it is also possible to find them in the literature as policies and logics.

## 2.2 RAID

RAID - Redundant Array of Independent Disks - is a storage technology that combines multiple disk drive components into a logical unit. That means that this technology gives a possibility to keep the information in a specific way. RAID controllers are the devices, which realize this technology. In simple words, computer without a RAID controller can see physical disks as logical disks without any difference. However, the computer will see only the logical disks, if the RAID controller is connected. Logical disks are definitely different in comparison with physical disks. Nevertheless, logical disks can be equal to physical if RAID controller is set in special mode called JBOD (Just Bunch of Disks). RAID controller takes all issues about creation of these logical disks.

There are several types of RAID: RAID 0, RAID 1, RAID 5, RAID 6 and some others [4]. These types of RAID are basic types of RAID, thus there are many other types, which also combine them together. For example, RAID 10 is actually combining of RAID 0 and RAID 1. Each type or architecture provides a different balance between the key goals: reliability and availability, performance, and capacity. That means that every RAID keeps the information in a different way.

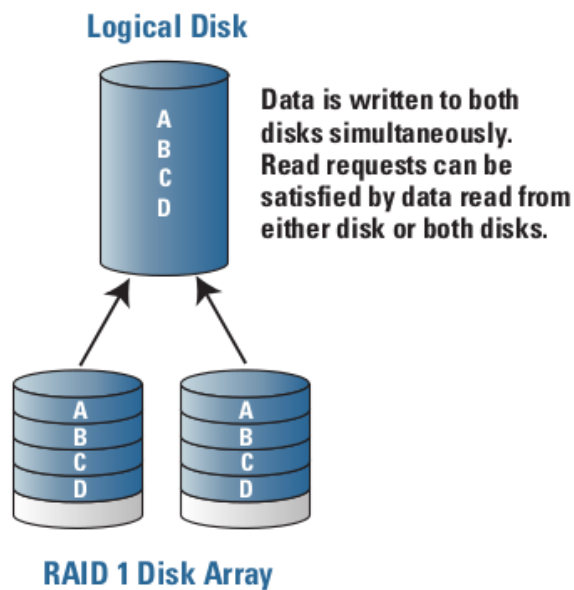
One of the huge advantages of using RAID is that if one of the disks breaks down others can recover the information on that disk. Not all RAID architectures support this functionality, but most of them do. Some types of RAID provide fault tolerance of even two drive failures (RAID 6).

Let consider some types of RAID in more detail. RAID 1 called also as "mirroring" is one of the main fundamental types of RAID, which refers to

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maintaining duplicate sets of all data on separate disk drives. There must be two disks in the configuration and there is a cost disadvantage as the usable capacity is half the number of available disks. RAID 1 provides cost-effective, high fault tolerance for configurations with two disk drives. The prototype of RAID 1 is presented on the Figure 2.1.



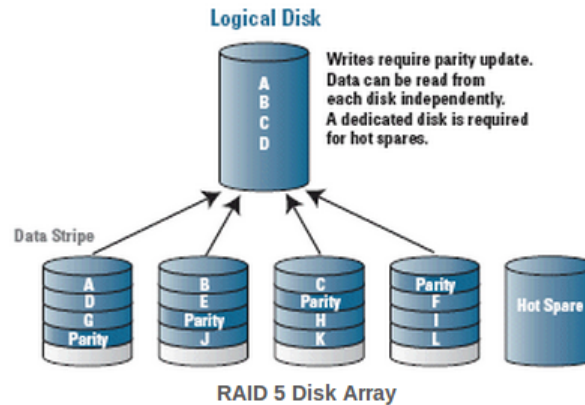
**Figure 2.1:** Prototype of RAID 1

Another type RAID 5, which is presented on the Figure 2.2, uses data striping in a technique designed to provide fault-tolerant data storage, but does not require duplication of data like RAID 1 [2]. Data is striped across all of the drives in the array, but for each stripe through the array (one stripe unit from each disk), one stripe unit is reserved to hold parity data calculated from the other stripe units in the same stripe. Read performance is therefore very good, but there is a penalty for writes, since the parity data has to be recalculated and written along with the new data. RAID 5 requires a

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minimum of three disks and a maximum of 16 disks. RAID 5 usable capacity is between 67% - 97% depending on the number of data drives in the RAID set. Moreover, nowadays there are RAID controllers, which have already



**Figure 2.2:** Prototype of RAID 5

load balancing system inside and the user can set the mode, which is more comfortable in the some situations. This system takes care only about logical disks, but we need to communicate only with physical disks. That is why we need to have our own load balancing system, which will help us to distribute the resources before the commands come to the controller. Load balancing system from the controller does not help up at all, because we should send the commands straight to the disks. Moreover, during communication directly with the disks, we do not need to remember if there is any RAID or not, because the commands are sent through the controller without any changes.

The Figure 2.3 presents one of the SATA RAID controllers. This 3ware SATA RAID controller can be connected to 8 SATA disks. It supports following types of RAID: 0, 1, 5, 10, 50 and JBOD (Just a Bunch of Disks).



**Figure 2.3:** 3ware SATA RAID controller 9500S-8

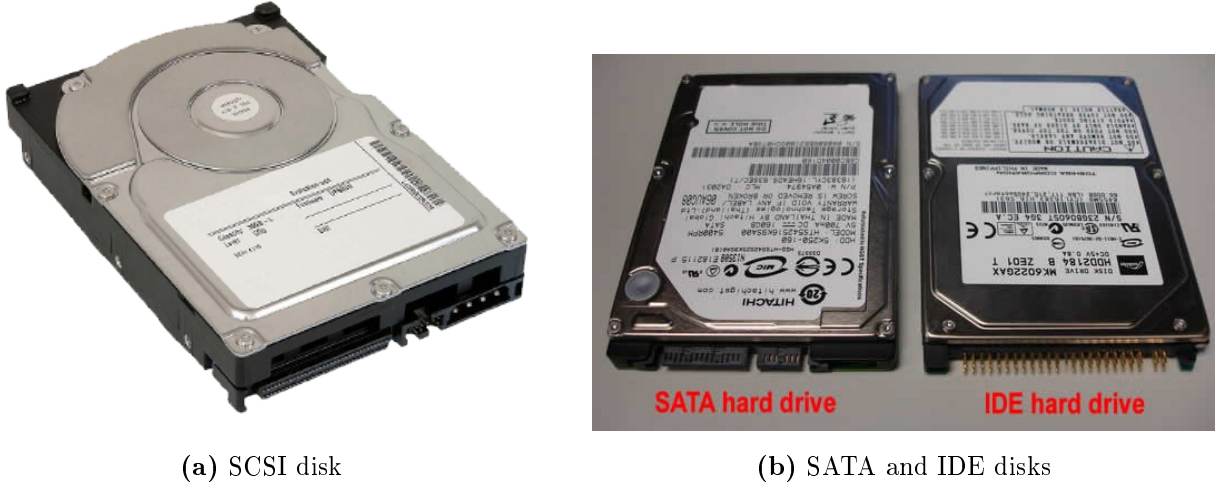
## 2.3 SCSI RAID controllers

SCSI - Small Computer System Interface - is a set of standards for physically connecting and transferring data between computers and peripheral devices [15]. The SCSI standards define commands, protocols, and electrical and optical interfaces. There are also other interfaces such as SATA (Serial ATA (AT Attachment)), IDE (Integrated Drive Electronics), SAS (Serial attached SCSI). In general, we divide the interfaces to two categories: ATA and SCSI. In the following content, it means the according protocol. IDE and SATA interfaces relate to ATA and SAS belongs to SCSI. Three different types of disks are presented on the Figure 2.4. In this paper, we will focus on SCSI interface, but sometimes we will compare it with ATA. If we compare SAS and SCSI, we consider them as similar interfaces. However, SAS is a new version of SCSI and it gives a single channel for each disk. SCSI has only

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one channel for all disks.



**Figure 2.4:** Three different types of disks

### 2.4 SCSI WRITE and WRITE SAME commands

This research is made for the Blancco Oy Ltd, which produces the erasure software. The main part of the erasure is performed by SCSI WRITE and WRITE SAME commands [9]. In general, all commands belongs to three groups: Non-Data, Data-In and Data-Out commands. For the last two groups it means that the programmer should send the command including the buffer. Data-Out means that the buffer is sent to the disk. For the Data-In group it is in opposite way and data comes from the disk. The example of Data-In command is any SCSI READ command. Write commands belongs to the Data-Out group because these commands must have Data-Out buffer, containing the data, which we write to the disk. Nowadays, for SCSI there are 4 different versions of WRITE command and 3 for the WRITE SAME



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command.

