QoS Based Multi-Constraints Bin Packing Job Scheduling Heuristic for Heterogeneous Volunteer Grid Resources

Saddaf Rubab, Mohd Fadzil Hassan, Ahmad Mahmood, and Nasir Mehmood
Department of Computer and Information Sciences, University Technology Petronas, Malaysia

Abstract: *Volunteer grid is a kind of distributed networks, consisting of contributed resources which are heterogonous and distributed. The heterogeneity of resources can be in terms of the time of availability, resource characteristics among others. Usually submitted jobs to volunteer grid usually require different heterogeneous resources depending on their requirements. Efficient scheduling of submitted jobs can be done if jobs are divided into small number of tasks to fulfil multiple requirements, which requires multi-resource scheduling policy to consider different constraints of resource and job before scheduling. In traditional scheduling policies only single scheduling or optimization constraint is considered to either complete job within specific deadline or to maximize the resource usage. Therefore, a scheduling policy is required to serve multiple constraints for optimizing resource usage and completing jobs within specified deadlines. The work presented in this paper proposed Quality of Service (QoS) based multi-constraint job scheduling heuristics for volunteer grid resources. Bin packing problem is also incorporated within the proposed heuristic for reordering and jobs assignment. The performance of proposed scheduling heuristic is measured by comparing it with other scheduling algorithms used in grid environment. The results presented suggest that there is a reasonable improvement in waiting time, turnaround time, slowdown time and job failure rate.*

Keywords: *Volunteer grid computing, volunteer resources, QoS, SLA, multi-constraints, rescheduling, bin-packing, back-filling.*

Received October 30, 2015; accepted April 13, 2017

1. Introduction

Distributed Networks have heterogeneous physically distributed resources. Figure 1 highlights the classification of distributed networks. Volunteer grid computing is one of the kind of distributed networks which has volunteered heterogeneous and distributed resources, to help serve scientific research and high computations [15, 23, 26]. Whereas, the volunteered resources are unpredictable and the resource availability cannot be assured for full length of job assigned. Efficient utilization of these resources is one of the major research issues. One possible way can be to schedule jobs such that the jobs are completed within deadline and resource utilization is maximized. The criteria or conditions for resource selection and jobs assignment are referred to as constraints. There are many traditional job scheduling algorithms and policies which can be incorporated in volunteer grid environment such as First Come First Serve (FCFS), Shortest Process Next (SPN), Longest Job First (LJF), Round Robin (RR) [13, 14, 21] etc., but all these lack the ability to consider multiple constraints. For example, if the submitted jobs are scheduled using FCFS, the job arriving first will be scheduled firstly and subsequent jobs will be scheduled in order of their arrival time until all jobs are submitted or no more resources are available. However, if a large job arrived first and demands multiple resources, it will block most of the resources and delays the next arriving jobs. This will affect the resource usage ratio and most of resources will be underutilized.

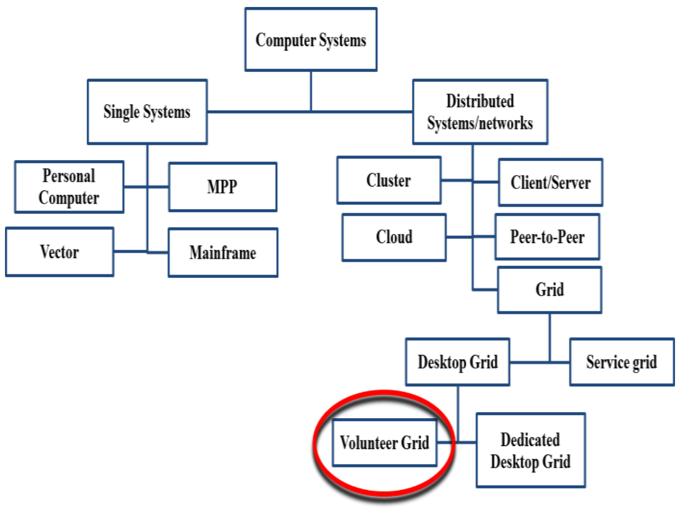

Figure 1. Classification of distributed networks.

