REPLICA CREATION ALGORITHM FOR DATA GRIDS

MOHAMMED KAMEL MADI

DOCTOR OF PHILOSOPHY
UNIVERSITI UTARA MALAYSIA
2012

< INSERT PERAKUAN KERJA TESIS / DISERTASI

(CERTIFICATION OF THESIS / DISSERTATION)>

Permission to Use

In presenting this thesis in fulfilment of the requirements for a postgraduate degree from Universiti Utara Malaysia, I agree that the Universiti Library may make it freely available for inspection. I further agree that permission for the copying of this thesis in any manner, in whole or in part, for scholarly purpose may be granted by my supervisor(s) or, in their absence, by the Dean of Awang Had Salleh Graduate School of Arts and Sciences. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to Universiti Utara Malaysia for any scholarly use which may be made of any material from my thesis.

Requests for permission to copy or to make other use of materials in this thesis, in whole or in part, should be addressed to :

Dean of Awang Had Salleh Graduate School of Arts and Sciences
UUMCollege of Arts and Sciences
Universiti Utara Malaysia
06010 UUM Sintok

Abstrak

Sistem grid data merupakan prasarana pengurusan data yang memudahkan pencapaian dan perkongsian data yang banyak, sumber storan, dan perkhidmatan pemindahan data yang boleh merentasi lokasi teragih. Tesis ini mengemukakan satu algoritma baru yang dapat mempertingkatkan prestasi capaian data pada grid data dengan mengagihkan salinan data yang berkenaan. *Data Replica Creation Algorithm (DRCM)* meningkatkan prestasi sistem grid data dengan mengurangkan masa pelaksanaan kerja dan memanfaatkan cara terbaik penggunaan sumber grid data (ruang storan dan jalur lebar rangkaian). Algoritma semasa tertumpu kepada bilangan capaian untuk menentukan fail mana yang patut disalin dan lokasi di mana ia patut diletakkan, yang mengabaikan kebolehan sumber. *DRCM* sebaliknya mengambil kira perspektif pengguna dan sumber; meletakkan salinan tersebut di tempat strategik yang memberikan kos pemindahan yang paling rendah. Algoritma ini menggunakan tiga strategi: *Replica Creation and Deletion Strategy (RCDS), Replica Placement Strategy (RPS),* dan *Replica Replacement Strategy (RRS). DRCM* dinilai menggunakan simulasi rangkaian (OptorSim) berdasarkan metrik prestasi terpilih (purata masa pelaksanaan kerja, penggunaan rangkaian yang cekap, purata penggunaan storan, dan penggunaan elemen pengkomputeran), senario, dan topologi. Hasil kajian mendapati masa pelaksanaan DRCM adalah lebih baik dengan penggunaan sumber yang lebih rendah berbanding pendekatan yang sedia ada. Penyelidikan ini telah menggabungkan beberapa strategi penyalinan dalam satu algoritma yang meningkatkan prestasi grid data, berkeupayaan membuat keputusan serentak ke atas penciptaan atau penghapusan sekurang-kurangnya satu fail dalam pembuatan keputusan yang sama. Di samping itu, kriteria tahap-kebergantungan-antara-fail telah diguna dan diintegrasikan dengan model pertumbuhan/penyusutan eksponen untuk memberi suatu penilaian fail yang tepat.

Kata Kunci: Penyalinan data, Grid data, Pembuatan salinan, Penilaian fail, Penempatan salinan.

Abstract

Data grid system is a data management infrastructure that facilitates reliable access and sharing of large amount of data, storage resources, and data transfer services that can be scaled across distributed locations. This thesis presents a new replication algorithm that improves data access performance in data grids by distributing relevant data copies around the grid. The new Data Replica Creation Algorithm (DRCM) improves performance of data grid systems by reducing job execution time and making the best use of data grid resources (network bandwidth and storage space). Current algorithms focus on number of accesses in deciding which file to replicate and where to place them, which ignores resources' capabilities. DRCM differs by considering both user and resource perspectives; strategically placing replicas at locations that provide the lowest transfer cost. The proposed algorithm uses three strategies: Replica Creation and Deletion Strategy (RCDS), Replica Placement Strategy (RPS), and Replica Replacement Strategy (RRS). DRCM was evaluated using network simulation (OptorSim) based on selected performance metrics (mean job execution time, efficient network usage, average storage usage, and computing element usage), scenarios, and topologies. Results revealed better job execution time with lower resource consumption than existing approaches. This research contributes replication strategies embodied in one algorithm that enhances data grid performance, capable of making a decision on creating or deleting more than one file during same decision. Furthermore, dependency-level-between-files criterion was utilized and integrated with the exponential growth/decay model to give an accurate file evaluation.

Keywords: Data replication, Data grid, Replica creation, File evaluation, Replica placement.

Acknowledgement

First, I would like to express my utmost gratitude to Almighty Allah for his creation and making me submissive to Him.