Lets consider SCSI WRITE commands first. Mostly the commands are different because of the length. Each command has not only operation code, which is the main criteria for the command, but also some other variables such as Logical Block Address (LBA), transfer length, control and some others. These variables do not include Data-Out buffer. The Figure 2.5 shows the example how the commands are defined in SCSI specification [9].

| Table 108 — WRITE (10) command |     |                      |                       |   |              |     |          |        |          |
|--------------------------------|-----|----------------------|-----------------------|---|--------------|-----|----------|--------|----------|
| Byte                           | Bit | 7                    | 6                     | 5 | 4            | 3   | 2        | 1      | 0        |
| 0                              |     | OPERATION CODE (2Ah) |                       |   |              |     |          |        |          |
| 1                              |     | WRPROTECT            |                       |   | DPO          | FUA | Reserved | FUA_NV | Obsolete |
| 2                              |     | (MSB)                | LOGICAL BLOCK ADDRESS |   |              |     |          |        |          |
| ...                            |     |                      |                       |   |              |     |          |        |          |
| 5                              |     |                      |                       |   |              |     |          |        |          |
| 6                              |     | Reserved             |                       |   | GROUP NUMBER |     |          |        |          |
| 7                              |     | (MSB)                | TRANSFER LENGTH       |   |              |     |          |        |          |
| 8                              |     |                      |                       |   |              |     |          |        |          |
| 9                              |     | CONTROL              |                       |   |              |     |          |        |          |

**Figure 2.5:** Definition of WRITE 10 command

The following commands exist for writing the data to the disk:

- WRITE (10)
- WRITE (12)
- WRITE (16)
- WRITE (32)

The numbers in brackets shows the length of the command in bytes. It is obvious that the WRITE (10) command is the base for others. It seems that by now the best choice is WRITE (16) because in [9] there are some notes, that

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«Migration from the WRITE (10) command to the WRITE (16) command is recommended for all implementations». WRITE (32) should be used only in some special cases [9]. In this research, we will focus only on WRITE 10 command, because after some test, it started to be understandable, that bus plays an important role in this model, and there is no reason to send more data.

SCSI WRITE SAME commands have the same purposes as SCSI WRITE commands. The difference and biggest advantage is that SCSI WRITE SAME command can be sent once and the Data-Out buffer can be written to the disk several times. That gives faster speed because the bus is not busy any more - only one command was sent, but the buffer is still writing.

There are three different types of WRITE SAME commands, as we mentioned before:

- WRITE SAME(10)
- WRITE SAME(16)
- WRITE SAME(32)

The number in brackets also shows the length of the command in bytes. Number of logical blocks is one of the most important variables in these commands because we write this number of blocks to the disk with the same buffer. It is obvious that if the length of the SCSI WRITE SAME command is quite big, we can write to the disks much more number of blocks. We will consider only WRITE SAME 10 command, because the results after few tests showed that there is no reason to send bigger buffer, because the disk could not work faster. ATA specification has the similar command, but it should be send differently and the device should support SMART (Self-Monitoring, Analysis

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and Reporting Technology) [10]. It is a monitoring system for computer hard disk drives to detect and report on various indicators of reliability.

## Chapter 3

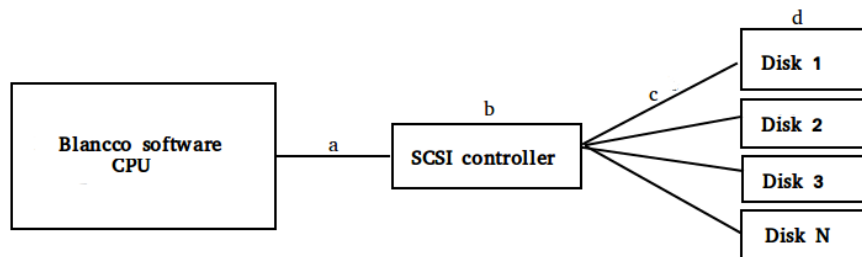
### Mathematical problem definition

This chapter opens our communication model between a SCSI controller and the disks from mathematical point of view. Moreover, we define the mathematical problem which we will solve in the thesis. In the beginning of the chapter, we consider the parameters which influence on the complete erasure. Later we model the dynamic load balancing system, which could help with improvement of the speed, and, finally, we pose the optimization problem. After that, we try to estimate the limitations which exist from theoretical and technical sides. This part of the chapter gives an idea what we should expect during practical tests of the erasure. Moreover, it helps to understand what parameters we should take into consideration during searching the solution for our problem.

### 3.1 Communication model between SCSI controller and SCSI disks

Currently, it is important to make programs as fast as possible because the time costs a lot. That is why optimization problem is one of the most significant ones. In general, the problem is to find the best solution from the set of all feasible solutions. There are many different algorithms, which analyze the solutions during variable changing. In our case, the optimization problem bases on time optimization. That means that we will optimize the time by varying several variables.

Lets consider the model presenting on the Figure 3.1, which shows how SCSI controller is connected to the disks and CPU (Central processing unit). This picture can be divided to 5 parts: CPU, where Blanco software is running, bus  $a$  - from CPU through motherboard to the SCSI controller, SCSI controller  $b$ , buses  $c$  - from SCSI controller to the disks  $d$ . Let consider that the SCSI controller is connected to  $N$  disks.



**Figure 3.1:** Communication model of SCSI controller

The Figure 3.1 presents how SCSI controller is connected in our case.

All the time people want to do everything as fast as possible, but of course, there are limitations in different places. The same situation is in this model - each part has the limitation of the speed. Moreover, there are also limitations for the memory.

Lets consider the Figure 3.1 in more detail. We will skip CPU part in this model, because there are so powerful computers in current time that it should not be taken into consideration. The main idea of Blancco software is to write the data to the disks. Lets discuss what *data* means in this context. On the Figure 3.1 there are  $N$  disks and each of them has its own capacity  $d_i$ , where  $i = \overline{1, N}$  shows the number of the disk. Capacity  $d_i$  is calculated in megabytes. Each disk  $i$  should get the amount of data, which is at least equal to the capacity of the disk. Moreover, we might need to send the commands to set the connection with the disk.

We discussed in the Section 2.4 that Blancco software uses two different versions of write command. Each of these commands has its own capacity. Let define these capacities in a mathematical way. The capacity of the WRITE command is  $c_1$ , the capacity of the WRITE SAME command is  $c_2$  and the capacity of other commands is  $c_3$ . In this context, other commands mean the commands for identification the device and setting the connection. All these three variables  $c_1$ ,  $c_2$ ,  $c_3$  are constant and are defined by Blancco software. Hence, it should be sent  $F$  MB from SCSI controller  $b$  to the disks  $d$  through the buses  $c$  to replace all data on  $N$  disks. Let call  $F$  as *complete erasure*, if it is calculated by the following formula:

$$F = \sum_{i=1}^N F_i, \quad (3.1)$$

where  $F_i$  is the amount of megabytes, that should be sent to the disk  $i$ , which

is calculated as

$$F_i = c_1 m_{i1} + c_2 m_{i2} + c_3 m_{i3}, \quad (3.2)$$

where  $m_{ik}$  is the number of times that command  $c_k$  should be sent, where  $k = \overline{1, 3}$ . Furthermore, complete erasure  $F$  should fulfill the following condition:

$$c_1 c_2 = 0, \forall F_i, i = \overline{1, N}. \quad (3.3)$$

This condition means that only 1 command  $c_1$  or  $c_2$  can write to each disk. Thus, the software can not erase the same disk with both commands  $c_1$  and  $c_2$ . That means that only software decides which command is better to use and dynamic load balancing system should apply the strategy how to apply it more efficiently.

For clear vision and comprehension, it is convenient to present the set of  $F_i$  as a matrix  $F_m$ :

$$F_m = \begin{pmatrix} F_1 \\ \vdots \\ F_N \end{pmatrix} = \begin{pmatrix} c_1 m_{11} & c_2 m_{12} & c_3 m_{13} \\ \dots & \dots & \dots \\ c_1 m_{N1} & c_2 m_{N2} & c_3 m_{N3} \end{pmatrix}, \quad (3.4)$$

where  $F_m$  is the matrix with dimension  $N \times 3$ .

Using WRITE command  $c_1$  we send more data for each disk  $i$  than its capacity because with each command we need to send the buffer which will be written to the disk. That means that the following condition should be fulfilled:

$$d_i < F_i, i = \overline{1, N}. \quad (3.5)$$

However, with WRITE SAME command  $c_2$  we send the buffer once, but it is written to the disk several times. That means that we do not need to send this buffer all the time and the bus is not so busy any more. Thus, for the

WRITE SAME command  $c_2$  we have another condition:

$$d_i > F_i, i = \overline{1, N}. \quad (3.6)$$

We can see that WRITE SAME command has much more advantages than WRITE command, but there are situations when we can not use it. For example, we could not use WRITE SAME command when we want to send different buffers. Moreover, some devices do not support WRITE SAME command.

The main aim of the research is to find the way to send the data faster to the disks. Of course, that it depends on all the devices which are in the model, on the strategy how the software sends the commands and on the parameters of the command that we use for erasure. Let define the variable  $S_{max}$  for maximum speed and it is obvious that this variable is constant. According to the Formula 3.1 and maximum speed  $S_{max}$  it is possible to calculate the minimum time  $T_{min}$  for realization complete erasure  $F$  by the following formula:

$$T_{min} = \sum_{i=1}^N t_i = \frac{\sum_{i=1}^N F_i}{S_{max}} = F/S_{max}, \quad (3.7)$$

where  $t_i$  is the time for sending  $F_i$  MB to  $i$  disk with the maximum speed  $S_{max}$ .

## 3.2 Mathematical problem definition

Let consider that in the same model there is dynamic load balancing system and it calculates the application state  $m = F/s$  times, where  $F$  is the amount of megabytes to complete the application task and  $s$  is the step. In this



context step  $s$  means the amount of commands and  $m$  means how many times the dynamic load balancing system should apply another input data for the next step.