The solution to such a scheduling problem is back-filling [20], which takes out the job from running queue and submits it to the waiting queue. Back-filling can be used if a large job is assigned to multiple resources and it is blocking resources or delaying the smaller jobs arriving later; which have the potential to make maximum use of unassigned resources.

While studying the multiple constraints of a resource, it is possible to have one over-loaded resource whereas the remaining available resources are starving for jobs even though back-filling mechanism is employed in job scheduling. The reason of blocking here is the nature of traditional scheduling algorithms and policies that most of them are not considering multiple constraints of resource and only focus on single constraint like required CPU cycles, time of availability among others. Given FCFS algorithm as an illustration, it only selects jobs based on arrival times and not considering multiple resource constraints. If multiple resource constraints are considered before a job assignment, it is possible to find a better match of job and resource which in turn will affect the overall performance.

In dynamic environments like volunteer grid computing, the resources are not permanently available and jobs can arrive at any time which makes the system very complex [5]. On that account, the resource users and providers can come to an agreement on the services offered and makes use of Service Level Agreements (SLAs) which further support Quality of Service (QoS). SLAs basically emphasize on utilization agreements made between users and providers considering user requirements and provider constraints imposed [18, 19]. QoS of any resource can present multiple schemas depending on factors like availability time, response time, failure probability etc. In our work QoS schema has been limited to the time, so the QoS will be based on the time a resource is available. Provided QoS are handled by infrastructure manager which is responsible for mapping the SLAs settled between user and provider. This mapping is also known as scheduling, which is difficult to be efficient because of dynamic behavior of resources.

If a job submitted to a system like volunteer grid, requests for a matching resource by providing multiple resource requirements required to complete submitted job, the resources can be more efficiently used. Thus, the resources requested are selected based on multiple resource constraints can improve resource utilization and job completion efficiently. This gives a research motivation to implement multi-constraint resource scheduling in volunteer grid where resources are heterogeneous and unpredictable.

This paper proposed a QoS based multi-constraint bin packing job scheduling heuristic in volunteer grid environment; with the ability to assign a resource which matches multiple constraints required to be fulfilled for a job completion. The work presented here is an extension to. A sub-queue mechanism is implemented within a resource to reorder the jobs in order to improve the scheduling.

The outline of this paper is as follows. The overview of related literature is explained in section 3, which is followed by section 4discussing bin-packing problem. The proposed heuristic is discussed in section 5. The simulation results and comparisons are presented in section 6 and scope of work is concluded in section 7.

2. Materials and Methods

The related work referred is collected through restrictive search criteria. The literature review covers the job scheduling algorithms have been used in distributed computing. The literature also discusses the Bin Packing problem and its applications for job scheduling in different distributed computing environments. The proposed work considers only the resource availability time, therefore only QoS schema has been defined on the basis of time a resource is available.

3. Related Literature

The related work referred is collected through restrictive search criteria. The literature review covers the QoS based scheduling and multi-constraint scheduling been used in distributed computing specifically grid computing environment. The literature also discusses the ‘Bin Packing problem’ and its applications for heterogeneous resource scheduling.

This section includes literature referred for resource selection of resource, rescheduling jobs and QoS based scheduling. A brief review of literature on single and multi-constraint scheduling along with the bin-packing policies is also presented. Job scheduling in grid computing has been extensively researched in past. Nevertheless, the past research mainly focused on single resource constraint scheduling.

There are many actively researched approaches for selection of resources and scheduling jobs. An agent based resource selection mechanism presented in [9], mainly consider the resource requester benefits. It has a two phase process, discovery and negotiation. In discovery phase the static resource requirements are separated and in negotiation phase, the resource requester directly communicates and negotiates about the remaining resources to select suitable one for jobs waiting for execution. Resources can also be selected by using heuristics in dynamic environments. In [25], grid resource selection heuristics are proposed that are deterministic and probabilistic in nature. The authors reported to reduce the turnaround time of jobs [25].

Scheduling jobs in advance and rescheduling are also methods to reduce the job waiting time and increasing the system optimization. Few of the scheduling heuristics and models are discussed briefly in [27]. An advance scheduling technique is proposed in [24], which reserve the resources for jobs based on the network. It presented a technique to use idle resource cycles using red-black trees which considers network as first level of resource. Rescheduling the jobs can make use of deadlines of jobs so that the jobs complete in time. The authors in [1], claimed to improve the resource utilization and meeting job deadlines if jobs are required to reschedule the deadline based approach is used.

