Meta-brokering solution for establishing Grid Interoperability

Summary of the Ph.D. dissertation

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Introduction

Grid Computing [4] has become a separate research field in the '90s and since then it has been targeted by many projects all around the world. Several years ago users and companies having computation and data intensive applications looked sceptical at the forerunners of Grid solutions that promised less execution time and easy-to-use application development environments by creating a new virtually unified high performance system of interconnected computers from all around the world. Research groups were forming around specific parts of Grid systems and different research areas emerged, because former techniques of distributed computing were not applicable in Grid systems. Many user groups from various research fields (biology, chemistry, physics, etc.) put their trust in Grids and today usage statistics and research results show that they were undoubtedly right. Grid Computing has been in the spotlight, several international projects have aimed to establish sustainable Grids (eg. CoreGRID [15], EGEE [13], NextGRID [25], GEANT [16], KnowARC [20], EUAsiaGrid [14] and OSG [27]).

Core Grid services are provided and implemented by a so-called Grid middleware [5]. The first widespread middleware was the Globus Toolkit [3], which became a de facto standard for Grid Computing around 2002. Since then several middleware solutions have appeared, and the production Grids using these solutions formed separate islands that represent borders for both researchers and user communities. A decade of Grid development has established many national and international production Grids based on different middleware solutions (eg. HunGrid [22], NGS [24], EGEE [13], UNICORE [34], NorduGrid [26] and OSG [27]). As a result of the numerous Grid projects and available production Grids, user support centers [33, 17, 35, 19] have been set up in order to ease application porting to Grid environments. In some cases these applications are so large and complex that their executions require more computing resources than a particular Grid can provide. Therefore similarly to the World-Wide Web, the interconnection of these separate islands can result in a World-Wide Grid in the future. Such an aggregated system could cope with the growing number of users and computation-intensive applications.

Resource management in Grid systems is the research field most affected by user demands. Though well-designed, evaluated and widely used resource managers (also called as brokers) have been developed, new capabilities are required, such as interoperability and agreement support. The available resource managers have already been surveyed by other research groups [8], but these publications do not detail capabilities related to interoperability and do not separate operational roles (eg. scheduling, brokering, management). This dissertation aims at providing a high-level brokering solution to establish Grid Interoperability [11], which means the bridging of different Grid infrastructures in order to allow users on one Grid to run computing jobs and exchange data with users on other Grids. The current solutions of Grid resource management will not be able to fulfil the high demands of future generation Grid systems, though several Grid resource brokers [1] have been developed supporting different Grid systems. The main problem is that most of them cannot cross the borders of separate Grid islands caused by different Grid middleware solutions, therefore they can mature as slowly as middleware solutions evolve. These newly arisen problems need to be treated by novel research approaches in order to aggregate the separated Grid islands and manage them together, because currently used Grid middleware solutions do not support real interoperation other then restricted bilateral ones.

Solving these problems is crucial for the next generation of Grids, which should spread from the academic to the business world. The advance of Grids seems to follow the way foreseen by the Next Generation Grids Expert Group, which has been established by the European Commission. In their third report [10] they have pointed out that Grid and web services are converging and envisaged hybrid services called as SOKUs (Service Oriented Knowledge Utility), which enable more flexibility, adaptability and advanced interfaces, therefore interoperability is evident and congenital in these systems. Following these expert guidelines and the latest requirements of Grid user groups, I propose in this dissertation such a high-level Grid brokering solution that enables Grid Interoperability by providing the highest number of brokering capabilities in a way that it does not require any changes to the underlying Grid middleware services.

In the following I give short descriptions of my contributions. Table 1 shows the connections between the theses and the publications, and Table 2 shows the independent citations for the publications.