There is matrix  $H = \{h_{ij}\}$ , where  $i = \overline{1, N}$  is the disk number,  $j = \overline{1, m}$  is the step number of the dynamic load balancing system and  $h_{ij}$  is the number of commands, which is sent to the  $i$  disk at  $j$  step. That means that for complete erasure  $F$  we need the following amount of commands:

$$\sum_{i=1}^N \sum_{j=1}^m h_{ij} = \sum_{i=1}^N \sum_{k=1}^3 m_{ik}. \quad (3.8)$$

As an example of matrix  $H$  it is convenient to consider 4 disks, which can be erased by 100 commands with the condition that we can not send more than 100 commands per step. Thus the matrix  $H$  can be presented as

$$H_1 = \begin{pmatrix} 100 & 0 & 0 & 0 \\ 0 & 100 & 0 & 0 \\ 0 & 0 & 100 & 0 \\ 0 & 0 & 0 & 100 \end{pmatrix} \quad (3.9)$$

or a bit more complicate:

$$H_2 = \begin{pmatrix} 50 & 10 & 20 & 20 \\ 20 & 50 & 10 & 20 \\ 20 & 20 & 50 & 10 \\ 10 & 20 & 20 & 50 \end{pmatrix}. \quad (3.10)$$

Matrix  $H_1$  and  $H_2$  are practical examples of the matrix  $H$ . The first matrix shows the trivial strategy - to send as many commands as the program can to fulfill the condition during each step. Matrix  $H_2$  shows that it could be done in a different way and we can divide the whole amount of commands and send it separately. The strategy should be applied by some dynamic

load balancing algorithm and the aim of the research is to find out what is the optimal matrix  $H_{opt}$  and could load balancing help in this case or not.

Also there is matrix  $Q = q_{ij}$ , where  $q_{ij}$  is the order number in the queue for sending commands to  $i$  disk at  $j$  step. In this case, it is possible to show to which disk the program should send the command first. The dimension of  $Q$  is the same as dimension of  $H$ :

$$\dim(Q) = \dim(H) = N \times m, \quad (3.11)$$

where  $N$  is the number of disks and  $m$  is the number of steps in the load balancing system. Of course, that if we apply the parallel strategy matrixes  $H$  and  $Q$  do not make any sense, because we will not know how many commands are sent to which device.

For mathematical problem definition, it is convenient to introduce the functional of time. Let the *functional of time* be defined as the functional

$$T = \sum_{j=1}^m t_j, \quad (3.12)$$

where  $t_j$  is the time for sending  $\sum_{i=1}^N h_{ij}$  commands at  $j$  step of dynamical load balancing process.

The main idea of the optimization problem is to minimize the functional of time  $T$

$$\min_{F, H, Q, s} T. \quad (3.13)$$

According the Formula 3.7 we can rewrite current minimization problem as

$$T \xrightarrow{F, H, Q, s} T_{min}. \quad (3.14)$$

That means that the application of dynamic load balancing algorithm should make the program faster and the value of  $T$  should come close to the minimum

time  $T_{min}$ . The algorithm should use  $F$ ,  $H$ ,  $Q$ ,  $s$  as parameters for making the program faster. As we mentioned, usage parallel strategy removes some of these parameters and the amount of megabytes  $F$ , which we need to send to erase all  $N$  disks, starts to be the most important value. However, complete erasure  $F$  also hides some interesting parameters such as amount of sending commands and buffer size of the command, which will play quite important role in the following paper.

### 3.3 Technical limitations

Every device has its own technical limitations. For example, a car has a limitation for the speed, capacity of petrol tank, maximum engine power and so on. Discussing the SCSI controllers, every device has special characteristics, which we can compare with characteristics of the car.

Let introduce some parameters, which can influence on the communication between controller and disk. In this paper the word SCSI is used a lot, but there was no clear explanation what is it. We mentioned in the beginning of the paper that SCSI is Small Computer System Interface. The main word in this abbreviation is interface, which shows *how* the devices connect with each other. Lets again consider the Figure 3.1 and the situation that we write some data from CPU to the disk. Controller  $b$  has 2 interfaces, because it connects to the CPU and disks  $d$ . Let call bus  $a$  as *input* interface and buses  $c$  as *output* interface. For the disks  $d$  there is only input interface, that is why it is possible to skip the word *input* and use only interface. If there is a sentence, which includes "the controller has SCSI interface", that means that the controller has the possibility to connect SCSI disks and the output

interface is SCSI. The controller has also an input interface because it has two connections. This interface can be, for example, different modifications of PCI (Peripheral component interconnect) such as PCI-X, PCI64, PCI Express or some others. In general words, we mean only the buses  $c$  if there is a discussion about SCSI interface.

Moreover, SCSI is also a data protocol, which shows what commands can be sent through buses  $c$ . Depends on the previous content SCSI interface connection has different technical limitations. There are several SCSI interfaces such as SCSI-1, Fast-Wide SCSI, Ultra2 SCSI, Ultra-320 SCSI and some others, but we will consider in this research only Ultra-320 because the testing device supports this interface. Nowadays there is interface with faster bandwidth - 640 MB/s - but it did not get popular, because it supports maximum 2 devices per cable.

Ultra320 SCSI [6] is the seventh generation of SCSI I/O (Input/Output) technology. The dominant feature is the speed of 320 megabyte per second (MB/s). In Ultra320 protocol all SCSI devices support packetized protocol and may support Quick Arbitration and Selection (QAS). Expander communications techniques have also been defined. In general, Ultra320 shows that only buses  $c$  from the Figure 3.1 have this speed and not disks  $d$ , and of course, not controller  $b$ . If we want to get the maximum speed between devices from our communication model we should fulfill the following condition:

$$S_a > S_b > S_c > S_d. \quad (3.15)$$

Otherwise, there is a question, how controller is going to manage several disks if it has the same speed. Currently there are different PCI buses, which can have the maximum bandwidth up to 4 GB/s. There are also some

possibilities to increase the performance of PCI [1]. However, even this is not the limit, because there are also some other buses, such as QPI (QuickPath Interconnect) and HyperTransport with different modification, which can easily have the bandwidth around 25 GB/s. By now the maximum bandwidth has HyperTransport 3.1 with value 51,20 GB/s. Of course, that bus depends on the frequency quite a lot. HyperTransport 3.1 has the maximum frequency 3,2 GHz. Depends on the data content and the number of the disks the data for the transport through bus  $a$  can increase, but the numbers show that it is not a problem, but still it is better to keep this fact in mind.

All SCSI devices are always backward compatible, which means that when we attach newer SCSI devices to a system with devices from a previous generation, the newer devices will fall back to the maximum operating speed of the older generation when they are talking. When not talking to older devices, the newer devices operate at their normal speeds. That means that if one of SCSI drives from the Figure 3.1 works on Ultra160 interface, the controller, which supports Ultra320, will communicate with the disk using Ultra160 interface.

Most of the time, if some hardware device or cable connects to some place that means that it will probably work. The same situation is with SCSI interfaces, but for some generations connectors are the same. For the interfaces Ultra2 Wide, Ultra3, Ultra320, and Ultra640 the connectors can be 68-pin and 80-pin, which belong to the connection type SCA/SCA-2 (Single Connector Attachment). The examples of the connectors are presented on the Figure 3.2.

Our discussion about technical limitations mostly contains the information about the buses  $a$  and  $c$ , but what about controller and disks? Let consider



**Figure 3.2:** 68-pin and 80-pin SCA connectors

the disks first. In this chapter, we already mentioned that each disk  $i$  has capacity  $d_i$ , speed  $S_d$  and special interface. Nevertheless, there are some other parameters, which can be also important. It is *cache*, *spindle speed*, average *seek time* for reading and writing, connector type and dimension. The last parameter is not very interesting, because we assume that there is enough space.

In general, cache is used in many situations, for example, in operation systems, in controllers, in disks and some other places. Cache is the part of memory, which has very fast speed access [12]. For the disks it means that cache is stored before the physical hard disk platter, which gives the possibility to get the data much faster. Current disks can have cache with capacity from 8 to 64 MB. Of course, that big cache gives higher performance for the disk. Moreover there are different cache algorithms such as LRU (Least Recently Used), MRU (Most Recently Used), LFU (Least-Frequently Used), Direct-mapped cache and some others [20], [17]. The aim of every cache

algorithm is to manage the data in the cache and show, which data block to delete and which one to keep. Depends on the disk it can be applied different cache algorithms, which could give the advantage or disadvantage in the current problem. Also, depends on the number of the disks maybe load balancing system should find some tricky steps through disk cache, which can make the process faster.

Another important characteristic of disk is spindle speed, which shows the frequency of rotation. This value is measured in revolutions per minute (RPM). The value of spindle speed shows how many full rotations were completed in one minute around a fixed axis. Usually for ATA disks spindle speed can be 5400 or 7200 rpm (90 or 120 Hz) and in this case SCSI disks win, because their spindle speed can be 10,000 or 15,000 rpm (160 or 250 Hz). This value is constant and is set by manufacture. Therefore, there is no reason to try making it higher; the only possibility is to take the disk with higher spindle speed.

Both of described parameters cache and spindle speed are influenced on the seek time of the disk. Seek time means the time, which needs for the head of the disc to move to the right position. It is clear that this time can be only average, because in different situations there are different values of cache, spindle speed and data task. In general there are two values of seek time - one for reading operations and another for writing, but usually it is only one value for both operations. Most of the time in the research we will consider it only as writing seek time, but the value of seek time for the reading should not be thrown out. There are two seek measurements called track-to-track and full stroke. The track-to-track measurement is the time required to move from one track to an adjacent track. This is the shortest (fastest) possible seek time. In hard disk drives (HDD) this is typically between 0.2 and 0.8

milliseconds. The full stroke measurement is the time required to move from the outermost track to the innermost track. This is the longest (slowest) possible seek time.