Providing QoS in grid environments is an open issue. Scheduling jobs is one way to contribute towards QoS of grid. There are many QoS based scheduling algorithms proposed like [4, 6, 10]. A QoS guided min-min heuristic [6], considering network bandwidth as QoS parameter reported a reduced makespan if the tasks are divided in two high and low QoS tasks. Then tasks are mapped to the respective resources provisioning the same level of QoS. There might be multiple QoS requested by tasks. A scheduling strategy with multi-QoS constraints in presented in [4]. Three matrices are defined for task requirements, resource capabilities and QoS level requested. This matrices scheduling helped to define QoS constraints to meet user requirements from different perspective and improve the resource utilization too.

The work reported in [7], introduce a multi-constraint preemptive scheduling algorithm which optimizes multiple metrics like turnaround time and slowdown time. The algorithm is based on theoretical analysis of job trigger conditions. The algorithm is proposed for parallel jobs.

Branch and bound approach was used in a shared memory system [17], to select jobs which fits in the available memory and later will allocate jobs to those CPUs. It also considers the load of the system. The aim was to utilize minimum resources to complete a job, whereas later the findings proved that if more resources are utilized the performance is better.

Job scheduling algorithms have also used bin-packing policies. An algorithm proposed Multi-Capacity Bin Packing (MCBP) by [12] is used in [22] to schedule jobs for single homogeneous cluster. In [22], the resource load is shared among virtual machines and heuristics that have been proposed to optimize the scheduling metrics. First Fit Decreasing (FFD), is an extension of FF, and claimed better execution times if incorporated in job scheduling [16]. FFD is a bin-centric method; pack the items that maximize the product of remaining all capacities.

4. Bin Packing Problem

In bin packing problem the consideration is to pack all the items using minimum bins and also the maximum value set like total weight, volume etc. should not exceed [2, 11]. Before the details on the proposed heuristic supported by bin-packing are given; the concept of bin-packing problem need to be highlighted, along with the job scheduling perspective.

Suppose that there is n number of bins, B_n representing n number of available resources R in volunteer grid.

$$B=\{B_1, B_2, \ldots, B_n\} \quad R=\{R_1, R_2, \ldots, R_n\} \tag{1}$$

Each of the bin is also having a volume, V associated to it that is allowed to be filled.

$$V=\{V_1, V_2, \ldots, V_n\} \tag{2}$$

Where 'V' represents volume of each bin available and from job scheduling perspective it represents the CPU cycles available at each resource. The n jobs submitted to volunteer grid are represented by J

$$J= \{J_1, J_2, .., J_n\} \tag{3}$$

A job J_i can only be packed to bin B_i, if and only if, its volume V_i is greater than or equal to the sum of J_i and already packed jobs in B_i.

$$B_i + J_i \leq V_i \tag{4}$$

In the interpretation of job scheduling, the job J_i can only be submitted to resource R_i, if and only if, R_i can complete the job J_i and already submitted jobs to R_i. The total of all the jobs submitted to resource R_i must be equal or less than the total CPU time available V_i at that resource.

$$R_i + J_i \leq V_i \tag{5}$$

There are a few practiced algorithms like [3, 8] Next Fit (NF), First Fit (FF) and Best Fit (BF) to solve the bin packing problem; have already been incorporated in job scheduling. In NF, a job will be submitted to current resource available if it fits and if the resource not available, NF will try to submit the job to next resource. In FF, all the jobs are arranged in increasing order of required CPU time and assign each job to the resource job fits first. Whereas in BF, will be selected the best of all the available resources where a submitted job fits best.

5. Proposed Job Scheduling Heuristic

The proposed approach assumes the trust level and time of resource availability is already known and will classify the resources in five Virtual Organizations (VOs) namely A-E represented in Table 1based on the trust level.

VO are comprised of small networks in same physical location or large group of resources installed in different networks distributed around the world. Mainly there are multiple VOs in a volunteer grid computing environment.

