***A CLUSTER-BASED HYBRID REPLICA CONTROL PROTOCOL FOR HIGH AVAILABILITY IN DATA GRID***

**ZULAILE MABNI**

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# A CLUSTER-BASED HYBRID REPLICA CONTROL PROTOCOL FOR HIGH AVAILABILITY IN DATA GRID

By

ZULAILE MABNI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

February 2019

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**DEDICATIONS**

*I wish to dedicate this thesis to:*
*My late mother, Hajjah Siti Ramlah Roslan and my father, Haji Mabni Othman*
*My Husband, Feizal Bin Badli*
*My Children, Faten Zuhairah, Farah Zafirah, Fikri Zabir and Faeez Zimam*

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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**February 2019**

**Chairman** : **Associate Professor Dr Rohaya Latip**
**Faculty** : **Computer Science and Information Technology**

Data Grid provides a scalable infrastructure for managing and storing large amount of data files in Grid computing system. In Data Grid, data replication is a widely used technique for managing data, where exact copies of data or replicas are created and stored at many distributed sites. This technique provides high data availability and increases the performance of the distributed systems. In recent years, the number of distributed nodes has become very large in Grid computing system. The growing number of nodes has raised few issues in data replication. The first issue is, nodes in the Grid systems are dynamic where they can join or leave the system at any time. Therefore, a replica control protocol must consider the dynamic aspects of the Data Grid. Next important issue is replica placement which determines the suitable nodes to place the replicas. Previously, replica placement has not been an issue since the research only focuses on small-scale systems. However, in a larger system such as Data Grid, the existing replica control protocols require bigger number of replicas to construct read and write quorums. As the number of replicas increases, the communication cost also increases and thus, degrades the performance of the protocols. Another issue is replica consistency that needs to be ensured when copying data in a large-scale system. In order to maintain replica consistency, if there is concurrent update to several replicas of the same file, then all other replicas must have the same updated contents. Thus, an efficient mechanism is needed to improve performance of the system while ensuring replica consistency in Data Grid. Therefore, in this thesis, we proposed a new replica control protocol named *Cluster-Based Hybrid* (*CBH*) protocol for large-scale system with the objectives to reduce the communication cost, increase data availability, and maintain replica consistency. CBH employs a hybrid replication strategy by combining the advantages of two common replica control protocols to improve the performance of the existing protocols. A clustering algorithm has been proposed to group the large nodes into clusters and organize these clusters into a tree structure. Another proposed algorithm is replica placement algorithm which selects and places only one replica in each cluster.

The performance of CBH protocol is evaluated theoretically and using simulations. A discrete event simulator called GridSim and Java programming language is used to simulate the proposed protocol. The performance metrics which are communication cost and data availability of the protocol are evaluated and compared with two latest quorum-based protocols which are Dynamic Hybrid (DH) and Duplication on Grid (DDG) protocol. CBH shows that by grouping the nodes into clusters and having only one replica in each cluster, has minimized the number of replicas involved in constructing read and write quorums. This research has contributed a dynamic cluster-based hybrid replica control protocol which proposed a clustering algorithm to determine the number of clusters, a mechanism for dynamic participation of nodes in the network, and a replica placement algorithm that produces low communication cost and high data availability as compared to DH and DDG protocols. CBH has proven that replica consistency is maintained by satisfying the Quorum Intersection Properties.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PROTOKOL KAWALAN REPLIKA HIBRID BERDASARKAN KLUSTER UNTUK KETERSEDIAAN DATA YANG TINGGI DALAM DATA GRID**