Lets consider the controller now and figure out what parameters this device has. First of all, it has the possibility to connect buses  $a$  and  $c$ , which was decided to call as input interface and output interface, which also follow the specific parameter, such as speed. In the literature, it is also possible to find that input interface is called as host interface. Secondly, it is the amount of RAIDs, which is supported by this controller. There are also some more parameters, which are still important, such as cache, cache function or algorithm, maximum amount of physical disks, maximum amount of logical disks. We discussed what does cache mean and controller's cache has more power in comparison with disk cache. Currently cache of the controllers can have values up to 512 MB. Moreover, some controllers have even their own cache algorithms, which make it stronger. However, this fact is obvious, because the controller should have enough power to communicate with all connected disks.

There is one parameter, which should be marked out. It is the bandwidth of the controller, which definitely influences on the performance of the device. Nevertheless, most of the time in the parameters of the controller, it is possible to find only the bandwidth of the input and output interfaces. It is like this, because currently the controllers are so powerful, that they can manage all the data, which comes to the device. That means that the speed of the controller is not the bottleneck and is not very important in our case.



## 3.4 Theoretical estimations

Lets model the real situation and try to estimate how long time does it take to write some data to the disk. Let consider that there is a Compaq SCSI disk BD01864552 with the following parameters:

- Capacity: 18.2 GB
- Spindle speed: 10,000 RPM
- Interface: Ultra3 SCSI
- Seek time: 3 ms

From these parameters, mostly we will focus on the interface, which has a speed 320 MB/s. That means that the speed of the bus  $c$  is equal to 320 MB/s. Basically all data on disks are divided to the sectors. Most of the time the size of the sector is 512 bytes, but in some cases this value can be different. In this research, we consider that the sector size is 512 bytes. We will focus on the parameters of the commands and the disks because the controller should not be a bottleneck, but we still need to remember that there are some limitations in the controller.

**WRITE SAME command** Let consider the WRITE SAME 10 command, which comes from the CPU [9]. This command has 32 bits for the LBA (Logical block addressing) and 16 bits for the Number of Logical Blocks. The main huge advantage of that command is that we can send the same buffer to several logical blocks only with one command. It gives us a possibility to write much more data than we really send with the command.

We can calculate the maximum amount of data that we can write with one

WRITE SAME 10 command to the disk:

$$\frac{2^{16} * 512}{1024^2} = 32MB. \quad (3.16)$$

Let consider that the Model 3.1 consists of 1 disk and we do not need any other commands except WRITE SAME one. That means that in Condition 3.3 parameter  $c_2$  will be equal to zero. We also assume that we do not need any special commands for the communication and  $c_3$  is equal to zero. It gives a possibility to calculate complete erasure  $F$  as a multiplication of command  $c_1$  and amount of commands  $m_{11}$ . According to the knowledge of the capacity of the disk we can compute the number of commands  $m_{11}$  that we need to send for erasure 18.2 GB disk. We write the buffer of 32 MB to the this disk with one WRITE SAME command that it why the number of commands

$$m_{11} = \frac{d_1}{buffer\ length} = \frac{18.2 * 1024}{32} = \frac{18636.8MB}{32MB} = 582.4. \quad (3.17)$$

For performance of real erasure, we should divide the data to fill the last part of the disk, because we can not send 0.4 part of command. The main aim of the research is testing the erasure time that is why we will not consider this little part and will use the approximate value of 582.

The size of WRITE SAME 10 command is 10 bytes. Including the buffer, which is 512, we get that one whole command is 522 B. So, to erase one disk by WRITE SAME command we need to send the following amount of data:

$$F_1 = c_1 * m_{11} = (Command\ length + Buffer\ length) * m_{11}. \quad (3.18)$$

Thus to perform the erasure of one 18.2 GB disk we need only

$$F_1 = (10 + 512) * 582 = 303804B = 304kB. \quad (3.19)$$

That means that for complete erasure of one disk we need to send only 304 kB. Another command WRITE 10 does not have so huge advantage, but

lets compare these two commands, because in some cases WRITE SAME 10 command does not work.

**WRITE command** Let consider another pass through command WRITE 10 [9]. The structure of this command is completely the same in comparison with WRITE SAME 10 command, but some parameters have different values. For example, WRITE SAME 10 command has operation code 0x41 and WRITE 10 command has 0x2A. The main difference of these 2 commands is that with WRITE 10 command we need to send whole buffer all the time. The buffer length is calculated by the following Formula:

$$Buffer\ length = Sector\ size * Transfer\ length. \quad (3.20)$$

In our situation, the disks have constantly sector size 512 and this value depends only on the disk. However, we can vary the buffer length by transfer length, which can have a value up to 65536. That means that if we decide to set the maximum transfer length we could send 32 MB with one WRITE 10 command. In comparison with WRITE SAME 10 command, which has 512 B buffer, our buffer can increase to 512\*65536, which is quite big value if we consider that the controller connect to several disks. Usually, in Linux driver of the controller there is a value of maximum buffer, which is 4096\*512 in our case. It can be optimal for some amount of disks, but we should check it, because we can influence on the buffer which we send with the command.

If many data go with one command through the controller, it can make the erasure process slower because the cache of the controller will be full of messages, waiting in the queue. We should influence on the erasure speed by this parameter and find the optimal value during testing. Blancco software has transfer length 256, which means that we send 128 kB at once. We can

calculate how many commands we need to erase one 18.2 GB disk by WRITE 10 command with 128 KB buffer:

$$m_{11} = \frac{d_1}{buffer\ length} = \frac{18.2GB}{128kB} = \frac{18636.8MB}{0.125MB} = 149094.4 \quad (3.21)$$

The derived value is 256 times bigger than the amount of commands that we need to send for erasure by WRITE SAME command. It is obvious, because the current value of buffer length is 256 bigger. In the Chapter 4, we will see the results of erasure testing with different transfer lengths.

## Chapter 4

# Application of load balancing strategies to the HP Smart Array 642

This part of the thesis shows how is it possible to apply load balancing during communication between SCSI controller and disks. We discuss several strategies of sending the commands and try to estimate which one is better. Moreover, we suggest to apply a dynamic load balancing system for finding the optimal values for the erasure. That system solves our optimization Problem 3.13, which is the main task in this research.

### 4.1 HP Smart Array 642

HP Smart Array 642 is a SCSI RAID controller, which supports protocol Ultra-320 SCSI [3]. This device has one internal and one external VHDCI

(Very-High-Density Cable Interconnect) SCSI ports. The internal port gives the possibility to connect up to 6 internal disks and the external one up to 14 disks. That means that HP Smart Array 642 controller supports 20 disks. Maximum capacity for all disks in total is 6 TB. Controller has PCI-X bus, which has a 133-MHz frequency. That means that the maximum bandwidth of the bus is 1 GB/s. Moreover, the architecture is 64-bit.

The Figure 4.1 presents the described controller.



**Figure 4.1:** HP Smart Array 642 controller

## 4.2 Load balancing strategies

This section presents a description of the methods for solving the problem presented above in the Chapter 3. The solutions that we offer are simple, but effectively show the results in practice. We applied them for testing the erasure of several disks and find out which one is optimal. The main problem of the research is to minimize the functional of time  $T$  or prove that

it is not possible because of some limiting factor. That means that we try to find the fastest way of sending the write commands to the disks through the controller.

We applied three load balancing strategies during testing the erasure of the disks behind HP Smart Array 642 controller. In several papers [7], [11] there were some discussions about strategies. Because of the specificity of the problem it was difficult to apply them in our case, but it gave an idea how it should work. First two strategies, which we applied, are sequential and the third one is parallel, which works more effectively than others. Because first two strategies are much slower than the third one, we tested them with 5 disks connected with the backplane to the internal port of the controller. The third strategy was tested with the enclosure of 14 disks connected to the external port of the controller. In both cases we chose 18.2 GB disks from Compaq. The Section 3.4 discusses the theoretical expectations about these disks.

Lets consider the strategies in more detail. The first strategy performs the complete erasure disk by disk. That means that until we do not erase the current disk the program does not start the erasure of the next disk. From the Section 3.4 we know that for the erasure one 18.2 GB disk we need to send 582 WRITE SAME 10 commands. According to the point that for testing first strategy we took 5 disks we get the following matrix  $H_{s1}$  from

the Model 3.8 for complete erasure:

$$H_{s1} = \begin{pmatrix} 582 & 0 & 0 & 0 & 0 \\ 0 & 582 & 0 & 0 & 0 \\ 0 & 0 & 582 & 0 & 0 \\ 0 & 0 & 0 & 582 & 0 \\ 0 & 0 & 0 & 0 & 582 \end{pmatrix} \quad (4.1)$$

From the matrix  $H_{s1}$  we can conclude that first strategy has only 5 steps in the algorithm.

Second strategy sends one command per disk and then changes the disk. That means that in this case matrix  $H$  is completely different:

$$H_{s2} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & \dots & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \end{pmatrix}. \quad (4.2)$$

For the second strategy the dimension of matrix  $H$  is  $5 \times 2910$ . Value 2910 came from multiplication of number of disks and number of commands that we need to send for the erasure. From the logic of sending commands the devices should be changed quite often, which can be a disadvantage of this strategy.