In the proposed approach there are two levels of scheduling jobs to a resource:

1. Jobs will firstly be classified on the basis of QoS.
2. Jobs classified in groups will then be scheduled incorporating Bin-Packing multi-constraint scheduling.

Table 1. QoS classification.

VOs Name	QoS level	Available time	
		From	To
A	Best	$T1_{ON}$	$T1_{OFF}$
B	Good	$T2_{ON}$	$T2_{OFF}$
C	Average	$T3_{ON}$	$T3_{OFF}$
D	Below Average	$T4_{ON}$	$T4_{OFF}$
E	Poor	$T5_{ON}$	$T5_{OFF}$

The resources which are most trusted are grouped in VO A 'Best' and the resources which are least trusted or new are grouped in VO E 'Poor'. Each of the VOs specify the availability time of their respective resources, as an example VO A resources are available from time $T1_{ON}$ to time $T1_{OFF}$.

5.1. QoS based Classification

The jobs requesting for resources have two main parameters i.e., arrival time 't_a' and CPU time 't_{CPU}'. The job data set is generated randomly using Monte Carlo simulation to test the proposed approach before simulating with the real job traces. Here, the job requirements are considered as user requirements in SLA.

The submitted jobs to the volunteer grid will be pre-processed by arranging them in an increasing order of their arrival time 't_a'. Then, arrival time 't_a' of each job will be compared with resource availability times and group all the jobs accordingly. There is a possibility that availability time of more than one VO will match with the job arrival time. In that case, the job will be assigned to the VO of resources with fewer jobs. Figure 2 explains the flow of job assignment in details.

The difference of arrival time 't_a' and CPU time 't_{cpu}' for each job i.e., diff (t_a,t_{cpu}) will be calculated. The jobs are then rearranged in increasing order of diff (t_a,t_{cpu}). The proposed approach also supports rescheduling. There are two possibilities of rescheduling a job:

1. Most of the jobs are falling under one VO.
2. A new job arrived and all matching VO resources are allocated already

If most of the jobs are allocated to any one VO, the resources in that VO are possibly being utilized to maximum. However, to optimize the resource usage such that the rest of resources from other VOs are not underutilized and are starving for jobs. In this scenario few of the jobs satisfying the arrival time 'ta' condition that job arrival time is matched with the other VO will be rescheduled but not compromising the QoS of job.

5.2. Bin Packing Multi-Constraint Scheduling Heuristic within a VO

In bin-packing problem, it is supposed that all items to be packed in bins should arrive before selection of bins and packing of items start. In proposed heuristic resources within a VO are representing bins and jobs as items. There is a supposition that all jobs must arrive before assigning jobs to resources. In bin-packing, the goal is to use minimum number of bins, where as in proposed heuristic it is aimed to use less number of cycles for assigning jobs to matching resources.

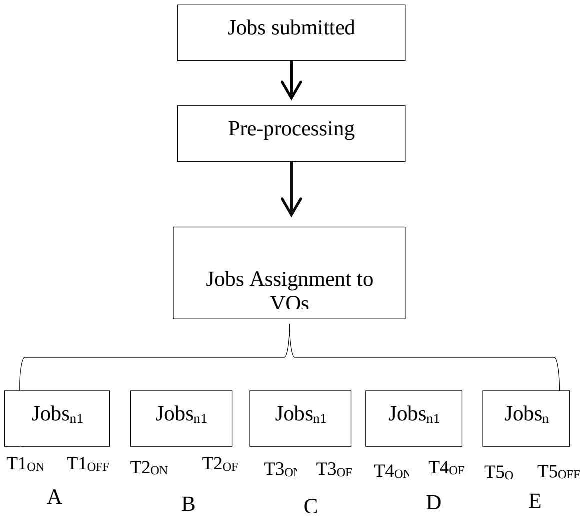

Figure 2. Job assignment to VOs.

In the basic bin-packing policy i.e., FF, NF or BF, the resource constraints are not considered like available CPU time, resource availability time etc. Therefore, giving attention to job requirements and ignoring resource constraints will lead to single criteria of scheduling job. Hence, in proposed heuristic not only the job requirements but also the resource constraints are studied before scheduling a job which leads to multi-constraint job scheduling and optimizing resource utilization in volunteer grid environment.