I would like to gratefully acknowledge the enthusiastic supervision of my thesis supervisor, Associate Professor Dr. Suhaidi Hassan and my Co-supervisor Dr. Yuhanis Yusof. I could not have imagined having a better adviser and mentor for my Ph.D., and without their inspiration, stimulating suggestions, sound advice, guidance, and active participation in the process of work, I would never have finished

Parts of this work would not have been possible without the active contribution of my colleagues InterNetWorks Research Group. I thank them for the long discussions we had, the papers they helped write, and their valuable feedback; among them are Dr Massudi Mahmuddin, Dr Omar Almomani, Dr Mohamad Kadhum, Dr. Ahmad Suki, Hasbullah, Khuzairi Mohd Zaini, Yaser Miaji, Mahmoud Alshogran, Shahrudin, and many others.

Throughout this work I have met with many great people; among them are Associate Professor Dr. Hassan Bouzahir and Associate Professor Mustafa Kalmun, my deep gratitude to them for their valuable suggestions and comments. Their proactive support, advice, and ideas have been critically essential to this research.

I am also grateful to School of Computing, UUM College of Arts and Sciences, for providing research facilities and related resources that facilitates my study. It was an enjoyable place to work and study.

Finally, I am immeasurably grateful to my family for their kindness and support. They have always been there and encourage me; without their selfless love, I know I could not have successfully completed my doctoral studies.

Table of Contents

List of Tables

List of Figures

List of Appendices

List of Abbreviations

AC	Access Cost
ASU	Average Storage Usage
CMS	Compact Muon Solenoid
CE	Computing Element
CE Usage	Computing Element Usage
CDN	Content Delivery Network
DDB	Distributed Database
DMS	Dynamic Maintenance Service
DORS	Dynamic Optimal Replication Strategy
DRCP	Dynamic Replica Creation And Placement
ENU	Efficient Network Usage
EU DataGrid	European data grid
FSR	Fair Share Replication
FL	File Lifetime
FTT	File Transfer Time
FV	File Value
FW	File Weight
GridFTP	Grid File Transfer Protocol
BHR	Hierarchy Based Replication
ISP	Information Service Provider
LALW	Last Access Largest Weight
LFF	Least Frequent Files

The contents of the thesis is for internal user only

REFERENCES

[1] J. P. M. G.A.Gravvanis, H.R. Arabina, D.A. Power, "Grid Technology and Applications: Recent Developments," New York: Nova Science Publishers, Inc., 2009.

[2] I. Foster and C. Kesselman, "The Grid: Blueprint for a New Computing Infrastructure," *San Francisco: Morgan Kaufmann Publishers*, vol. 24, p. 8, 1999.

[3] S. Venugopal, R. Buyya, and L. Winton, "A Grid service broker for scheduling e Science applications on global data Grids," *Concurrency and Computation: Practice and Experience*, vol. 18, pp. 685-699, 2006.

[4] I. Foster, C. Kesselman, and S. Tuecke, "The anatomy of the Grid: Enabling scalable virtual organizations," *International Journal of Supercomputing Applications*, vol. 15, pp. 200-222, 2001.

[5] G. Wasson and M. Humphrey, "Policy and enforcement in virtual organizations," in *Proceedings of the 4th International Workshop on Grid Computing*, 2003, p. 125.

[6] I. Foster, "The grid enabling resource sharing within virtual organizations," in *WWW 2000 Conference*, 2002.

[7] Frederic Magoulès, *Fundamentals of grid computing: theory, algorithms and technologies*. USA: Chapman & Hall/CRC Numerical Analysis & Scientific Computing, 2010.

[8] A. Chervenak, E. Deelman, C. Kesselman, B. Allcock, I. Foster, V. Nefedova, J. Lee, A. Sim, A. Shoshani, and B. Drach, "High-performance remote access to climate simulation data: A challenge problem for data grid technologies," in *Super Computing*, 2003, pp. 1335-1356.

[9] I. Foster, E. Alpert, A. Chervenak, B. Drach, C. Kesselman, V. Nefedova, D. Middleton, A. Shoshani, A. Sim, and D. Williams, "The Earth System Grid II: Turning climate datasets into community resources," in *Annual Meeting of the American Meteorological Society*, 2002.

[10] B. Wilkinson, *Grid computing: techniques and applications*: Chapman & Hall/CRC, 2009.

[11] C. Nicholson, D. G. Cameron, A. T. Doyle, A. P. Millar, and K. Stockinger, "Dynamic data replication in lcg 2008," *Concurrency and Computation: Practice and Experience*, vol. 20, pp. 1259-1271, 2008.

[12] A. Chervenak, E. Deelman, I. Foster, W. Hoschek, A. Iamnitchi, C. Kesselman, M. Ripeanu, B. Schwartzkopf, H. Stockinger, and B. Tierney, "Giggle: A framework for constructing scalable replica location services," in *International IEEE Supercomputing Conference (SC 2002)* Baltimore, USA, 2002, pp. 1-17.