The third strategy is using parallel computing, which makes the process for complete erasure much faster. The application creates separate thread for each disk and start sending WRITE SAME commands to that disk. It is obvious that during increasing the amount of disks the value of functional of time will increase too, but slowly, because threads are working completely separately. However, important limitations are the speeds of the disks and



the bus. We can see from Figure 3.1 that separate buses  $c$  give the possibility to send data from the controller  $b$  to the disks  $d$ . In our situation, only one bus  $c$  exists, which is connected to the enclosure containing several disks. If we write information in parallel to several disks the bus speed can be the limitation for data transfer. The maximum speed of the current bus is 320 MB/s. For the third strategy it is difficult to present matrix  $H$ , because we do not know in which order WRITE SAME commands come to the disks.

### 4.3 Planning dynamic load balancing system

During whole research we try to find the optimal parameters for sending write commands to the disks, but it seems that our conclusions about them can be wrong before some testing or special calculations. As we mentioned in the beginning of the paper, load balancing system should take care of these things. Lets discuss what kind of static and dynamic load balancing systems we could provide for our situation. There are so many parameters which depend on the speed of erasure that it is much better to use dynamic load balancing system. However, it is also possible to apply static load balancing system using some special conditions. Currently we consider the situation when we send WRITE 10 commands to several disks using the parallel strategy. We do not take in consideration WRITE SAME command, because the bottleneck is the bus in this case and we cannot influence on that.

Main condition that we should focus on is knowledge about the cache of the controller. If we know this parameter before the erasure process it is possible to calculate the optimal buffer and optimal number of disks for erasure. The problem is that getting cache from the controller is very specific task

and sometimes maybe even impossible one. However, we can manually find the maximum value for the transfer buffer inside the Linux driver. In our situation for the HP Smart Array 642, which uses the driver cciss, this value is defined as  $MAX\_KMALLOC\_SIZE(4096*512)$ , which means that the maximum buffer can not be larger than 2 MB. We do not know exactly if it is cache, but the value looks quite similar to the cache size. If we consider this value as cache we can calculate what is the closest value for the transfer length to the optimal one using several disks:

$$\frac{MAX\_BUFFER}{SECTOR\_SIZE * MAX\_DISKS} \quad (4.3)$$

In our case we send the buffer with the value of power of two, that is why we should find the value, which is closest from the bottom, otherwise we exceed the cache size. If we consider 14 disks, we can see that the value  $4096 * 512 / 512 * 14 = 292.57$  is closest to 256. Blancco software sends the buffer exactly with the transfer length 256, but it is optimal only when the number of disks is more than 8. Lets calculate the transfer length in case that we have 8 disks:  $4096 * 512 / 512 * 8 = 512$ . This fact explains that we should use another transfer length to get an optimal way of sending commands. Moreover, we understand that for 4 disks we need 1024 and for 2 disks - 2048. We proved this theory by making several tests. The Figure 5.12 shows that if we base on our theory Blancco software sends the optimal buffer only for disks 9-14. If we have less than 9 disks in the enclosure, we can erase them faster using another transfer length.

Based on our theory if we have 9 disks and transfer length is 512, the buffer will exceed the limit of 2 MB and the erasure process should go slower than with transfer length 256. However, in practise, the results of testing show that even for disks 9-14 the buffer with transfer length 512 allows to erase

the devices faster than with transfer length 256. The Figure 5.13 explains it more clear. From these results we could make a conclusion that some other parameters, that we did not include, influence on the speed. Anyway, suggested static load balancing system helps to improve the erasure, which gives a possibility to do it faster than Blancco software currently does. Moreover, if we base on the testing results, we could provide even faster load balancing system.

In some versions of Blancco software it is possible to add disks during the erasure process. In this case our static load balancing system should recalculate the optimal transfer length and set it correctly to the commands during the erasure process. From the programming point of view it could be difficult to access the function, which performs the erasure, but not impossible. If we cannot influence on the transfer length of the currently working disks, it could be better to wait until the application erases them, because the bus can be already filled completely. So, if we decide to add more commands because of new disks, we could come to the situation that the commands will stay in the queue before coming to the bus. It can make the speed of the erasure much slower.

If we consider the situation that we can influence on the transfer length during the erasure process, we get that our static load balancing system transforms to the dynamic load balancing system. The purpose of this load balancing system is to calculate and set the optimal transfer length for the write command depending on the amount of disks. In the situation of ending the erasure this load balancing system can help us one more time. Of course, that if we have disks, which have the same size and rotation speed, there is no reason to make any more calculations for searching the optimal parameters after some disks are erased, because the time should be almost equal to each

other. But if we have disks with the different capacities, it makes sense to set another transfer length after some disks are erased. That means that suggested dynamic load balancing system should work in three situations:

1. Before the erasure
2. During the erasure, when some disks are added or stopped
3. After some disks finish the erasure

However, if we consider the situation that the optimal value was found and look to the Figure 5.6 we can notice that the maximums of 2 curves belongs to different disks. It gives an idea that not only speed of the disk and buffer length influence on the erasure speed. It could be possible to find the way of sending commands, which will give the results with almost equal times for all disks. In this case we mean that the time of erasure for each disk should be almost the same. However, it can be difficult because for each disk a separate thread exists. These results could give us a great advantage, because the time for complete erasure will decrease. Moreover, our load balancing system will not need to analyse the optimal transfer length for last disks, which do not finish the erasure yet.

One of the possible ways of trying to find these results is to analyse each thread. For example, we can make that each thread will return the percentage of process with some step. Using this value we can analyse which disk works faster or slower. After that the dynamic load balancing system stops the erasure process for some fast disks. Thus, we will get some free space in the bus and could increase the transfer length for the slow disk. This action could give us an advantage if the limit is not a disk speed. After the next returns from the threads if the result of the slow disk is larger than fast disks

we turn on the erasure for all disks. Because user is allowed to stop or add disks this strategy can give several problems for the software developer.

# Chapter 5

## Experiments and results

In this chapter we present the test results of the application, which sends WRITE 10 and WRITE SAME 10 commands with different parameters. We made all the tests with WRITE 10 command, when the disks were connected with the enclosure to the controller. But some tests with WRITE SAME 10 command were done with the backplane. Mostly we are interested in decreasing the time of complete erasure, but sometimes, because of the different speed of the disks, the results started to be useless and strange, that is why we started to calculate also the time of erasure for single disks.

### 5.1 Results with WRITE SAME 10 command

Using WRITE SAME 10 command we tested 3 different strategies that we described in the Section 4.2. The tests for the first and second strategies were done with 5 disks, connected with the backplane to the internal port of the HP Smart Array 642 controller. The third strategy was tested with 14 disks, connected with the enclosure to the external port of the controller.

## CHAPTER 5. EXPERIMENTS AND RESULTS

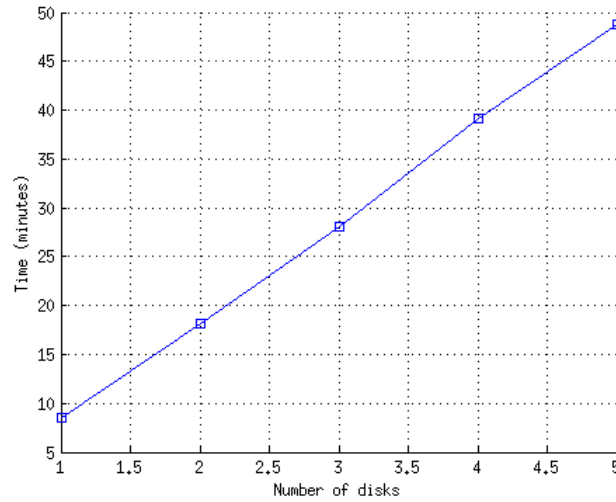
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Table 5.1 presents the results, which we got during testing the complete erasure with the first strategy.

**Table 5.1:** Results for complete erasure by first strategy

| Disks | Capacity | Time          | Average<br>time/disk | Average<br>speed |
|-------|----------|---------------|----------------------|------------------|
| 1     | 18.2 GB  | 8 min 32 sec  | 8 min 32 sec         | 35.5 MB/s        |
| 2     | 36.4 GB  | 18 min 12 sec | 9 min 6 sec          | 33.3 MB/s        |
| 3     | 54.6 GB  | 28 min 5 sec  | 9 min 21 sec         | 32.4 MB/s        |
| 4     | 72.8 GB  | 39 min 7 sec  | 9 min 46 sec         | 31.0 MB/s        |
| 5     | 91 GB    | 48 min 45 sec | 9 min 45 sec         | 31.1 MB/s        |

Figure 5.1 presents the results from the Table 5.1 more clearly.



**Figure 5.1:** Time results for complete erasure by first strategy

## CHAPTER 5. EXPERIMENTS AND RESULTS

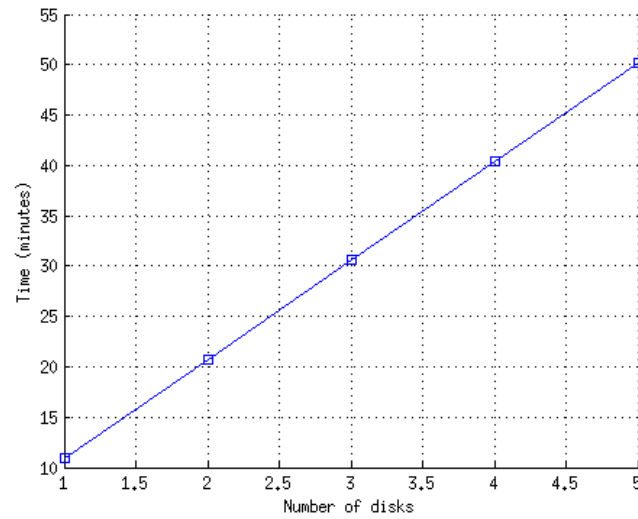
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Table 5.2 presents the results, which we got during testing the complete erasure with the second strategy.