If a resource R_i has least available volume/available CPU time that can be utilized, search a job J_i which fits in R_i. This will reduce the scheduling cycles and will allow the next job assignment to other resource and will help skip R_i for any resource selection until the current batch of jobs finished. All the resources can have different volumes/available CPU time. Resources will firstly arrange in decreasing order of their available CPU time V. Suppose there are six (06) volunteer resources and their respective CPU time

$$R=\{R_1,R_2, R_3, R_4, R_5, R_6\}$$
$$V=\{V_1,V_2, V_3, V_4, V_5, V_6\}. \quad (6)$$

The set of resources R is arranged in decreasing order of V.

$V_1<V_2<V_3<V_4<V_5<V_6$ such that $R_1<R_2<R_3<R_4<R_5<R_6$

There are five (5) jobs submitted to volunteer grid that can be assigned to matching resources from set R.

$$J=\{J_1, J_2, J_3, J_4, J_5\} \quad (7)$$

The jobs are arranged in increasing order of their required CPU time and the arrival time. Suppose

$$J_1>J_2>J_3>J_4>J_5 \quad (8)$$

A job J_i will be assigned to the resource that can allocate the required CPU time such that the total of all the jobs submitted to resource 'R_i'must be equal or less than the total CPU time available 'V_i'at that resource.

$$R_i + J_i \leq V_i \quad (9)$$

If there are multiple resources satisfying this condition, job J_i will be submitted to the resource with less remaining CPU time available. This will reduce scheduling time and number of cycles for scheduling which in turn will decrease the overhead and slowdown time. There is a possibility that multiple jobs are assigned to one resource.

In the second stage of proposed heuristic, the jobs within a resource will be organized in increasing order of the CPU time required by each job assigned to resource R_i to process the smallest job first but keeping in view which job starting time. Let's suppose J_1, J_2 and J_3 are assigned to R_1 where:

$J_1 > J_3 > J_2$ according to CPU time required and $J_2 > J_1 > J_3$ according to start time. The jobs in R_1 will then be processed starting with J_2 followed by $J1$ and J_3 at end.

6. Results and Discussion

The proposed job scheduling heuristic has been simulated in volunteer grid environment to evaluate the performance by comparing with the baseline job scheduling heuristics in practice including First Come First Serve (FCFS) Shortest Process Next (SPN), Longest Job First (LJF), Round Robin (RR) [7, 15, 25].

For the experimental setup, the volunteer grid infrastructure of High Performance Computing Center (HPCC) at University Technology PETRONAS, Malaysia has been used. The resources in aforementioned volunteer grid are heterogeneous and their availability time is also varying. Only ten (10) resources are selected to limit the test run for performance evaluation in a real volunteer grid environment.

Apart from the resource setup, the job dataset is also required to test run and evaluate the performance of proposed heuristic. The job dataset consisting of 500 has been generated using the Monte Carlo method that is synthesized the jobs based on the CPU time required, start time and deadline of job. Whereas, the arrival time of 500 jobs is supposed to be same. Before going into simulation details of proposed heuristic in volunteer grid environment, following job scheduling performance metrics need to be revised:

- Average waiting time: the average waiting time of a job before its execution.
- Average turnaround time: the average time between a job submission and completion time.
- Average slowdown time: the average ratio of response time to run time of a job.
- Jobs failure rate: the amount of jobs not completed within the deadline.

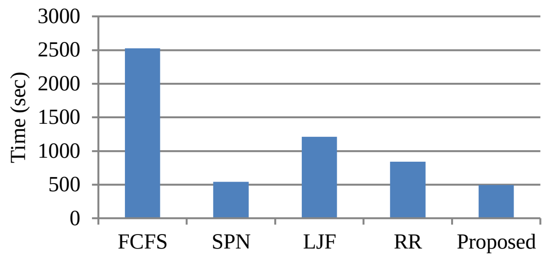

Figure 3. Average waiting time.

The proposed QoS multi-constraint Bin Packing job scheduling heuristic performs better than the baseline scheduling algorithms in all the performance metrics selected. The average waiting time of baseline scheduling algorithms and proposed heuristic is presented in Figure 3. The average waiting time of proposed and SPN is very close whereas it is comparable to the other three baseline algorithms.