New scientific results

During the research presented in this dissertation my first goal was to elaborate a classification of Grid resource brokers. At that time, the less than ten-year-old Grid Computing had several resource management solutions named by different expressions operating on different middleware addressing various user needs. During the preparation of the first thesis I examined the widespread Grid resource brokers used by different user communities, identified their key functionalities and properties, gathered them into a taxonomy, and classified them in a survey using the elements of the taxonomy. I analysed the connections and inner structures of the available Grid resource manager components, identified different operational roles and resolved their contradictory naming acronyms and expressions by creating an anatomy of Grid resource managers. I formalized the identified brokering roles, and inserted them into the Abstract State Machine (ASM) model of Grid systems [9]. I identified and defined interoperability levels for Grid brokering solutions and expressed them in the presented model that enables the classification of related brokering approaches. I stated the following thesis based on these results:

> **Thesis I. I designed a category framework of broker capabilities that I used to create a general taxonomy of Grid brokers. I designed an anatomy of Grid resource managers that I used to formalize Grid brokering levels based on the ASM model of Grids [9].**

Grid Interoperability [11] is a fundamental challenge of Grid Computing nowadays. The presented broker taxonomy also points out the heterogeneity in most brokering components and methods. The resource management anatomy revealed their similarities and possible interactions that paved the way for introducing a meta-level in Grid brokering to interoperate different Grid systems. Some of the surveyed brokers are capable of low-level interoperation by accessing resources of different Grids. I showed how these approaches address multi-grid brokering by broker-extension and multi-brokering from Grid portals. For a higher level of interoperability, a general broker description language is needed in order to enable the unified management of Grid brokers. The second thesis contains the elaboration of such language based on a meta-data model, using the categories of the broker taxonomy.

> **Thesis II. I designed a new, XML-based description language called Broker Property Description Language (BPDL) that is able to describe any Grid resource broker that can be categorized in the taxonomy. A high-level brokering service can use this language for the unified management of these brokers.**

I named the novel approach that performs high-level brokering at the meta-level of Grid resource management as meta-brokering. The next, third thesis includes the description of the required components of a general meta-brokering architecture (besides the broker description language) and a realization of the abstract architecture in a meta-brokering service that does not require any modifications to the utilized brokers and Grids.

Thesis III. I determined the general requirements of Grid meta-brokering, and developed a general architecture based on these requirements that introduces a higher abstraction layer for enabling Grid Interoperability by the unified management of Grid brokers. Based on this general architecture, I designed the necessary components to build the Grid Meta-Broker Service (GMBS).

The components of the realized meta-brokering service perform user interactions, monitoring of resource and Grid load, tracking broker performance and automatic broker selection. After publishing this meta-brokering approach, other research groups have also realized the need for interoperable brokering and started to develop their own solutions. I designed a classification of these solutions based on the interoperability levels introduced in Thesis I. The final part of the research was to evaluate the proposed meta-broker. The GridSim Toolkit [2] is a widely accepted and used Grid simulator that can be easily tailored to analyse Grid brokering methods. The fourth thesis presents a meta-brokering simulation architecture that extends GridSim, and the performance evaluation of the implemented meta-broker in this environment by using real world resource usage traces form the publicly available Parallel and Grid Workloads Archive [28, 21].

Thesis IV. I developed a new simulation environment based on the GridSim [2] simulator that is able to evaluate meta-brokering. I performed the evaluation of GMBS in this environment with a performance analysis using both real parallel and Grid workload traces. I proved the effectiveness of the interoperable meta-brokering service with the evaluation.

The evaluation results showed that the interoperable meta-brokering solution of GMBS was able to achieve an order of magnitude better performance in Grid application execution compared to the general, non-interoperable Grid utilization simulated by random broker selection.

Conclusions

Current Grid systems are used by a high number of various research communities, but the lack of interoperability among them represents borders for further development and efficient usage. Numerous user applications are so large and complex that the execution may require more computing resources than a particular Grid can provide. In order to solve this problem, I proposed in this dissertation a novel resource management solution that is able to serve complex user requirements by providing transparent access to resources of several Grid systems simultaneously, in an automated way.

The brokering-related services of the P-GRADE portal [6] and the gUSE/WS-PGRADE system [7] are based on the contributions of this dissertation. Several scientific projects use or are supported by these systems. Therefore the results of this dissertation are applied in the following European Union projects: SHIWA project [31], EDGI project [12], CancerGrid project [18] and GASuC project [19], and in the following national projects: UK ProSim project [29], MoSGrid project [23] and a biology project of ETH Zurich [32].