[13] A. Chervenak, I. Foster, C. Kesselman, C. Salisbury, and S. Tuecke., "The Data Grid: Towards an Architecture for the Distributed Management and Analysis of Large Scientific Datasets," *Journal of Network and Computer Applications*, vol. 23, 2001.

[14] L. Guy, P. Kunszt, E. Laure, H. Stockinger, and K. Stockinger, "Replica management in data grids," in *Global Grid Forum*. vol. 5, 2002.

[15] H. Lamehamedi, Z. Shentu, B. Szymanski, and E. Deelman, "Simulation of dynamic data replication strategies in data grids," in *Proceedings of 12th Heterogeneous Computing Workshop (HCW2003)*, Nice, France, , 2003.

[16] H. Lamehamedi, B. Szymanski, Z. Shentu, and E. Deelman, "Data Replication Strategies in Grid Environments," in *Fifth International Conference on Algorithms and Architectures for Parallel Processing*, 2002, p. p.378.

[17] E. Otoo, F. Olken, and A. Shoshani, "Disk cache replacement algorithm for storage resource managers in data grids," in *2002 ACM/IEEE conference on Supercomputing*, Baltimore, Maryland 2002, pp. 1-15.

[18] K. Ranganathan and I. Foster, "Identifying Dynamic Replication Strategies for a High-Performance Data Grid," *International Grid Computing Workshop*, pp. 75-86, 2001.

[19] X. You, G. Chang, X. Chen, C. Tian, and C. Zhu, "Utility-Based Replication Strategies in Data Grids," in *Fifth International Conference on Grid and Cooperative Computing*, 2006, pp. 500-507.

[20] M. Tang, B. S. Lee, X. Tang, and C. K. Yeo, "The impact of data replication on job scheduling performance in the Data Grid," *Future Generation Computer Systems*, vol. 22, pp. 254-268, 2006.

[21] Srikummar Venugopal, "Scheduling Distributed Data-Intensive Applications on Global Grids," PhD thesis, University of Melbourne, Australia, 2006.

[22] K. Ranganathan and I. Foster, "Design and Evaluation of Dynamic Replication Strategies for a High Performance Data Grid," in *International Conference on Computing in High Energy and Nuclear Physics*, Beijing, 2001.

[23] R. S. Chang and P. H. Chen, "Complete and fragmented replica selection and retrieval in Data Grids," *Future Generation Computer Systems,* vol. 23, pp. 536-546, 2007.

[24] M. Tang, B. S. Lee, C. K. Yeo, and X. Tang, "Dynamic replication algorithms for the multi-tier Data Grid," *Future Generation Computer Systems,* vol. 21, pp. 775-790, 2005.

[25] R. M. Rahman, K. Barker, and R. Alhajj, "Replica placement strategies in data grid," *Journal of Grid Computing,* vol. 6, pp. 103-123, 2008.

[26] R. M. Rahman, R. Alhajj, and K. Barker, "Replica selection strategies in data grid," *Journal of Parallel and Distributed Computing,* vol. 68, pp. 1561-1574, 2008.

[27] R. M. Rahman, K. Barker, and R. Alhajj, "A Predictive Technique for Replica Selection in Grid Environment," in *Seventh IEEE International Symposium on Cluster Computing and the Grid CCGRID 2007*, 2007, pp. 163-170.

[28] R. M. Ken, K. Barker, and R. Alhajj, "Study of different replica placement and maintenance strategies in data grid," 2007, pp. 171-178.

[29] R. M. Rahman, K. Barker, and R. Alhajj, "Performance evaluation of different replica placement algorithms," *International Journal of Grid and Utility Computing,* vol. 1, pp. 121-133, 2009.

[30] Abdelsalam A. Helal, Abdelsalam A. Heddaya, and Bharat B. Bhargava, *Replication techniques in distributed systems*: Kluwer Academic Publishers, 1996.

[31] Caitriana M. Nicholson, "File management for HEP data grids," PhD thesis, University of Glasgow, 2006.

[32] M. Xie, Y. S. Dai, and K. L. Poh, *Computing systems reliability: models and analysis*: Springer Us, 2004.

[33] H. Lamehamedi and B. K. Szymanski, "Decentralized data management framework for data grids," *Future Generation Computer Systems,* vol. 23, pp. 109-115, 2007.

[34] C. T. Yang, C. J. Huang, and T. C. Hsiao, "A Data Grid File Replication Maintenance Strategy Using Bayesian Networks," in *Intelligent Systems Design and Applications, 2008. ISDA'08*, 2008.

[35] H. H. E. Al Mistarihi and C. H. Yong, "Replica management in data grid," *International Journal of Computer Science and Network Security IJCSNS,* vol. 8, p. 22, 2008.

[36] M. Tang, B. Lee, X. Tang, and C. Yeo, "Combining data replication algorithms and job scheduling heuristics in the data grid," *Lecture notes in computer science*, vol. 3648, p. 381, 2005.

