Prof. Jacek Błażewicz

Instytut Informatyki

Politechnika Poznańska

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Report
on a Ph.D. thesis of Krzysztof Rządca
"Resource Management Models and Algorithms for Multi-Organizational Grid"

1. Research area of the thesis

Grid computing is currently one of the most intensive research areas in Computer Science. A number of actually realized ambitious projects aim to build virtual computing systems interconnecting geographically distributed heterogeneous computer systems to be able to solve computational problems faster at a gigantic scale. The grid has emerged as a promising platform to tackle large-scale problems in various areas, such as bioinformatics, high energy physics, image processing or data mining.

In opposite to classical computational systems, grids are not only a collection of different and distributed resources, which need to be efficiently managed, but additionally grid sites are owned and managed by different organizations, which realize their own purposes and may have different priorities. Due to this fact, to classical but open for grid systems problems like resource management and scheduling, new issues arrive, such as the presence of a conflict, a possibility of a selfish behavior of grid participants, centralized versus decentralized control and its influence on a grid performance.

Mr. Rządca have well recognized the current state of the research and practice in the area of grid computing. He critically analyzed a number of recently proposed approaches related to management of grid resources, such as architectural oriented paradigms known as service oriented grids and lightweight grids, and economic approaches such as an auction approach, and semi-market or market approaches based on the concept of money. He points out drawbacks of these approaches and he decides to cope with these drawbacks by setting as a central issue of his thesis the question: how decentralization of a grid systems influents on its performance. As the basic tool of his study he uses game theory models, and also the theory of equitable multicriteria optimization. He constructs a number of grid models with different degree of decentralization, proposes for them scheduling algorithms and study theoretically and experimentally the performance of grids under these models. The results of the study give a new interesting insight into the area of grid computing. They show that fully decentralized systems will not work efficiently, but it is possible to obtain well performing grid, where resources are fairly shared among participants, and he proposes a number of efficient scheduling algorithms for this type of grid organization.

2. Contents of the thesis

The thesis consists of the Abstract written in English, French and Polish, Preface, followed by six chapters and bibliography consisting of 76 references. The whole work contains 174 pages and it has both theoretical and experimental character. The main results of the thesis are presented in chapters 3-5.

Chapter 1 is an introduction to the subject of the thesis. It presents the goal and the scope of the work. It shortly presents the main concepts of theoretical tools used in the thesis, their basic notions, definitions and theorems. It also overviews the current state of the research in the area of grid computing and presents the summary of contributions of the thesis.

Chapter 2 outlines the main components of the proposed grid model, which is studied in next chapters. The main definitions, performance measures and the main assumptions of the model are presented. The proposed model is discussed in the context of real-world grids.

Chapter 3 is the first one where original results of the thesis study are presented. The problem of scheduling sequential jobs produced by grid participants in a distributed set of grid resources is considered, under assumption that release times of all jobs are known before the scheduling starts (off-line model). The problem is considered from three perspectives which differ by the level of control the grid scheduler has over the resources' schedules. It leads to three different models, where different mathematical tools are applied. The first model assumes that the grid scheduler has a complete control over all local schedulers and the problem is formulated in terms of equitable optimization. According to my knowledge it is the first attempt to use equitable optimization in the context of scheduling. It results in a heuristic algorithm which optimizes performance of all grid participants. The second model assumes that local schedulers can alter the schedule derived by the central scheduler. The analysis of the model with the use of tools provided by non-cooperative games is given. The analysis shows that for the complete decentralization, a solution of the problem corresponds to the Nash equilibrium and may lead to a significant loss of performance of the system. A strong community control is required to achieve acceptable performance. The third model assumes that local schedulers cannot alter their schedules but the owner of the resources can leave the grid, and constrained equitable optimization is applied to this model. For both, the first and third models three algorithms are proposed: an exhaustive search, an exact dynamic programming, and a greedy heuristics. Results of experimental study have shown that proposed heuristics deliver results which are not far from the optimum and work a few orders of magnitude faster than exact algorithms.

In chapter 4 the problem of load balancing of divisible jobs produced by grid participants during life time of the system (on-line model) is considered. The latest finish time of each submitted job must be guaranteed by the system. First, in this chapter a new cost function for the problem was proposed, in which the cost of execution depends both on the size of a job and on the local load. A game-theoretic approach applied to the problem has shown that equitable-optimal load balancing will be never achieved by players in this model if grid participants are willing to cooperate only during short period of times. To overcome these difficulties two new load balancing algorithms are proposed. The first algorithm assumes forcing players to commit to their decisions for longer periods of time. The second one called

Bounded Iterative Load Balancing delivers better results that the first one. It employs two techniques: controlling the maximum length of the foreign load queue, and load balancing the least-loaded resource first. Both algorithms were validated by a theoretical analysis and experimentation.