Oleh

**ZULAILE MABNI**

**Februari 2019**

**Pengerusi** : **Profesor Madya Dr Rohaya Latip**
**Fakulti** : **Sains Komputer dan Teknologi Maklumat**

Data Grid menyediakan prasarana untuk mengurus dan menyimpan fail data yang sangat besar dalam sistem pengkomputeran Grid. Dalam Data Grid, replikasi data adalah satu teknik yang digunakan secara meluas untuk mengurus data, di mana beberapa salinan data dibuat dan disimpan di beberapa lokasi dalam sistem teragih. Replikasi data menyediakan ketersediaan data yang tinggi dan meningkatkan prestasi bagi sesebuah sistem teragih. Dalam beberapa tahun kebelakangan ini, bilangan nod teragih telah bertambah dengan pesatnya dalam sistem pengkomputeran Grid. Pertambahan yang banyak dalam bilangan nod telah menimbulkan beberapa isu dalam replikasi data. Isu yang pertama adalah, nod di dalam sistem Grid adalah dinamik, di mana nod boleh menyertai atau meninggalkan sistem pada bila-bila masa. Oleh itu, protokol kawalan replika mesti mengambil kira aspek dinamik dalam Data Grid. Isu penting yang seterusnya adalah penempatan replika yang menentukan nod yang sesuai untuk menempatkan replika. Dalam kajian yang lalu, penempatan replika tidak dianggap sebagai satu isu kerana kajian dibangunkan hanya untuk sistem berskala kecil. Walau bagaimana pun, untuk sistem berskala besar seperti Data Grid, protokol kawalan replika tersebut memerlukan jumlah replika yang banyak untuk membina korum bagi operasi baca dan tulis. Apabila bilangan replika bertambah maka bertambahlah kos komunikasi dan justeru itu, menyebabkan penurunan prestasi protokol. Isu yang lain adalah konsistensi replika yang perlu dipastikan apabila membuat penyalinan data dalam sistem berskala besar. Untuk mengekalkan konsistensi replika, sekiranya kandungan replika bagi data yang sama dikemaskini, maka semua replika yang lain juga mesti dikemaskini dengan kandungan yang terkini. Oleh yang demikian, satu mekanisma yang efisien adalah sangat diperlukan untuk meningkatkan prestasi sistem sekaligus mengekalkan tahap konsistensi replika dalam Data Grid. Justeru itu, dalam tesis ini, kami mencadangkan satu protokol kawalan replika berdasarkan kluster yang dinamik diberi nama protokol *Cluster-Based Hybrid* (*CBH*) untuk sistem berskala besar dengan objektif untuk menurunkan kos komunikasi, menaikkan tahap ketersediaan data, dan mengekalkan konsistensi replika. CBH menggunakan strategi replikasi hibrid dengan menggabungkan kelebihan dua protokol kawalan replikasi untuk meningkatkan lagi

prestasi protokol yang telah sedia ada. Satu algoritma pengklusteran telah dicadangkan untuk mengumpulkan nod dalam beberapa kluster dan kemudian, kluster-kluster tersebut disusun dalam struktur pokok (tree). Satu lagi algoritma iaitu algoritma penempatan replika telah dicadangkan bagi menempatkan hanya satu replika dalam satu kluster.

Kami membuat penilaian terhadap protokol kawalan replika yang dicadangkan secara teori dan menggunakan simulasi. Kami menggunakan satu simulator berdasarkan event diskret bernama GridSim dan bahasa pengaturcaraan Java untuk proses simulasi protokol. Matrik prestasi yang dinilai adalah ketersediaan data dan kos komunikasi serta dibuat perbandingan dengan dua protokol kawalan replika berdasarkan korum yang terkini seperti Dynamic Hybrid (DH) dan Duplication on Grid (DDG). Dengan mengumpulkan nod dalam beberapa kluster dan dengan hanya ada satu replika dalam setiap kluster telah meningkatkan prestasi kos komunikasi dan ketersediaan data. Kajian ini telah menyumbangkan satu protokol kawalan replika hibrid berdasarkan kluster yang dinamik dengan mencadangkan satu algoritma pengklusteran bagi menentukan bilangan kluster, menyediakan satu mekanisma penyertaan nod secara dinamik di dalam rangkaian, dan satu algoritma penempatan replika yang dapat menghasilkan kos komunikasi yang rendah dan tahap ketersediaan data yang tinggi berbanding dengan protokol DH dan DDG. CBH telah membuktikan bahawa konsistensi replika adalah dikekalkan dengan memenuhi syarat dalam “Quorum Intersection Properties”.