[37] C. Ruay-Shiung, C. Hui-Ping, and W. Yun-Ting, "A dynamic weighted data replication strategy in data grids," in *AICCSA 2008: Proceedings of IEEE/ACS International Conference on computer systems and applications*, 2008, pp. 414-421.

[38] H. P. Chang, "A Dynamic Data Replication Strategy Using Access-Weights in Data Grids," 2006.

[39] C. Wang, C. Yang, and M. Chiang, "A Fair Replica Placement for Parallel Download on Cluster Grid," *Lecture Notes in Computer Science*, vol. 4658, p. 268, 2007.

[40] C. T. Yang, C. P. Fu, and C. J. Huang, "A dynamic file replication strategy in data grids," in *TENCON 2007-2007 IEEE Region 10 Conference*, 2007, pp. 1-5.

[41] Q. Rasool, L. Jianzhong, G. S. Oreku, Z. Shuo, and Y. Donghua, "A load balancing replica placement strategy in Data Grid," in *Proceedings of Third International Conference on Digital Information Management, ICDIM*, London, UK, 2008, pp. 751-756.

[42] M. Shorfuzzaman, P. Graham, and R. Eskicioglu, "Popularity-Driven Dynamic Replica Placement in Hierarchical Data Grids," in *Parallel and Distributed Computing, Applications and Technologies, 2008. PDCAT 2008*, 2008, pp. 524-531.

[43] K. Ranganathan, A. Iamnitchi, and I. Foster, "Improving data availability through dynamic model-driven replication in large peer-to-peer communities," in *Global and Peer-to-Peer Computing on Large Scale Distributed Systems Workshop*, 2002, pp. 376–381.

[44] L. Yi-Fang, L. Pangfeng, and W. Jan-Jan, "Optimal placement of replicas in data grid environments with locality assurance," in *Parallel and Distributed Systems, 2006. ICPADS 2006. 12th International Conference on*, 2006, p. 8.

[45] L. Pangfeng and W. Jan-Jan, "Optimal replica placement strategy for hierarchical data grid systems," in *Cluster Computing and the Grid, 2006. CCGRID 06. Sixth IEEE International Symposium on*, 2006, p. 4 pp.

[46] Y. Mansouri, M. Garmehi, M. Sargolzaei, and M. Shadi, "Optimal Number of Replicas in Data Grid Environment," in *First International Conference on Distributed Framework and Applications, 2008. DFmA 2008.* , 2008, pp. 96-101.

[47] David G. Cameron, "Replica management and optimisation for data grids," PhD. Thesis, University of Glasgow, 2005.

[48] W. B. David, "Evaluation of an economy-based file replication strategy for a data grid," in *International Workshop on Agent based Cluster and Grid Computing*, 2003, pp. 120–126.

[49] W. Hoschek, J. Jaen-Martinez, A. Samar, H. Stockinger, and K. Stockinger, "Data management in an international data grid project," *Lecture Notes in Computer Science*, pp. 77-90, 2000.

[50] J. H. Abawajy, "Placement of file replicas in data grid environments," *Lecture Notes in Computer Science*, pp. 66-73, 2004.

[51] B. Allcock, J. Bester, J. Bresnahan, A. L. Chervenak, I. Foster, C. Kesselman, S. Meder, V. Nefedova, D. Quesnel, and S. Tuecke, "Data management and transfer in high-performance computational grid environments," *Parallel Computing*, vol. 28, pp. 749-771, 2002.

[52] B. Allcock, J. Bester, J. Bresnahan, A. L. Chervenak, C. Kesselman, S. Meder, V. Nefedova, D. Quesnel, S. Tuecke, and I. Foster, "Secure, efficient data transport and replica management for high-performance data-intensive computing," in *IEEE Mass Storage Systems and Technologies*, 2001.

[53] I. Foster, "The Grid: A New Infrastructure for 21st Century Science," *PHYSICS TODAY*, vol. 55, pp. 42-47, 2002.

[54] W. E. Johnston, "Computational and data Grids in large-scale science and engineering," *Future Generation Computer Systems*, vol. 18, pp. 1085-1100, 2002.

[55] P. Avery, "Data Grids: a new computational infrastructure for data-intensive science," *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences*, vol. 360, p. 1191, 2002.

[56] I. Foster, C. Kesselman, J. M. Nick, and S. Tuecke, "Grid services for distributed system integration," *Computer*, vol. 35, pp. 37-46, 2002.

[57] S. Shen, *Grid computing: International Symposium on Grid Computing*: Springer-Verlag New York Inc, 2008.

[58] F. Magoulès, J. Pan, K. A. Tan, and A. Kumar, *Introduction to grid computing* vol. 6: CRC, 2009.

[59] F. Gagliardi, B. Jones, F. Grey, M. E. Bégin, and M. Heikkurinen, "Building an infrastructure for scientific Grid computing: status and goals of the EGEE project," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences,* vol. 363, p. 1729, 2005.

[60] T. Hey and A. E. Trefethen, "Cyberinfrastructure for e-Science," *Science,* vol. 308, p. 817, 2005.