**Table 5.2:** Results for complete erasure by second strategy

| Disks | Capacity | Time          | Average time/disk | Average speed |
|-------|----------|---------------|-------------------|---------------|
| 1     | 18.2 GB  | 10 min 54 sec | 10 min 54 sec     | 27.8 MB/s     |
| 2     | 36.4 GB  | 20 min 42 sec | 10 min 21 sec     | 29.3 MB/s     |
| 3     | 54.6 GB  | 30 min 41 sec | 10 min 13 sec     | 29.6 MB/s     |
| 4     | 72.8 GB  | 40 min 25 sec | 10 min 6 sec      | 30.0 MB/s     |
| 5     | 91 GB    | 50 min 10 sec | 10 min 2 sec      | 30.2 MB/s     |

Figure 5.2 presents the results from the Table 5.2 more clearly.



**Figure 5.2:** Time results for complete erasure by second strategy

From these results we can notice that the second strategy works slower than



## CHAPTER 5. EXPERIMENTS AND RESULTS

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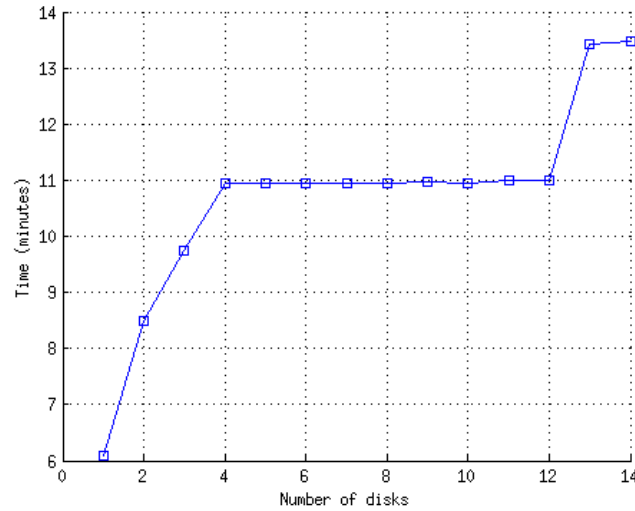
the first one, which is obvious because it needs to change the devices quite often. However, if we compare the Figures 5.1 and 5.2 we can see that the difference is only about 1 minute, which is insignificant value in comparison with time for complete erasure of 5 disks, which takes around 50 minutes.

Table 5.3 presents the results, which we got during testing the complete erasure with the third strategy.

**Table 5.3:** Results for complete erasure by third strategy

| Disks | Capacity | Time          | Average<br>time/disk | Average<br>speed |
|-------|----------|---------------|----------------------|------------------|
| 1     | 18.2 GB  | 6 min 5 sec   | 6 min 5 sec          | 49.8 MB/s        |
| 2     | 36.4 GB  | 8 min 29 sec  | 4 min 15 sec         | 71.5 MB/s        |
| 3     | 54.6 GB  | 9 min 45 sec  | 3 min 15 sec         | 93.3 MB/s        |
| 4     | 72.8 GB  | 10 min 57 sec | 2 min 44 sec         | 111.2 MB/s       |
| 5     | 91 GB    | 10 min 57 sec | 2 min 11 sec         | 138.5 MB/s       |
| 6     | 109.2 GB | 10 min 57 sec | 1 min 50 sec         | 166.2 MB/s       |
| 7     | 127.4 GB | 10 min 57 sec | 1 min 34 sec         | 194.0 MB/s       |
| 8     | 145.6 GB | 10 min 57 sec | 1 min 22 sec         | 221.7 MB/s       |
| 9     | 163.8 GB | 10 min 58 sec | 1 min 13 sec         | 249.0 MB/s       |
| 10    | 182 GB   | 10 min 57 sec | 1 min 6 sec          | 277.1 MB/s       |
| 11    | 200.2 GB | 11 min 0 sec  | 1 min 0 sec          | 303.4 MB/s       |
| 12    | 218.4 GB | 11 min 0 sec  | 55 sec               | 331.0 MB/s       |
| 13    | 236.6 GB | 13 min 26 sec | 1 min 2 sec          | 293.6 MB/s       |
| 14    | 254.8 GB | 13 min 28 sec | 58 sec               | 315.5 MB/s       |

Figure 5.3 presents the results from the Table 5.3 more clearly.



**Figure 5.3:** Time results for complete erasure by third strategy

From the Figure 5.3 we can see that for disks from 4 to 12 the time of complete erasure is constant. Third strategy sends the commands parallel to several disks. That means if there is one slow disk in the task, the whole time of the erasure will be slow. Therefore, we decided to calculate the time of the erasure for single disk.

## CHAPTER 5. EXPERIMENTS AND RESULTS

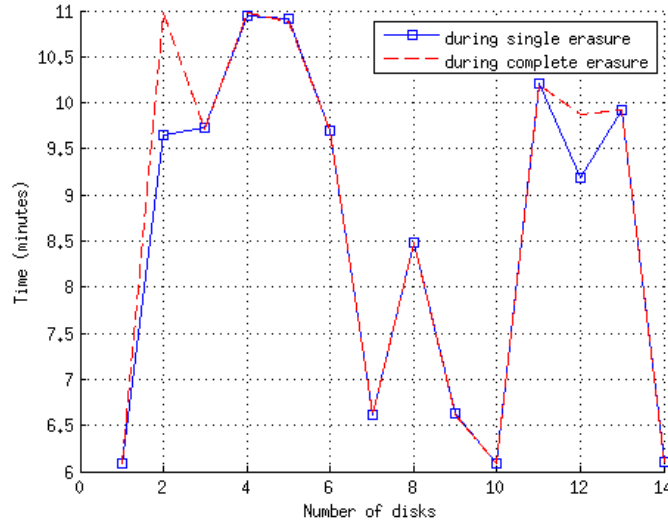
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During testing the erasure of single disks with third strategy we got the results presented in the Table 5.4. Moreover, in the Table 5.4 we present the time of erasure for single disk during complete erasure.

**Table 5.4:** Results for erasure of single disks by third strategy

| Disks | Capacity | Time          | Time during complete erasure |
|-------|----------|---------------|------------------------------|
| 1     | 18.2 GB  | 6 min 5 sec   | 6 min 5 sec                  |
| 2     | 36.4 GB  | 9 min 39 sec  | 10 min 59 sec                |
| 3     | 54.6 GB  | 9 min 44 sec  | 9 min 43 sec                 |
| 4     | 72.8 GB  | 10 min 57 sec | 10 min 59 sec                |
| 5     | 91 GB    | 10 min 55 sec | 10 min 53 sec                |
| 6     | 109.2 GB | 9 min 42 sec  | 9 min 42 sec                 |
| 7     | 127.4 GB | 6 min 37 sec  | 6 min 37 sec                 |
| 8     | 145.6 GB | 8 min 29 sec  | 8 min 29 sec                 |
| 9     | 163.8 GB | 6 min 38 sec  | 6 min 37 sec                 |
| 10    | 182 GB   | 6 min 5 sec   | 6 min 5 sec                  |
| 11    | 200.2 GB | 10 min 13 sec | 10 min 12 sec                |
| 12    | 218.4 GB | 9 min 51 sec  | 10 min 31 sec                |
| 13    | 236.6 GB | 9 min 55 sec  | 9 min 55 sec                 |
| 14    | 254.8 GB | 6 min 6 sec   | 6 min 5 sec                  |

Figure 5.4 presents the results from the Table 5.4 more clearly.

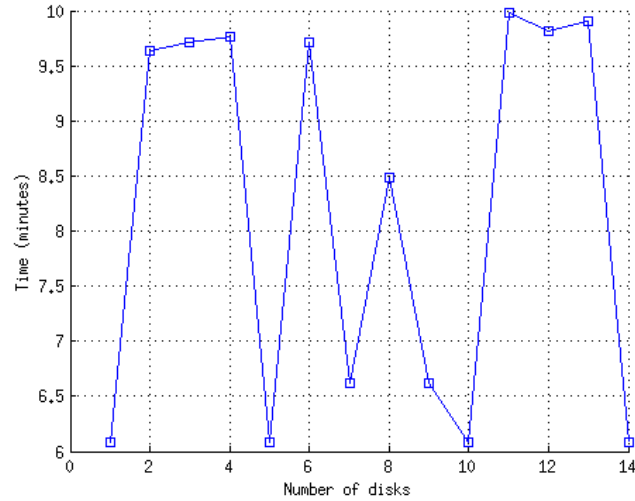


**Figure 5.4:** Time results for complete erasure by third strategy

The third strategy works without any problems, but the results of several disks are quite different, which gives an idea that there are some other parameters of software or hardware, which influence on the speed of the erasure. We can see from the Figures 5.1 and 5.2 that the time of first and second strategies is increasing linearly. We could not say the same about the third strategy because the disks have different speed or some other parameters affect on the maximum speed of the disk. Figure 5.4 shows that the difference is very low between the times of erasure for single disk and for single disk during complete erasure. That means that the bus is not a bottleneck in the situation, when we send WRITE SAME 10 commands parallel to 14 disks, which are connected to the controller. Thus, only speed of the disks is a limiting factor.