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Name of Member of
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Supervisory Committee: Associate Professor Dr Azizol Abdullah

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| | |
|---|---|
| CAD | Computer-Aided Design |
| ROWA | Read-One Write-All |
| VT | Voting Protocol |
| GS | Grid Structure |
| TQ | Tree Quorum |
| LP | Logarithmic Protocol |
| TDGS | Three Dimension Grid Structure |
| DR2M | Diagonal Replication on 2D Mesh |
| DH | Dynamic Hybrid |
| DDG | Duplication on Grid |
| CBH | Cluster-Based Hybrid |

# CHAPTER 1

# INTRODUCTION

This chapter introduces the concepts of distributed computing, Grid computing, and Data Grid. In this chapter, the background of the research that is carried out is presented. The need for replicating the data as well as the problems of data replication in large-scale systems such as Data Grid is also discussed.

## 1.1 Background

Distributed computing is a computing model that has evolved for the last few decades. A distributed system consists of independent computers which are physically distributed within some geographical area and communicate with each other through the computer network (Tanenbaum and Van Steen, 2002). These computers have limited processing power and memory and are grouped together to take part in solving a complex problem. With the advances in technology, Grid computing has overcome the limitation in distributed computing and has emerged as a way to share and access the computing resources across a larger-scale network. Grid computing involves heterogeneous computational resources, shares large-scale resources, and supports high performance computing (Foster et al., 2001). It is designed for the users to be able to access data and computer resources which are geographically distributed and from various domains (Foster, 2002; Buyya and Venugopal, 2005;). In Grid computing, individual users can easily access data and computational resources without knowing where the resources are physically located or which resources are being used. This technology has made data and computational resources located in different geographical areas to be easily shared and accessed.

As a consequence of the powerful computing resources, scientists are able to conduct simulations and experiments in variety of data intensive scientific applications such as high-energy physics, astronomy and computational genomics. The size of data that is required by these applications can reach terabytes and even petabytes. The challenges are how to manage and store such huge data. Therefore, Data Grid was developed to provide a scalable infrastructure for managing and storing the large amount of data files (Chervenak et al., 2000; Hoschek et al., 2000). However, storing large volume of data in the same locations is difficult since an application may need to access data from any other remote application located in different geographical locations. Thus, the great challenge in Data Grid is to manage such huge and geographically distributed data. To address the challenge, data replication is widely used as a technique to manage the large volume of data effectively in Data Grid (Abawajy and Mat Deris, 2014; Tos et al., 2015).

Data replication is a process of creating and storing exact copies of data at many distributed sites. By creating many replicas, the time for fetching the data files stored at selected locations can be reduced (Venugopal et al., 2006). If a copy of the data at one location is lost or corrupted, that data can be easily recovered. Therefore, data replication can increase availability, fault tolerance, and increase the performance of the system (Lamehamedi et al., 2002; Dayyani and Khayyambashi, 2013). However, replicating data at many distributed sites has created some issues. A major challenge with replication is data consistency which occurs when many copies are created at many distributed sites. Whenever a copy of data is updated, this updated copy will be different from the other replicated copies and thus, it causes the data to be inconsistent (Thomas, 1979; Belalem and Slimani, 2006). In another words, replicas must be kept consistent and up to date to ensure that users can access the most recent data. Mainly, there are two types of approaches for consistency in data replication. The first approach is synchronous replication where the replicas are written or updated simultaneously. Thus, the replica should always remain synchronized. On the other hand, an asynchronous approach allows a certain delay in updating the replicas where replicas are updated in a periodic basis. However, to maintain consistency of data, a complex and expensive synchronization mechanisms are needed (Bernstein and Goodman, 1984; Mat Deris et al., 2003; Abawajy and Mat Deris, 2014).

Other issues are communication cost and data availability. Communication cost is measured based on the number of replicas involved for performing the read or write operations (Agrawal and El Abbadi, 1996; Latip et al., 2009; Abawajy and Mat Deris, 2014). The communication cost of a system increases as the system size grows, due to the increasing number of replicas. On the other hand, data availability refers to the ability of the replica control protocol to tolerate node failures (Mat Deris et al., 2008; Choi and Youn, 2012). For executing a read or write operation, it is based on the probability of the operation to terminate successfully.