[61] The LHCb Collaboration. LHCb Computing Model. Technical Report CERN-LHCC-2004-036/G-084, CERN, January 2005.

[62] F. Berman, G. Fox, and T. Hey., *The Grid: Past, Present, Future, Grid Computing: Making the Global Infrastructure a Reality*. London, UK: Wiley Press, 2003.

[63] G. Fox, S. H. Ko, M. Pierce, O. Balsoy, J. Kim, S. Lee, K. Kim, S. Oh, X. Rao, and M. Varank, "Grid services for earthquake science," *Concurrency and Computation: Practice and Experience,* vol. 14, pp. 371-393, 2002.

[64] I. Foster, "Internet computing and the emerging grid," *Nature Web Matters,* vol. 7, 2000.

[65] N. Kelly, P. V. Jithesh, D. R. Simpson, P. Donachy, T. J. Harmer, R. Perrott, J. Johnston, P. Kerr, M. McCurley, and S. McKee, "Bioinformatics data and the grid: The GeneGrid data manager," in *UK e-Science All Hands Meeting 2004 (AHM04)*, 2004.

[66] F. Magoulès and L. Yu, *Grid resource management: towards virtual and services compliant grid computing*: CRC Press, 2009.

[67] J. Yu and R. Buyya, "A taxonomy of scientific workflow systems for grid computing," *ACM Sigmod Record,* vol. 34, pp. 44-49, 2005.

[68] High Energy Physics Experiment Website, "http://www.hep.net."

[69] European Organization for Nuclear Research (CERN), "http://public.web.cern.ch/Public/Welcome.html."

[70] The ALICE Collaboration. ALICE Computing Model. Technical Report CERN-LHCC-2004-038/G-086, CERN, January 2005.

[71] The ATLAS Collaboration. The ATLAS Computing Model. Technical Report CERN-LHCC-2004-037/G-085, CERN, January 2005.

[72] The CMS Collaboration. The CMS Computing Model. Technical Report CERN-LHCC-2004-035/G-083, CERN, January 2005.

[73] K. Holtman, "CMS data grid system overview and requirements," *CMS Note*, vol. 37, July 2001.

[74] CMS Data Challenge 2004, " http://www.uscms.org/s&c/dc04/."

[75] The MONARC Project. Models of Networked Analysis at Regional Centres for LHC Experiments (MONARC) Phase 2 Report. Technical Report CERN/LCB 2000-001, CERN, March 2000.

[76] D. Bernholdt, S. Bharathi, D. Brown, K. Chanchio, M. Chen, A. Chervenak, L. Cinquini, B. Drach, I. Foster, and P. Fox, "The earth system grid: Supporting the next generation of climate modeling research," *Proceedings of the IEEE*, vol. 93, pp. 485-495, 2005.

[77] Sloan Digital Sky Survey website. Available online at: http://www.sdss.org/

[78] R. Dooley, K. Milfeld, C. Guiang, S. Pamidighantam, and G. Allen, "From proposal to production: Lessons learned developing the computational chemistry grid cyberinfrastructure," *Journal of Grid Computing*, vol. 4, pp. 195-208, 2006.

[79] U. Farooq, S. Majumdar, and E. W. Parsons, "Engineering grid applications and middleware for high performance," in *Proceedings of the 6th international workshop on Software and performance*, 2007, pp. 141-152.

[80] R. Moore, T. A. Prince, and M. Ellisman, "Data-intensive computing and digital libraries," *Communications of the ACM*, pp. 56–62, 1998.

[81] J. Singh, N. Kaur, and R. Singh, "The Uniqueness of Data Grid Over Other Data-Intensive Paradigms," *Enterprise information systems in twenty-first century*, p. 334, 2009.

[82] C. E. Palau, J. C. Guerri, M. Esteve, F. Carvajal, and B. Molina, "CCDN: campus content delivery network learning facility," in *IEEE International Conference on Advanced Learning Technologies (ICALT'03)* 2003.

[83] J. P. Mulerikkal, "An Architecture for Distributed Content Delivery Network," in *15th IEEE International Conference on Networks, ICON*, 2007, pp. 359-364.

[84] B. Krishnamurthy, C. Wills, and Y. Zhang, "On the use and performance of content distribution networks," in *Proceedings of the 1st ACM SIGCOMM Workshop on Internet Measurement (IMW '01),*, San Francisco, CA, USA. ACM Press, New York, NY, USA., 2001, pp. 169-182.

[85] Akamai, "http://www.akamai.com."

[86] S. Ceri and G. Pelagatti, *Distributed databases principles and systems*. McGraw-Hill, New York, USA, 1984.

[87] Ozsu and P. Valduriez, "Principles of distributed database systems," *Alan Apt, New Jersey*, 1999.

[88] S. Venugopal, R. Buyya, and K. Ramamohanarao, "A taxonomy of data grids for distributed data sharing, management, and processing," *ACM Computing Surveys (CSUR)*, vol. 38, p. 3, 2006.