The scientific results of the theses have been published in numerous journals, conference and workshop papers and have been presented in various scientific forums. These publications have inspired further research, generated collaborations, and are well represented by many independent citations. Most of the research presented in this dissertation has resulted from active involvement in the CoreGRID and S-CUBE EU Network of Excellence projects [15, 30].

Table 1: Theses and publications

	[P4]	[P18]	[P16]	[P1]	[P5]	[P17]	[P2]	[P11]	[P6]
Thesis I.	•	•	•	•	•	•	•	•	•
Thesis II.						•			•
Thesis III.		•	•			•			•
Thesis IV.						•			

	[P7]	[P3]	[P8]	[P10]	[P14]	[P19]	[P12]	[P9]	[P13]	[P15]
Thesis I.	•					•				
Thesis II.	•		•	•	•	•		•		
Thesis III.	•	•	•	•	•	•	•	•	•	•
Thesis IV.						•			•	

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References

[1] E. Afgan, "Role of the Resource Broker in the Grid", In proceedings of the 42nd annual Southeast regional conference, 2004.

[2] 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., pp. 1175-1220, Volume 14, Issue 13-15, 2002.

[3] I. Foster, C. Kesselman, "The Globus project: A status report", in Proc. of the Heterogeneous Computing Workshop, IEEE Computer Society Press, pp. 4-18, 1998.

[4] I. Foster, C. Kesselman, "Computational Grids, The Grid: Blueprint for a New Computing Infrastructure", Morgan Kaufmann, pp. 15-52, 1998.

[5] I. Foster, C. Kesselman, S. Tuecke, "The Anatomy of the Grid: Enabling Scalable Virtual Organizations", International J. Supercomputer Applications, 15(3), 2001.

[6] P. Kacsuk, G. Sipos, "Multi-Grid, Multi-User Workflows in the P-GRADE Grid Portal", Journal of Grid Computing, Volume 3, num. 3-4, pp. 221-238, 2006.

[7] P. Kacsuk, K. Karóczkai, G. Hermann, G. Sipos, and J. Kovács, "WS-PGRADE: Supporting parameter sweep applications in workflows", Proc. of the 3rd Workshop on Workflows in Support of Large-Scale Science (in conjunction with SC08), Austin, 2008.

[8] K. Krauter, R. Buyya, M. Maheswaran, "A taxonomy and survey of grid resource management systems for distributed computing", Softw., Pract. Exper., vol. 32, pp. 135-164, 2002.

[9] Zs. Németh, and V. Sunderam, Characterizing Grids: Attributes, Definitions, and Formalisms, Journal of Grid Computing, vol. 1, pp. 9-23, 2003.

[10] Next Generation Grids Expert Group Report no. 3, ”Future for European Grids: GRIDs and Service Oriented Knowledge Utilities – Vision and Research Directions 2010 and Beyond”, NGG3, December 2006.

[11] M. Riedel et al., ”Interoperation of World-Wide Production e-Science Infrastructures”, Concurrency and Computation: Practice and Experience, Volume 21, Issue 8, pp. 961-990, 2009.

Web references

[12] Enabling Desktop Grids for e-Science, http://edgi-project.eu/, December 2010.

[13] Enabling Grids for E-sciencE (EGEE) project, http://www.eu-egee.org/, September 2010.

[14] EUAsiaGrid project, http://www.euasiagrid.org, September 2010.

[15] European Research Network on Foundations, Software Infrastructures and Applications for large scale distributed, GRID and Peer-to-Peer Technologies (CoreGrid Project), http://www.coregrid.net, December 2010.

[16] GEANT project, http://www.geant.net, September 2010.

[17] Global Grid User Support, http://www.ggus.org, December 2010.

[18] Grid aided computer system for rapid anti-cancer drug design, CancerGrid project, http://cancergrideu.w3h.hu/, December 2010.

[19] Grid Application Support Centre, http://www.lpds.sztaki.hu/gasuc/, December 2010.

[20] Grid-enabled Know-how Sharing Technology Based on ARC Services and Open Standards (KnowARC) project, http://www.knowarc.eu, November 2009.