By replacing disks 4, 5 and 11 we got different results for the erasure of single

disks during complete erasure, which are shown on the Figure 5.5.



**Figure 5.5:** Time results for single erasure by third strategy

The results from the Figure 5.5 proves the fact that only the disk speed is the limiting factor with the WRITE SAME 10 command. We replaced 3 slow disks and the results show that the time of complete erasure decreased from 11 to 10 minutes. However, it is still strange that the difference of the time of erasure for several disks can be even 4 minutes, which is almost half time of the complete erasure, but the disk parameters are completely the same.

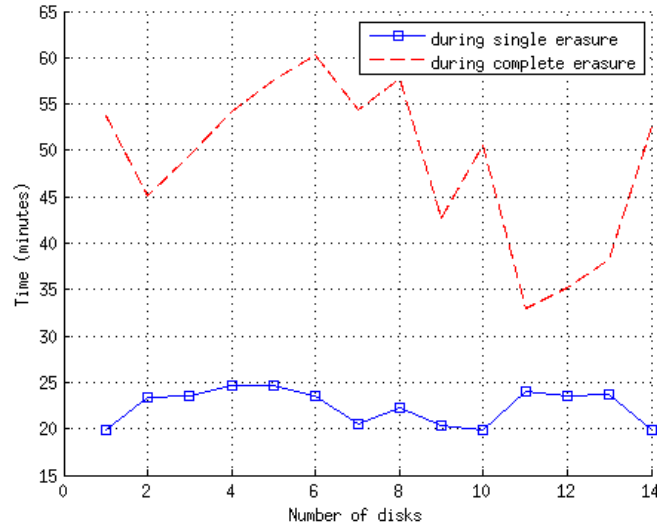
## 5.2 Results with WRITE 10 command

During the research with WRITE SAME 10 command we understood that parallel strategy works pretty well with HP smart Array 642 controller that is why we decided to focus our experiments with WRITE 10 command only on the third strategy. We realized several tests with transfer length 256 which Blancco software uses by default. Table 5.5 presents the results, which we got during testing the complete erasure with the third strategy.

**Table 5.5:** Results for erasure of single disks by third strategy

| Disks | Capacity | Time          | Time during complete erasure |
|-------|----------|---------------|------------------------------|
| 1     | 18.2 GB  | 19 min 52 sec | 53 min 43 sec (-3)           |
| 2     | 36.4 GB  | 23 min 24 sec | 45 min 6 sec (+4)            |
| 3     | 54.6 GB  | 23 min 28 sec | 49 min 25 sec (+3)           |
| 4     | 72.8 GB  | 24 min 43 sec | 54 min 15 sec (0)            |
| 5     | 91 GB    | 24 min 38 sec | 57 min 39 sec (-1)           |
| 6     | 109.2 GB | 23 min 28 sec | 60 min 19 sec (+3)           |
| 7     | 127.4 GB | 20 min 27 sec | 54 min 27 sec (+2)           |
| 8     | 145.6 GB | 22 min 15 sec | 57 min 47 sec (-3)           |
| 9     | 163.8 GB | 20 min 24 sec | 42 min 40 sec (+2)           |
| 10    | 182 GB   | 19 min 50 sec | 50 min 37 sec (-5)           |
| 11    | 200.2 GB | 24 min 1 sec  | 33 min 0 sec (-5)            |
| 12    | 218.4 GB | 23 min 32 sec | 35 min 10 sec (+1)           |
| 13    | 236.6 GB | 23 min 39 sec | 38 min 14 sec (-6)           |
| 14    | 254.8 GB | 19 min 51 sec | 52 min 40 sec (-5)           |

Table 5.5 presents the time results of the erasure of 14 disks with the transfer length 256. The third column shows how much time we need to spend for erasure one single 18.2 GB disk. The forth column consists of the results of time which we need to wait for the erasure of single disk during the parallel erasure of 14 disks. That means that, for example, for disk 13 we need to spend 23 min 39 sec when we erase it separately, but if we erase 14 disks together the erasure of disk 13 will take 38 min 14 sec. Figure 5.6 presents the results from the Table 5.5 more clearly.

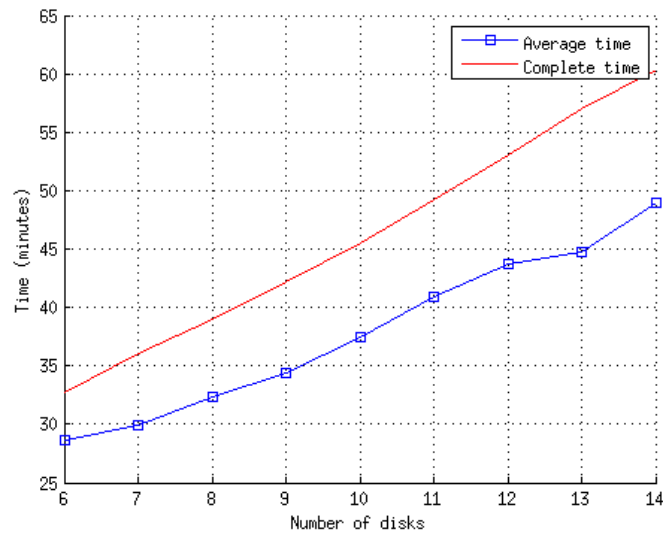


**Figure 5.6:** Results for erasure of single disks by third strategy with transfer length 256

The testing results do not depend on the application running and the erasure time is not divided randomly to different disks. Table 5.5 proved this fact by results from the same test running several times, which gave the whole difference with -13 seconds for erasure of 14 disks by WRITE 10 command. That means that 13 seconds will take only 0.01 of whole erasure process of the fastest disk. That is why we will ignore this difference.

From the Figure 5.6 we also can notice how big is the time difference for single erasure if we decide to erase 14 disks together using WRITE 10 command. The lower curve shows us that for erasure one of these 14 disks we need from 20 to 25 minutes. However, if we launch the application together with 14 disks, for the disk 2 it will take 45 minutes, but for disk 10 already 50 minutes. Anyway, the complete erasure takes a bit more than 60 minutes, which is just 3 times bigger than single erasure of the fastest disk.

The Figure 5.7 presents the graphics of erasure times depending on the amount of disks with the transfer length 256.



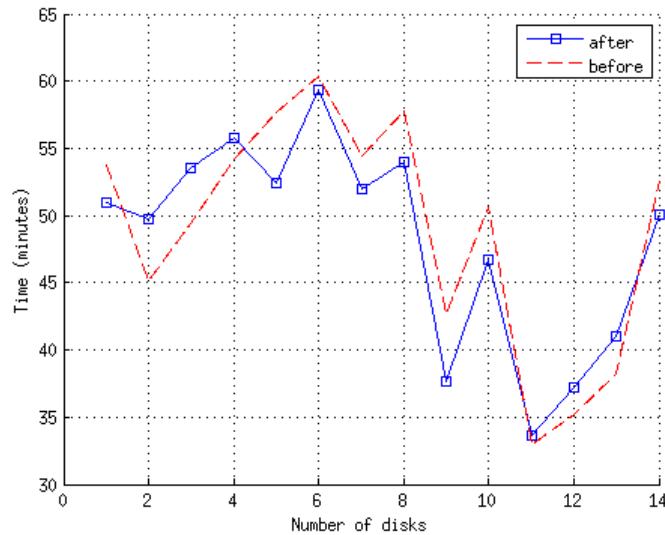
**Figure 5.7:** Time results for the complete erasure depending on the amount of disks

The upper curve of the Figure 5.7 shows the time results of the complete erasure. We can see that the result for the complete erasure of 14 disks is equal to the result from the Figure 5.6. The lower curve shows the average time results for single erasure during complete erasure. That means that



when we divide the sum of the values from the forth column of the Table 5.5 by 14, we will get the last value of the curve for average time from the Figure 5.7. From the Figure 5.7 we can make a conclusion that addition of 1 disk gives us addition of 3 minutes to the complete erasure.

We can notice from the Figure 5.4 that during complete erasure by WRITE SAME 10 command disks 2, 4 and 5 showed the worst time. In the same time the Figure 5.6 presents that during complete erasure by WRITE 10 command disks 6 and 8 showed the worst time. That gives an idea that there are some other parameters which also influence on the time of erasure. It is possible that the controller decides which command goes first and to which device. Thus, we could not influence on that fact. We decided to replace disks 4, 5 and 11 and check how it will change the situation. The Figure 5.8 shows these results.

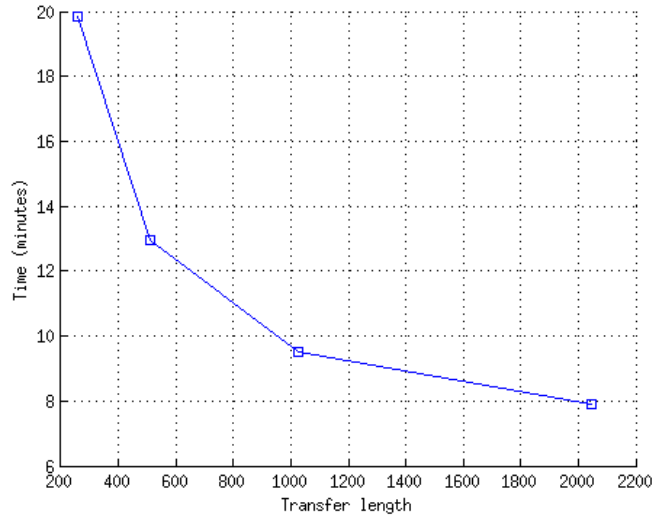


**Figure 5.8:** Results after replacement of the disks 4, 5 and 11.

From these results we can conclude that time for complete erasure decreased

for 1 minute and the same disks show the maximum and minimum times. However, it is strange that during single erasure by WRITE 10 command disks 1 and 14 were the fastest and during complete erasure their results are closed to very slow ones.