[89] S. Goel and R. Buyya, "Data Replication Strategies in Wide Area Distributed Systems," *Enterprise Service Computing: From Concept to Deployment*, pp. 211-241, 2006.

[90] S. Sivasubramanian, M. Szymaniak, G. Pierre, and M. Van Steen, "Replication for web hosting systems," *ACM Computing Surveys (CSUR)*, vol. 36, pp. 291-334, 2004.

[91] M. R. Rahman, "Replica placement and selection strategies in data grids," in *Department of Computer Science*. vol. PhD. thesis Alberta: University of Calgary, 2007.

[92] Stockinger and H, "Distributed database management systems and the data grid," in *Proceedings of Eighteenth IEEE Symposium on Mass Storage Systems and Technologies, MSS'01*, San Diego, CA, 2001.

[93] M. Di Stefano and J. Wiley, *Distributed data management for grid computing*: Wiley Online Library, 2005.

[94] M. Carman, F. Zini, L. Serafini, and K. Stockinger, "Towards an economy-based optimisation of file access and replication on a data grid," in *Proceedings of Second IEEE International Symposium on Cluster Computing and the Grid (CCGRID'02)*, 2002, p. 340.

[95] L. Dutka, R. Slota, D. Nikolow, and J. Kitowski, "Optimization of Data Access for Grid Environment," in *Grid Computing*, 2004, pp. 93-102.

[96] Mathew J. Wyatt, Nigel G.D. Sim, Dianna L. Hardy, and I. M. Atkinson, "YourSRB: A cross platform interface for SRB and Digital Libraries," in *Proceedings of the fifth Australasian symposium on ACSW frontiers-Volume 68*, 2007, pp. 79-85.

[97] S. Krishnamurthy, W. H. Sanders, and M. Cukier, "Performance evaluation of a probabilistic replica selection algorithm," in *Proceedings of the Seventh*

International Workshop on Object-Oriented Real-Time Dependable Systems, (WORDS 2002). , 2002, pp. 119-127.

[98] A. Rajasekar, M. Wan, R. Moore, W. Schroeder, G. Kremenek, A. Jagatheesan, C. Cowart, B. Zhu, S. Y. Chen, and R. Olschanowsky, "Storage resource broker-managing distributed data in a grid," *Computer Society of India Journal, special issue on SAN,* vol. 33, pp. 42-54, 2003.

[99] O. Othman, C. O'Ryan, and D. Schmidt, "The Design and Performance of an Adaptive CORBA Load Balancing Service," *IEEE Distributed Systems Online,* vol. 2, pp. 48-60, 2001.

[100] S. Vazhkudai, S. Tuecke, and I. Foster, "Replica selection in the globus data grid," in *Proceedings of International Workshop on Data Models and Databases on Clusters and the Grid (DataGrid 2001)*, 2001, pp. 106–113.

[101] The Globus Alliance, "http://www.globus.org/."

[102] S. B. Karl, K. Czajkowski, S. Fitzgerald, I. Foster, A. Johnson, C. Kesselman, J. Leigh, and S. Tuecke, "Application Experiences with the Globus Toolkit," in *Proceedings of Eighth IEEE Symposium on High Performance Distributed Computing*, 1998, pp. 81-89.

[103] A. Silberschatz, P. B. Galvin, and G. Gagne, *Operating System Principles*: Wiley India Pvt. Ltd., 2006.

[104] S. Y. Ko, R. Morales, and I. Gupta, "New worker-centric scheduling strategies for data-intensive grid applications," in *Proceedings of the 8th ACM/IFIP/USENIX international conference on Middleware*, 2007, pp. 121-142.

[105] L. Meyer, J. Annis, M. Wilde, M. Mattoso, and I. Foster, "Planning spatial workflows to optimize grid performance," in *Proceedings of the 2006 ACM symposium on Applied computing*, 2006, pp. 786-790.

[106] Q. Rasool, J. Li, and S. Zhang, "Replica Placement in Multi-tier Data Grid," in *Proceedings of 2009 Eighth IEEE International Conference on Dependable, Autonomic and Secure Computing*, 2009, pp. 103-108.

[107] D. G. Cameron, R. Carvajal-Schiaffino, A. P. Millar, C. Nicholson, K. Stockinger, and F. Zini, "Evaluating scheduling and replica optimisation strategies in OptorSim," *Journal of Grid Computing,* pp. 57-69, March 2004.

[108] W. H. Bell, D. G. Cameron, L. Capozza, P. Millar, K. Stockinger, and F. Zini, "Simulation of Dynamic Grid Replication Strategies in OptorSim," *Journal of High Performance Computing Applications,* vol. 17, 2003.

[109] F. Ben Charrada, H. Ounelli, and H. Chettaoui, "An Efficient Replication Strategy for Dynamic Data Grids," in *P2P, Parallel, Grid, Cloud and Internet Computing (3PGCIC), 2010 International Conference on*, pp. 50-54.