[21] The Grid Workloads Archive, http://gwa.ewi.tudelft.nl, September 2009.

[22] HunGrid virtual organisation, http://www.grid.kfki.hu/hungrid/, September 2009.

[23] Molecular Simulation Grid (MoSGrid), http://www.mosgrid.de/, December 2010.

[24] National Grid Service (NGS), http://www.ngs.ac.uk/, September 2010.

[25] NextGRID – Architecture for Next Generation Grids project, http://www.nextgrid.org/, December 2010.

[26] NorduGrid Middleware, http://www.nordugrid.org/middleware/, September 2010.

[27] Open Science Grid (OSG) project, http://www.opensciencegrid.org, September 2010.

[28] Parallel Workloads Archive, http://www.cs.huji.ac.il/labs/parallel/workload/, September 2008.

[29] ProSim Project/JISC Engage Program, https://sites.google.com/a/staff.westminster.ac.uk/engage/, September 2010.

[30] Software Services and Systems Network European Network of Excellence FP7 project, http://www.s-cube-network.eu/, September 2010.

[31] SHaring Interoperable Workflows for large-scale scientific simulations on Available DCIs (SHIWA) project, http://liferay.lpds.sztaki.hu:8080/web/shiwa/project, December 2010.

[32] Swiss Grid portal, http://alprose01.projects.cscs.ch:8080/gridsphere/gridsphere, September 2010.

[33] TeraGrid Advanced User Support (AUS) project, https://www.teragrid.org/web/user-support/aus_projects, September 2010.

[34] Uniform Interface to Computing Resources (UNICORE) project, http://www.unicore.eu, September 2010.

[35] Westminster Grid Application Support Service (W-GRASS), http://wgrass.wmin.ac.uk, September 2010.

Publications

[P1] A. Kertész, "Brokering solutions for Grid middlewares", In Pre-proc. of 1st Doctoral Workshop on Mathematical and Engineering Methods in Computer Science, (MEMICS 2005), Znojmo, Czech Republic, 14-17 October, 2005.

[P2] A. Kertész, G. Sipos, P. Kacsuk, "Brokering Multi-Grid Workflows in the P-GRADE Portal", In Euro-Par 2006: Parallel Processing, CoreGRID Workshop on Grid Middleware, Springer-Verlag LNCS, Volume 4375, pp. 138-149, June 2007.

[P3] A. Kertész, P. Kacsuk, "Grid Meta-Broker Architecture: Towards an Interoperable Grid Resource Brokering Service", In Euro-Par 2006: Parallel Processing, CoreGRID Workshop on Grid Middleware, Springer-Verlag LNCS, Volume 4375, pp. 112-115, June 2007.

[P4] A. Kertész, P. Kacsuk, "A Taxonomy of Grid Resource Brokers", In Distributed and Parallel Systems, Springer US, 6th Austrian-Hungarian Workshop on Distributed and Parallel Systems (DAPSYS'06), pp. 201-210, May 2007.

[P5] A. Kertész, G. Sipos, P. Kacsuk, "Multi-Grid Brokering with the P-GRADE Portal", In Post-Proceedings of the Austrian Grid Symposium (AGS'06), pp. 166-178, OCG Verlag, Austria, 2007.

[P6] A. Kertész, "Grid Brókerek evolúciója: Egységben az erő", Híradástechnika, Volume LXII, pp. 21–25, 2007/12.

[P7] A. Kertész, "The evolution of Grid Brokers: Union for Interoperability", Journal of Scientific Association for Infocommunications with co-operation with the National Council of Hungary for Information and Communications Technology, pp. 55-59, Volume LXIII, HU ISSN 0018-2028, January 2008.

[P8] A. Kertész, P. Kacsuk, "Meta-Broker for Future Generation Grids: A new approach for a high-level interoperable resource management", In Grid Middleware and Services: Challenges and Solutions, 2nd CoreGRID Workshop on Grid Middleware, Springer US, pp. 53-63, June 2008.

[P9] A. Kertész, I. Rodero, F. Guim, "Data Model for Describing Grid Resource Broker Capabilities", In Grid Middleware and Services: Challenges and Solutions, 2nd CoreGRID Workshop on Grid Middleware, Springer US, pp. 39-52, June 2008.