## 1.2 Problem Statement

At present, the number of distributed nodes has become very large in the Grid computing system. The growing number of nodes has raised few problems in Data Grid. Firstly is the problem of dynamicity of nodes. Grid systems are dynamic in their nature where participants or nodes can join or leave the system at any time (Bashir et al., 2011; Tos et al., 2015). In Data Grid, since there are so many resources, thus, the probability of the resources to fail is high. At any given time, the number of active nodes may change and affect the performance of the system. Therefore, a replica control protocol must consider the dynamic aspects of the Data Grid and deals with node failures and allow resources to join or leave the Data Grid as they want (Tos et al., 2015). Existing replica control protocols for Data Grid system such as Diagonal Replication 2D Mesh (DR2M) (Latip, 2009) and Duplication on Grid (DDG) (Abawajy and Mat Deris, 2014) have considered the dynamicity of nodes in the proposed protocols. However, the algorithm for handling dynamicity of nodes has not been described in details.

Secondly, the main problem for data replication is replica placement. In large-scale system, replica placement has become the main issue and has not been well investigated (Mansouri and Javidi, 2017; Nazir et al., 2018). Many quorum-based replica control protocols have been proposed in distributed and Grid environments which are discussed in Chapter 2 of this thesis such as Read-One Write-All (ROWA) (Bernstein and Goodman, 1984), Primary Copy (Zhou and Holmes, 1999), Tree Quorum (TQ)

(Agrawal and El Abbadi, 1990), Grid Structure (GS) (Cheung et al., 1992), Logarithmic Protocol (LP) (Koch, 1993), Three Dimension Grid Structure (TDGS) (Mat Deris et al., 2004a), Enhanced Diagonal Replication 2D Mesh (EDR2M) (Latip, 2009), and Dynamic Hybrid (DH) (Choi and Youn, 2012). These replica control protocols have not focused on the replica placement issue since the research only focus on small-scale systems (Abawajy and Mat Deris, 2014). Experiments in these protocols tested with the number of nodes ranges from a small number of nodes to a few hundred of nodes. However, in large-scale systems with a few thousand of nodes or greater, these protocols will require the consensus of bigger number of replicas to construct read and write quorums and will degrade the performance of the system (Abawajy and Mat Deris, 2014). Abawajy and Mat Deris (2014) has proposed a replica control protocol named Duplication on Grid (DDG) protocol for Data Grid. In DDG, a replica placement algorithm has been implemented, however, as the network size grows larger, the number of replicas increases rapidly and thus, increases the communication cost. This has degraded the performance of the protocol. Therefore, an efficient replica placement algorithm is needed to minimize the number of replicas for executing read or write operations in a large-scale system.

Thirdly, replica consistency is another problem that needs to be investigated in a large scale system (Abawajy and Mat Deris, 2014; Mansouri and Javidi, 2017). In data replication, by copying data at many distributed sites has affected the consistency of data. In order to maintain the consistency of data, if the content of one file is changed, then all other replicas must also have the same updated content. Replica consistency has to be ensured in the cases of concurrent updates to several replicas of the same file (Abawajy and Mat Deris, 2014). The replica consistency problem has not been well investigated in most existing replica control protocols since files are regarded as read-only files (Tos et al., 2015; Mansouri and Javidi, 2017). In distributed system, replica consistency is a traditional problem but in a large-scale system such as Data Grid, it creates new challenges because the replicas are distributed over various countries (Belalem and Slimani, 2006; Mansouri and Javidi, 2017). Thus, an efficient mechanism is needed to maintain the consistency of replica in a large-scale system.

Therefore, this thesis has proposed a dynamic replica control protocol that provides small number of replicas in executing the read or write operations as well as maintains replica consistency in large-scale system such as Data Grid.

## 1.3 Objectives

The main objective of this thesis is to develop a cluster-based replica control protocol in Data Grid that fulfils the following purposes:

- To propose a cluster-based algorithm to determine the number of clusters and provide a mechanism for dynamic participation of nodes in the network.

- To propose a replica placement algorithm to determine where to place the replicas and produce low communication cost and high availability.

- To propose a replica consistency policy to achieve replica consistency in the proposed protocol.