We discussed before that transfer length is one the most important parameters during the erasure by WRITE 10 command. Furthermore, we can influence on it. Figure 5.9 presents the time results for the erasure of disk 1 depending on the different transfer length.

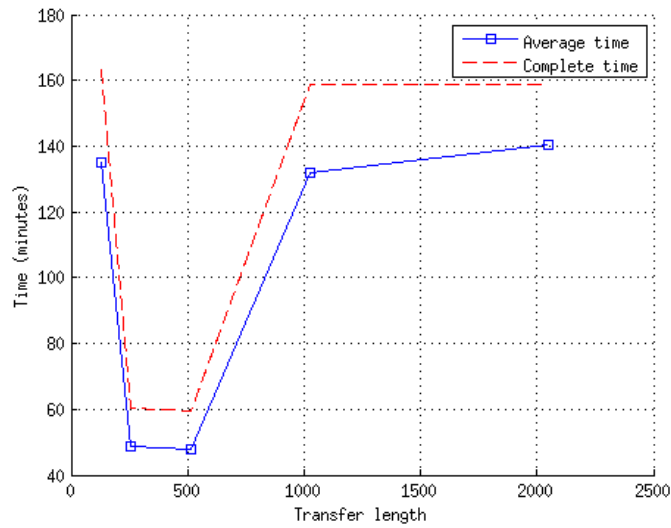


**Figure 5.9:** Time results for the disk 1

The Figure 5.9 shows that 2048 is the optimal value for 1 disk. If we take the value, for example, 4096, which is bigger than 2048, we come to the situation when we get errors from the WRITE 10 command. It happens because the limit of 2 MB is exceeded and the driver cannot handle so big amount of information. The Figure 5.9 shows that we need for erasure of disk 1 with transfer length 2048 only 8 minutes, which is 12 minutes faster than the erasure with transfer length 256. This result proves the fact that we can

influence on the speed erasure by varying the transfer length. Thus, we can achieve faster erasure by finding the optimal transfer lengths depending on the amount of disks. Our suggested load balancing system will help with solving this problem.

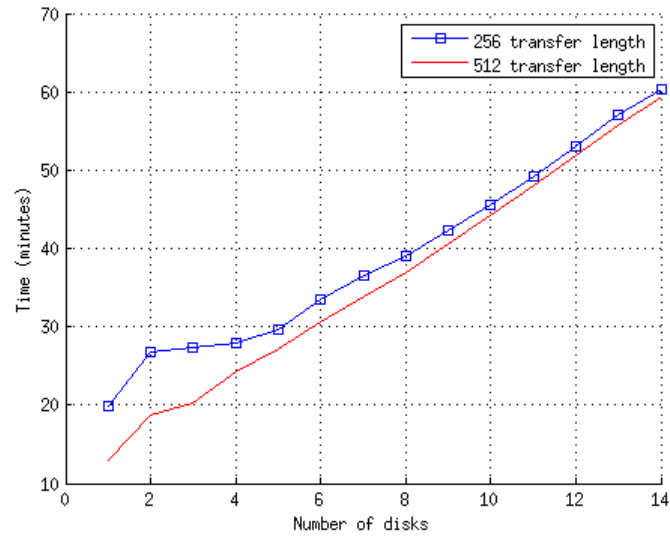
The Figure 5.10 shows the results of testing different transfer length during erasure of 14 disks in the same time.



**Figure 5.10:** Time results for average erasure and complete erasure depending on the transfer length

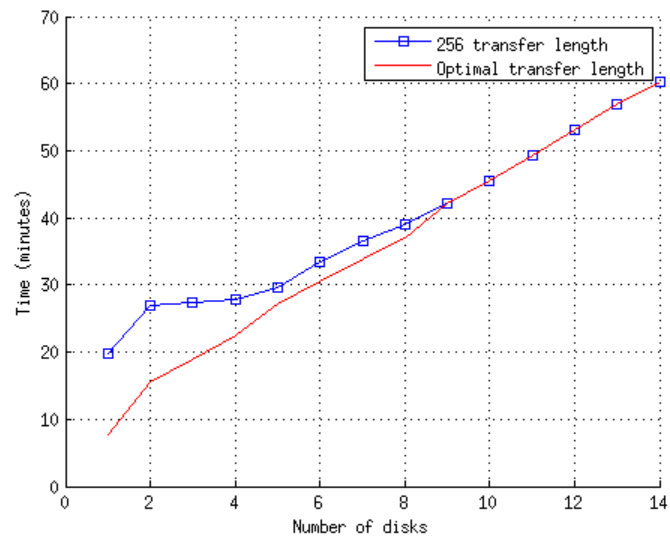
To summarize the results from the Figure 5.10 we can say that transfer lengths 512 and 256 give almost the same results, but the optimal value for 14 disks is 512, which is easier to see from Figure 5.11.

Figure 5.11 presents the time results of complete erasure with transfer length 256 and 512.



**Figure 5.11:** Results for complete erasure with transfer lengths 256 and 512 depending on the amount of disks

Figure 5.12 presents the time results of theoretical optimal complete erasure in comparison with the results with transfer length 256.



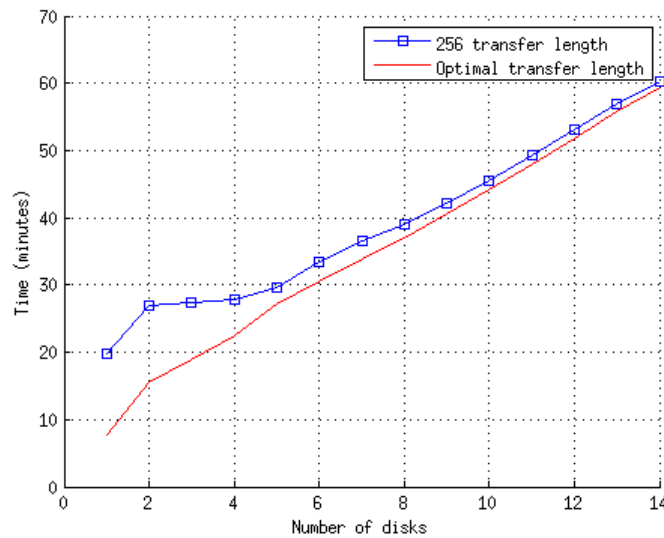
**Figure 5.12:** Results for theoretical optimal erasure

## CHAPTER 5. EXPERIMENTS AND RESULTS

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These graphics show the difference between the results of our suggested load balancing system and Blancco software at the moment. Load balancing system applies the Formula 4.3 to calculate the optimal transfer length. Thus, if we apply only our theoretical calculations the Figure 5.12 shows the results of time improvement. For the disks 1-8 we took another transfer length, which improves the time of erasure. For disk 1 and 2 the transfer length was 2048, for disk 3 and 4 - 1024, and for disks from 5 to 8 - 512.

Moreover, using our practical results we can suggest to apply the results from the Figure 5.13, which improves the Blancco software for any amount of disks. The difference between theoretical optimal erasure and practical optimal erasure is another transfer length for disks 9-14. In practise, when we took the transfer length 512 we got better results in comparison with theoretical optimal erasure. These results shows that the optimal transfer length, which was calculated by testing and load balancing system, makes the erasure faster for WRITE 10 command from disk 1 to disk 14.



**Figure 5.13:** Results for practical optimal erasure

# Chapter 6

## Conclusion

The aim of the research was to analyse the communication model between SCSI controller and disks and find out the optimal way of sending WRITE and WRITE SAME commands. We applied several strategies of sending commands, which gave the food for understanding where the bottlenecks are hidden. Moreover, these results supported to build the dynamic load balancing system, which can find the optimal values for commands.

The tests showed that if we send commands in series, the erasure time increases linearly. After finish of sending consecutive commands we decided to apply the parallel strategy. SCSI controller and disks handled it without any problems that is why we realized all the later experiments with the parallel strategy. The results gave a possibility to make several conclusions. First of all, usage of WRITE SAME command allows to erase one 18.2 GB disk by sending only 304 kB of information and the time of the erasure depends directly on the disk speed. Secondly, the bottleneck of sending WRITE commands is the bus, because with that command we need to send the amount of data, which exceeds the capacity of the disks. However, this fact gave a

possibility to vary the parameters and different tests helped to find out that the size of sending buffer played the main role. To make the process faster the buffer size should fit in the allocation memory of the SCSI controller that was found in the Linux driver. These facts played very important roles in building the suggested dynamic load balancing system, because it helped to calculate the optimal values for sending the commands for the erasure.

For the future research we suggest to figure out if we discussed all the parameters of this communication. For example, there is the question why the erasure times of the disks with the same properties are so different during single erasure. Moreover, it would be a great step forward to balance the results of single erasure, which gives a possibility to make lower the value of complete erasure. In this research we considered only one SCSI controller and it is possible that another controller will have similar behaviour, but with its own specificities.

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