[P10] A. Kertész, I. Rodero, F. Guim, "Meta-Brokering approaches in state-of-the-art Grid Resource Management", CoreGRID Integration Workshop 2008 – Integrated Research in Grid Computing, pp. 371-382, Hersonissos, Crete, Greece, April 2008.

[P11] A. Kertész, Z. Farkas, P. Kacsuk, T. Kiss, "Grid Interoperability by Multiple Broker Utilization and Meta-Brokering", In Grid Enabled Remote Instrumentation, Springer US Book Series on Signals and Communication Technology, (INGRID'07), pp. 303-312, October 2008.

[P12] P. Kacsuk, A. Kertész and T. Kiss, "Can We Connect Existing Production Grids into a World Wide Grid?", In High Performance Computing for Computational Science (VECPAR'08), Springer LNCS, Volume 5336, pp. 109-122, December 2008.

[P13] A. Kertész, J. D. Dombi, J. Dombi, "Adaptive scheduling solution for grid meta-brokering", Acta Cybernetica, Volume 19, pp. 105-123, 2009.

[P14] A. Kertész, I. Rodero, F. Guim, "Meta-Brokering Solutions for Expanding Grid Middleware Limitations", In Euro-Par 2008 Workshops – Parallel Processing, Workshop on Secure, Trusted, Manageable and Controllable Grid Services (SGS'08), Springer LNCS, Volume 5415, pp. 199-210, April 2009.

[P15] A. Kertész, G. Kecskeméti, I. Brandic, "An SLA-based Resource Virtualization Approach For On-demand Service Provision", In proceedings of 3rd International Workshop on Virtualization Technologies in Distributed Computing (VTDC'09) in conjunction with ICAC'09, Barcelona, Spain, ACM, pp. 27-34, June 15, 2009.

[P16] A. Kertész and Zs. Németh, "Formal Aspects of Grid Brokering", In EPTCS 14, 8th International Workshop on Parallel and Distributed Methods in verifiCation (PDMC'09), pp. 18-31, CoRR abs/0912.2549, 2009.

[P17] A. Kertész, P. Kacsuk, "Grid Interoperability Solutions in Grid Resource Management", IEEE Systems Journal's Special Issue on Grid Resource Management, Volume 3, Issue 1, pp. 131-141, March 2009.

[P18] A. Kertész and T. Prokosch, "The Anatomy of Grid Resource Management", In book: Remote Instrumentation and Virtual Laboratories, Eds.: Davoli, F.; Meyer, N.; Pugliese, R.; Zappatore, S., Springer Science+Business Media, LLC, pp. 123-132, 2010.

[P19] A. Kertész, P. Kacsuk, "GMBS: A New Middleware Service for Making Grids Interoperable", Future Generation Computer Systems, vol. 26, no. 4, pp. 542-553, 2010.

Independent citations of the publications

[R1] E. Afgan, and P. Bangalore, Dynamic BLAST–a Grid Enabled BLAST, IJCSNS, vol. 9, no. 4, 2009.

[R2] E.S. Alkayal and F.A. Essa, Service oriented distributed manager for grid system, In IEEE International Symposium in Information Technology (ITSim), vol. 3, pp. 1174-1179, 2010.

[R3] A. Alqaoud, I. Taylor, and A. Jones, Publish/subscribe as a model for scientific workflow interoperability, Proceedings of the 4th Workshop on Workflows in Support of Large-Scale Science, pp. 1-10, ACM, 2009.

[R4] R. Aoun and M. Gagnaire, Impact of traffic predictability on resource virtualization and job scheduling in grid networks, In proc. of the IEEE EUNICE summer school, Brest, France, Sep. 2008.

[R5] P. Balakrishnan, T.S. Somasundaram, SLA enabled CARE resource broker, Future Generation Computer Systems, 27 (3), pp. 265-279, 2011.

[R6] N. Bobroff, L. Fong, S. Kalayci, Y. Liu, J.C. Martinez, I. Rodero, S.M. Sadjadi, and D. Villegas, Enabling interoperability among meta-schedulers, Proceedings of 8th IEEE International Symposium on Cluster Computing and the Grid (CCGrid-2008), pp. 306-315, 2008.