## 1.4 Scope

This research focuses on data replication for replica control protocols that use quorum-based schemes to manage replicated data. In this research, the proposed replica control protocol named *Cluster-Based Hybrid* (*CBH*) is simulated using Java language and a discrete event simulator called GridSim (Sulisto et al., 2005; Buyya and Murshed, 2002) which is run on Eclipse IDE. The performance metrics for the simulation of the CBH protocol is narrowed down to communication cost and data availability. The replica consistency for the proposed protocol is proven analytically.

## 1.5 Contributions of Research

The main contributions of this research are as follows:

- A clustering algorithm is proposed to determine the number of clusters in the network. The nodes are grouped based on the geographical proximity of one node to other nodes. Our proposed restructuring algorithm considers the dynamic aspects of the Data Grid and provides mechanism for dynamic participation of nodes in the network. If there are more nodes need to join or leave the network, it will restructure the clusters. These operations are necessary to build the network, expand it, and reorganize it to maintain a high level of performance.

- A replica placement algorithm is proposed to determine where to place the replicas and how many replicas to be created. Our proposed replica placement algorithm selects only a node which has the minimum total number of hops to the other nodes in the same cluster to replicate the primary copy of the data object. Thus, if the required file is nearer and within the same cluster, the job will be executed and completed faster. Moreover, by having only one replica in each cluster has enabled the protocol to minimize the number of replicas for performing read or write operations. Comparisons of communication cost and data availability both theoretically and empirically of our proposed *Cluster-Based Hybrid* (*CBH*) replica control protocol with the other two latest quorum-based protocols named Dynamic Hybrid (DH) (Choi and Youn, 2012) and Duplication on Grid (DDG) (Abawajy and Mat Deris, 2014) protocol are performed. The simulation results show that CBH protocol provides lower overall read and write communication cost as well as high read availability as compared to DH and DDG protocols.

- A replica consistency policy is proposed for ensuring data consistency. CBH protocol has proven that the data accessed are consistent by satisfying the Quorum Intersection Property rules. Thus, CBH has achieved data consistency in the cases of reading and writing to the same data object at the same time.

## 1.6 Organization of Thesis

This thesis comprises of seven chapters which begins with Chapter 1 by introducing the concepts of distributed computing, Grid computing, and Data Grid. In this chapter, the research problems, objectives, and contributions are presented.

### Chapter 2: Literature Review

Chapter 2 of this thesis presents the background information on distributed systems, Grid computing, and Data Grid. This chapter also reviews on the quorum-based replica control protocols that have been proposed in distributed database and Grid environment. The formulation of the performance metrics which are communication cost and data availability for the read and write operations among the existing replica control protocols is also described.

### Chapter 3: Research Methodology

Chapter 3 discusses the methodology used for the simulation of the proposed CBH protocol which is Discrete Event Simulation (DES). Every phase in the DES methodology is explained in details in this chapter. The simulation model and mechanism used to simulate the proposed protocol is presented.

### Chapter 4: CBH Replica Control Protocol: Cluster Management

This chapter introduces the proposed *Cluster-Based Hybrid* (*CBH*) protocol. In this chapter, the framework, the system model, and flowchart of the protocol are presented. Next, the first component of the CBH framework which is Cluster Management is discussed. In Cluster Management, two proposed algorithms namely clustering algorithm and restructuring algorithm are explained in details in this chapter. The simulation results from the algorithms are also presented and analyzed.

### Chapter 5: CBH Replica Control Protocol: Replica Management

This chapter describes the Replica Management which is the second component in the CBH framework. This component handles the placement and replication of the primary file and creates indexes of the physical locations for the data files and its replicas in the system. It consists of two parts which are Replica Catalogue and Replica Placement. The comparisons of results in terms of communication cost and data availability between the proposed CBH protocol and other two protocols, namely: DH and DDG are presented.

### Chapter 6: CBH Replica Control Protocol: Consistency Management

This chapter discusses the third component of the CBH framework which is Consistency Management. This component is responsible to ensure that data are consistent in the cases of updates or changes to the same data file at the same time. The replica consistency policy for CBH protocol has satisfied the quorum intersection property and has been proven analytically.

**Chapter 7: Conclusion and Future Works**

Chapter 7 concludes the thesis with a conclusion and discussion on the contributions of this research. Recommendations of future research works are also presented.

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