[110] F. Ben Charrada, H. Ounelli, and H. Chettaoui, "An Efficient Replication Strategy for Dynamic Data Grids," in *Proceedings of International Conference on P2P, Parallel, Grid, Cloud and Internet Computing (3PGCIC),*, 2010, pp. 50-54.

[111] Z. Wuqing, X. Xianbin, W. Zhuowei, Z. Yuping, and H. Shuibing, "A Dynamic Optimal Replication Strategy in Data Grid Environment," in *Proceedings of International Conference on Internet Technology and Applications, ,* 2010, pp. 1-4.

[112] H. Zhong, Z. Zhang, and X. Zhang, "A Dynamic Replica Management Strategy Based on Data Grid," in *Proceedings of 2010 Ninth International Conference on Grid and Cloud Computing*, 2010, pp. 18-23.

[113] K. Sashi and A. S. Thanamani, "A New Replica Creation and Placement Algorithm for Data Grid Environment," in *Proceedings of 2010 International Conference on Data Storage and Data Engineering*, 2010, pp. 265-269.

[114] M. Teng and L. Junzhou, "A prediction-based and cost-based replica replacement algorithm research and simulation," in *Proceedings of 19th International Conference on Advanced Information Networking and Applications, (AINA 2005). ,* 2005, pp. 935-940.

[115] T. Tian and J. Luo, "A Prediction-based Two-Stage Replica Replacement Algorithm," in *Proceedings of 11th International Conference on Computer Supported Cooperative Work in Design, (CSCWD 2007)*, 2007, pp. 594-598.

[116] T. Tian and J. Luo, "A VO-Based Two-Stage Replica Replacement Algorithm," *Network and Parallel Computing,* pp. 41-50, 2010.

[117] W. Zhao, X. Xu, N. Xiong, and Z. Wang, "A Weight-Based Dynamic Replica Replacement Strategy in Data Grids," in *Proceedings of Asia-Pacific Services Computing Conference, ,* 2009, pp. 1544-1549.

[118] S. M. Park, J. H. Kim, Y. B. Ko, and W. S. Yoon, "Dynamic data grid replication strategy based on Internet hierarchy," *International Workshop on Grid and Cooperative Computing,* vol. 1001, pp. 1324–1331, 2004.

[119] M. Garmehi and Y. Mansouri, "Optimal Placement Replication on Data Grid Envirments," in *Proceedings of Information Technology, (ICIT 2007). 10th International Conference on*, 2007, pp. 190-195.

[120] K. Kalpakis, K. Dasgupta, and O. Wolfson, "Optimal placement of replicas in trees with read, write, and storage costs," *IEEE Transactions on Parallel and Distributed Systems*, pp. 628-637, 2001.

[121] M. Bsoul, A. Al-Khasawneh, Y. Kilani, and I. Obeidat, "A threshold-based dynamic data replication strategy," *The Journal of Supercomputing*, pp. 1-10, 2010.

[122] R. M. Rahman, K. Barker, and R. Alhajj, "Replica placement in data grid: considering utility and risk," in *Proceedings of Information Technology: Coding and Computing, 2005. ITCC 2005. International Conference on*, 2005.

[123] M. L. Fisher, "The Lagrangian relaxation method for solving integer programming problems," *Management science*, pp. 1861-1871, 2004.

[124] Y. F. Lin, J. J. Wu, and P. Liu, "A List-Based Strategy for Optimal Replica Placement in Data Grid Systems," in *Proceedings of Parallel Processing, 2008. ICPP'08. 37th International Conference on*, 2008, pp. 198-205.

[125] S. Naseera and K. V. M. Murthy, "Agent Based Replica Placement in a Data Grid Environement," in *Proceedings of First International Conference on Computational Intelligence, Communication Systems and Networks. CICSYN'09.*, 2009, pp. 426-430.

[126] Z. Challal and T. Bouabana-Tebibel, "A priori replica placement strategy in data grid," in *Proceedings of 2010 International Conference on Machine and Web Intelligence (ICMWI)*, , 2010, pp. 402-406.

[127] R. M. Rahman, K. Barker, and R. Alhajj, "Replica selection in grid environment: a data-mining approach," in *Proceedings of the 2005 ACM symposium on Applied computing*, 2005, pp. 695-700.

[128] S. Vazhkudai, "Enabling the co-allocation of grid data transfers," in *Proceedings of 4th International Workshop on Grid Computing*, Phoenix, Arizona, USA, , 2003, pp. 44-51.

[129] Y. Zhao and Y. Hu, "GRESS–a grid replica selection service," in *Proceedings of the 15th IASTED International Conference on Parallel and Distributed Computing and Systems (PDCS-2003)*, 2003.

[130] T. Ho and D. Abramson, "The griddles data replication service," in *Proceedings of First International Conference on e-Science and Grid Computing*, 2005, pp. 278 - 286.