[R7] A. Bouyer, A.H. Abdullah, S. Alizadeh, M. Jalali, Minimizing overhead computation time for grid scheduling system based on partitioned grid information service, In proc. of 2nd International Conference on Network Applications, Protocols and Services (NETAPPS 2010), art. no. 5636054, pp. 7-13, 2010.

[R8] S. Callaghan, E. Deelman, D. Gunter, G. Juve, P. Maechling, C. Brooks, K. Vahi, K. Milner, R. Graves, and E. Field, Scaling up workflow-based applications, Journal of Computer and System Sciences, Elsevier, 2009.

[R9] H.J. Choi, E. Kim, Y. Lee, H.Y. Yeom, D. Nam, and S. Hwang, A super-metascheduler-based approach for integrating multiple Heterogeneous Grids, In Proceedings of the 11th International Conference on Advanced Communication Technology, Volume 3, pp. 2065-2070, 2009.

[R10] A. Costan, C. Stratan, E.D. Tirsa, M.I. Andreica, and V. Cristea, Towards a Grid Platform for Scientific Workflows Management, in print, http://arxiv.org/ftp/arxiv/papers/0910/0910.0626.pdf.

[R11] E. Deelman, Grids and Clouds: Making Workflow Applications Work in Heterogeneous Distributed Environments, International Journal of High Performance Computing Applications, 2009.

[R12] E. Deelman, D. Gannon, M. Shields, and I. Taylor, Workflows and e-Science: An overview of workflow system features and capabilities, FGCS, vol. 25, no. 5, pp. 528-540, 2009.

[R13] J. D. Dhok, Learning Based Admission Control and Task Assignment for MapReduce, Thesis, Search and Information Extraction Lab International Institute of Information Technology, Hyderabad, India, 2010.

[R14] J. Echaiz, and J.R. Ardenghi, An Economic View of Indirect Reputation Management for Grids, JCS&T Vol. 9, No. 1, 2009.

[R15] J. Echaiz, J.R. Ardenghi, and GR. Simari, A novel algorithm for indirect reputation-based grid resource management, Computer Architecture and High Performance Computing, pp. 151-158, 2007.

[R16] E. Elmroth, and P.O. Ostberg, A Composable Service-Oriented Architecture for Middleware-Independent and Interoperable Grid Job Management, UMINF 09.14, Department of Computing Science, Umea University, Sweden. Submitted for journal publication, 2009.

[R17] E. Elmroth, and J. Tordsson, A standards-based Grid resource brokering service supporting advance reservations, coallocation and cross-Grid interoperability, Concurrency and Computation: Practice and Experience, 2006.

[R18] A. Goscinski, M. Brock, Toward dynamic and attribute based publication, discovery and selection for cloud computing, Future Generation Computer Systems, vol. 26, no. 7, pp. 947-970, 2010.

[R19] M.D. Halling-Brown, D.S. Moss, and A.J. Shepherd, Towards a lightweight generic computational grid framework for biological research, BMC bioinformatics, vol. 9, no. 1, 2008.

[R20] A. Harrison, and I. Taylor, Web enabling desktop workflow applications, Proceedings of the 4th Workshop on Workflows in Support of Large-Scale Science, ACM, pp. 1-9, 2009.

[R21] M.I. Hassan and A. Abdullah, Semantic-based grid resource discovery systems a literature review and taxonomy, In IEEE International Symposium in Information Technology (ITSim), vol. 3, pp. 1286-1296, 2010.

[R22] I.U. Haq, I. Brandic, E. Schikuta, SLA Validation in Layered Cloud Infrastructures, In Economics of Grids, Clouds, Systems, and Services, GECON 2010, LNCS Volume 6296/2010, pp. 153-164, 2010.

[R23] E. Huedo, R.S. Montero, and I.M. Llorente, A recursive architecture for hierarchical grid resource management, FGCS, vol. 25, no. 4,pp. 401-405, 2009.