In chapter 5 the classical version of a parallel job scheduling problem is extended to grid environment. It is assumed that parallel jobs are produced by grid participants (in off-line model) and these jobs can be executed on different grid sites through grid-level load balancing. The load balancing problem is studied from the point of view of delivering solutions which guarantee the worst-case performance ratio. Algorithms providing such solutions are called approximation algorithms, and they are the subject of the study in this chapter. First, the problem of scheduling on a single parallel machine is considered from the three perspectives (like it was in chapter 3) which differ by the degree of control over resources. In particular, it was shown that under full resources control the classical list scheduling algorithm degrades in such an environment, and in the case of lack of the central control and corresponding game-theoretical model the resulting game has a low price of anarchy. Next, the problem of scheduling parallel jobs in a grid environment consisting of a number of participants is considered. To solve the problem two new load balancing algorithms called MOLBA (Multi-Organizational Load Balancing Algorithm) and ILBA (Iterative Load Balancing Algorithm), respectively are proposed. It was shown that both algorithms guarantee the approximation ratio of the global makespan, and the second algorithm further improves both the global makespan and the equity between organizations' makespans. The theoretical results concerning these algorithms were validated by experimental study.

Last chapter, chapter 6, contains summary of the thesis and final conclusions.

3. The most important results

Mr. Rzadca has obtained in his dissertation a number of new interesting results concerning issues of scheduling and load balancing in grid systems. These results are in the form of theorems with formal proofs, algorithms and experimental results. There is no critical remark or objections to the way of obtaining these results. The formal tools used in the thesis, such as multicriteria optimization and game theory were the right choice and gave an opportunity to look at the reality of grid systems from positions of different degrees of decentralization. Obtained results give a new insight into both theory and practice of grid computation. In my opinion, the most interesting and valuable results of the thesis are the following:

- Working out two scheduling algorithms (exact algorithm based on Dynamic Programming and taboo search-based heuristic) for the problem of multi-organizational scheduling and a scheduler with full information (chapter 3)
- Proposing game-theoretical model (chapter 3) for the grid with local schedulers and proving that the Price of Anarchy in such an environment is linear with the number of jobs
- Proposing a new cost function (chapter 4) for the problem of divisible load balancing and proving that (a) averaging load balancing produces equitable results, (b) load balancing will never be performed in the system when participants have complete control over their resources

- Proving (chapter 4) that it is not possible to construct load balancing algorithm based on currently observed queue lengths when resources are controlled by independent entities
- Proposing (chapter 4) a new centralized load balancing algorithm which delivers equitable results even when loads of resources differ significantly
- Proposing for the problem of scheduling rigid, parallel jobs on multiple resources (chapter 5), a centralized scheduling algorithm with a fixed worst-case performance and at the same time not worsening local makespans of individual grid participants.

4. The quality of presentation

The thesis is well organized and written. At the end of each chapter a short chapter summary is provided what helps in reading and understanding the main points of the thesis. The most important results of experimental study are presented in the form of plots and tables and the main concepts are illustrated by pictures. The quality of English is very good and the way of presentation is clear and does not make any problems in understanding. I have not noticed any typographical or grammatical errors.

5. Critical remarks

The thesis contains a wide spectrum of issues concerning different modes of grid operation which are studied under different models constructed with use of also relatively wide spectrum of theoretical tools such as multicriteria optimization, equitable optimization, game theory models, dynamic programming, metaheuristics, etc. Results achieved in the thesis and the way of their presentation do not make any objections. As a consequence of a wide range of considered issues and tools, and naturally limited size of the work, a reader may fill sometimes some need to have enlarged information on some issues. In this connection, some questions appeared during reading the thesis, and I would be pleased to obtain more specific information on some of them. These are the following issues:

- One of the assumptions about grid participants is (section 2.4) that all of them are characterized by the same type of criteria; how this assumption is related to grid reality and what consequences would be if this assumption is changed ?
- Dynamic programming and tabu-search heuristics used in algorithms proposed in section 3 represent two wide classes of exact algorithms and metaheuristics, respectively. What was the reason to choose exactly these search algorithms ?
- Game-theoretic models used in the thesis and their solutions are mainly based on the concept of the Nash equilibrium in one-shot game; how this assumption is related to grid realities ?
- What are the parameters of tabu-search algorithm used in experiments (chapter 3) ?

6. Conclusions

Mr. Rzadca has presented in the thesis in a clear logical form substantially new, original results which enrich the current state of the theory and practice of grid computing. These results were discussed and accepted on a number of top international conferences in the area of parallel and grid computing, where the acceptance ratio is low. Results obtained in the thesis were published by very well recognized publishing houses, such as ACM, IEEE and Springer. Three papers were published in distinctive Springer series LNCS, and one paper is accepted for publication in widely recognized journal, European Journal of Operational Research. What is worth to notice is that these results were obtained in a short three year period of time assigned by co-tutelle grant and cooperation agreement between Polish-Japanese Institute of Information Technology in Warsaw and Institut Nationale Polytechnique in Grenoble.

In conclusion, I would like to state that all requirements concerning PhD thesis, defined by the binding Polish law have been fulfilled. In this connection, I recommend to admit Mr. Rzadca to public defence of his thesis. Taking Mr Rządca's scientific output into account I also recommend to consider his PhD thesis as the thesis with distinction.