[131] C. Ferdean and M. Makpangou, "A scalable replica selection strategy based on flexible contracts," in *Proceedings of the Third IEEE Workshop on Internet Applications (WIAPP'03)*, Washington, DC, USA,, 2003, pp. 95 - 99.

[132] B. M. E. Moret and H. D. Shapiro, "Algorithms and experiments: The new (and old) methodology," *Journal of Universal Computer Science*, vol. 7, pp. 434-446, 2001.

[133] R. Wolski, "Forecasting network performance to support dynamic scheduling using the network weather service," in *Proceedings of The Sixth IEEE International Symposium on High Performance Distributed Computing*, 1997, pp. 316-325.

[134] W. Dubitzky and I. ebrary, *Data mining techniques in grid computing environments*: Wiley Online Library, 2008.

[135] MONORAC Project, "http://cern.ch/MONORC."

[136] R. Buyya and M. Murshed, "Gridsim: A toolkit for the modeling and simulation of distributed resource management and scheduling for grid computing," *Concurrency and Computation: Practice and Experience*, vol. 14, pp. 1175-1220, 2002.

[137] K. Ranganathan and I. Foster, "Decoupling computation and data scheduling in distributed data-intensive applications," in *Proceedings 11th IEEE International Symposium on High Performance Distributed Computing, 2002. HPDC-11 2002.* , 2002, pp. 352-358.

[138] Grid Datafarm, "http://datafarm.apgrid.org."

[139] Rohaya Latip, "Data Replication with 2D Mesh Protocol for Data Grid," in *Faculty of Computer Science and Information Technology*. vol. PhD. thesis: Universiti Putra Malaysia, 2009.

[140] M. Radi, "Maintaining Replica Consistency Over Large-Scale Data Grid Using Update Propagation Technique," in *Faculty of Computer Science and Information Technology*. vol. PhD: Universiti Putra Malaysia, 2009.

[141] D. G. Cameron, A. P. Millar, C. Nicholson, R. Carvajal-Schiaffino, K. Stockinger, and F. Zini, "Analysis of scheduling and replica optimisation strategies for data grids using OptorSim," *Journal of Grid Computing*, vol. 2, pp. 57-69, 2004.

[142] W. H. Bell, D. G. Cameron, A. P. Millar, L. Capozza, K. Stockinger, and F. Zini, "Optorsim: A grid simulator for studying dynamic data replication strategies," *International Journal of High Performance Computing Applications*, vol. 17, pp. 403-416, 2003.

[143] The European Data Grid Project, " http://eudatagrid.web.cern.ch/eu-datagrid/."

[144] H. H. E. Al-Mistarihi and C. H. Yong, "Response Time Optimization for Replica Selection Service in Data Grids," *Journal of Computer Science*, vol. 4, pp. 487-493, 2008.

[145] L. Hong, Q. Xue-dong, L. Xia, L. Zhen, and W. Wen-xing, "Fast Cascading Replication Strategy for Data Grid," in *Proceedings of the 2008 International Conference on Computer Science and Software Engineering-Volume 03*, 2008, pp. 186-189.

[146] M. Lei, S. V. Vrbsky, and X. Hong, "A dynamic data grid replication strategy to minimize the data missed," in *Proceedings of 3rd International Conference on Broadband Communications, Networks and Systems. BROADNETS.* , 2007, pp. 1-10.

[147] B. T. Huffman, R. McNulty, T. Shears, R. S. Denis, and D. Waters, "The CDF/D0 UK GridPP Project," *CDF Internal Note*, vol. 5858, 2002.

[148] D. G. Cameron, R. Carvajal-Schiaffino, A. P. Millar, C. Nicholson, K. Stockinger, and F. Zini, "UK grid simulation with OptorSim," in *Proceedings of UK e-Science All Hands Meeting*, Nottingham, UK, 2003.

[149] R. G. Sargent, "Verification and validation of simulation models," in *proceedings of Winter Simulation Conference*, 2005, pp. 130-143.

[150] D. Minoli, *A networking approach to grid computing*. USA.: Wiley-Interscience, 2005.

[151] K. Ranganathan and I. Foster, "Identifying dynamic replication strategies for a high-performance data grid," *Grid Computing—GRID 2001*, pp. 75-86, 2001.

[152] S. P. Kapitza, "The statistical theory of global population growth," in *Formal descriptions of developing systems*, 2003, p. 35.

[153] M. Kremer, "Population growth and technological change: one million BC to 1990," *The Quarterly Journal of Economics*, vol. 108, pp. 681-716, 1993.

[154] J. U. Kreft, G. Booth, and J. W. T. Wimpenny, "BacSim, a simulator for individual-based modelling of bacterial colony growth," *Microbiology*, vol. 144, p. 3275, 1998.

[155] A. D. MacCormack, J. Rusnak, and C. Y. Baldwin, *Exploring the structure of complex software designs: An empirical study of open source and proprietary code*: Citeseer, 2004.

[156] M. Hassan and R. Jain, *High performance TCP/IP networking*. United States of America: Pearson Prentice Hall, 2004.