[R24] I. Khalil, F. Sufi, CardioGrid: ECG analysis on demand to detect cardiovascular abnormalities, In proc. of 9th International Conference on Information Technology and Applications in Biomedicine (ITAB 2009), art. no. 5394436, 2009.

[R25] T. Kiss, and T. Kukla, Achieving Interoperation of Grid Data Resources via Workflow Level Integration, Journal of Grid Computing, vol. 7, no. 3, pp. 355-374, 2009.

[R26] V.V. Korkhov, Hierarchical resource management in grid computing, Thesis, University of Amsterdam, Faculty of Science, 2009.

[R27] K. Leal, E. Huedo, and I.M. Llorente, A decentralized model for scheduling independent tasks in federated grids, Future Generation Computer Systems, 2009.

[R28] K. Leal, E. Huedo, and I.M. Llorente, Performance-based scheduling strategies for HTC applications in complex federated grids, Concurrency and Computation: Practice and Experience, 2009.

[R29] Z. Longwen, F. Xiaoning, Design of Collaborative Innovation Platform of Industrial Clusters in Guangdong Province Based on OGSA, In proc. of IEEE International Conference on Management and Service Science (MASS'09), pp. 1-4, 2009.

[R30] G. Molto and V. Hernandez, On Demand Replication of WSRF-based Grid Services via Cloud Computing, In proc. of 9th International Meeting High Performance Computing for Computational Science (VECPAR'10), Berkeley, CA (USA), June 22-25, 2010.

[R31] P. Muthuchelvi, G.S. Anadha Mala and V. Ramachandran, IRBAS-An Intelligent Resource Broker with Alternate Solution for Expanding Grid Meta Schedulers, International Journal of Computing and Applications (IJCA), pp. 177-184, 2009.

[R32] G. Pashov, K. Kaloyanova, and K. Boyanov, Information Models for Lightweight Grid Platforms, CoreGRID Workshop on Grid Systems, Tools and Environments, 2006.

[R33] I. Rodero, F. Guim, J. Corbalana, L. Fong, Y.G. Liu, and S. M. Sadjadi, Looking for an evolution of grid scheduling: Meta-brokering, Proceedings of the Second CoreGRID Workshop on Middleware at ISC2007, Springer, 2007.

[R34] I. Rodero, F. Guim, J. Corbalana, L. Fong and S. M. Sadjadi, Grid broker selection strategies using aggregated resource information, FGCS, Volume 26, Issue 1, pp. 72-86, 2010.

[R35] M. Sivagama Sundari, S.S. Vadhiyar, and R.S. Nanjundiah, Grids with multiple batch systems for performance enhancement of multi-component and parameter sweep parallel applications, FGCS, vol. 26, no. 2, pp. 217-227, 2010.

[R36] R. Spurzem, P. Berczik, I. Berentzen, D. Merritt, N. Nakasato, H.M. Adorf, T. Brusemeister, P. Schwekendiek, J. Steinacker, and J. Wambsgan, From Newton to Einstein – N-body dynamics in galactic nuclei and SPH using new special hardware and astrogrid-D, Journal of Physics: Conference Series, vol. 78, 2007.

[R37] J. Tordsson, Portable Tools for Interoperable Grids: Modular Architectures and Software for Job and Workflow Management, Doctoral thesis, 2009.

[R38] D. Villegas, I. Rodero, L. Fong, N. Bobroff, Y. Liu, M. Parashar, and S.M. Sadjadi, The Role of Grid Computing Technologies in Cloud Computing, In Handbook of Cloud Computing, Springer, pp. 183-218, 2010.

[R39] M. Wieczorek, A. Hoheisel, and R. Prodan, Towards a general model of the multi-criteria workflow scheduling on the grid, Future Generation Computer Systems, vol. 25, no. 3, pp. 237-256, 2009.

[R40] C. Wen, H. Shiau, C. Wang, S. Wang, A SLA-based dynamically integrating services SaaS framework, IET Conference Publications 2010 (568 CP), pp. 306-311, 2010.

Table 2: Publications and their independent citations

	[P1]	[P2]	[P3]	[P4]	[P5]	[P8]	[P9]	[P10]	[P11]	[P13]	[P15]	[P17]	[P19]
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