Figure 4 presents the average turnaround time of proposed heuristic. It has been observed that average turnaround time of proposed heuristic is less than the other algorithms in comparison. It can be an effect of less waiting time for stating a job execution. The jobs are arranged within a resource also. The jobs are assigned to the resource with least CPU time available which minimized the resource selection time.

The response to job is quick using proposed heuristic which minimized the delay in starting job execution. This further minimized the average slowdown time of proposed heuristic because the job are getting response faster and average waiting time is reduced (Figure 5). The slowdown time of RR is comparable to proposed heuristic as the waiting time and turnaround time of RR is also less. The longer jobs are executed using LJF which results in increased average slowdown time.

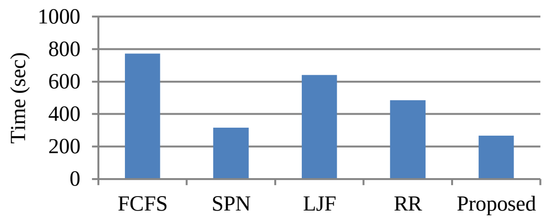

Figure 4. Average turnaround time.

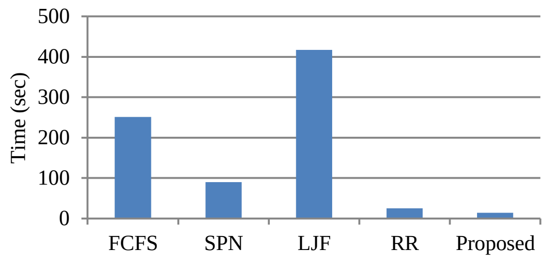

Figure 5. Average slowdown time.

In the job dataset, deadline of job is also included to check whether jobs are completing within the deadline specified and not lagging. The comparison of proposed heuristic and baseline scheduling algorithms verified that the proposed heuristic completes maximum number of jobs within the deadline Figure 6. The less number of jobs are delayed using proposed heuristic whereas the more jobs are delayed is scheduling jobs using LJF. The delaying jobs or not completing jobs within the deadline can occur because of the unpredictable resources in volunteer grid environment and not having enough free resources to complete the jobs.

The number of jobs delayed or failed when scheduled using proposed and baseline scheduling algorithms. The difference of failed jobs is comparatively less when smaller numbers of jobs are considered in simulation. This performance of proposed scheduling algorithm can be observed more clearly with more number of jobs submitted to volunteer grid. Table 2 illustrates the comparison briefly.

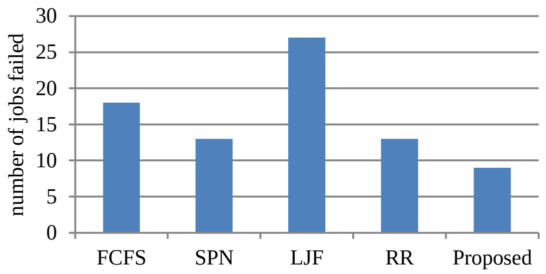

Figure 6. Job failure rate.

Table 2. Jobs failed.

Scheduling Algorithm	No. of Jobs Failed when	
	500 Jobs Submitted	5000 Jobs Submitted
FCFS	18	241
SPN	12	197
LJF	22	272
RR	13	208
Proposed	8	94

7. Conclusions

The paper proposed a multi-constraint job scheduling heuristic for volunteer grid resources, which are unpredictable and distributed in nature. The traditional scheduling algorithms are based on single constraint to select a job for scheduling. The scheduling algorithm if consider multi-constraints can improve the job scheduling.

The optimized solution of resource utilization is also possible by implementing multi-constraint job scheduling heuristic. The proposed heuristic attempts to use the maximum of available resources in volunteer grid environment. The re-ordering of jobs in a resource emphasized more on reducing the average waiting and turnaround time of jobs.

By extensive simulation on volunteer resources using synthetic job dataset, authors have verified that multi-constraint scheduling address the improvement in scheduling performance metrics. The proposed heuristic is also proved to complete a maximum of jobs assigned in comparison to the baseline scheduling algorithms. The proposed work will be incorporated to test the real workload job datasets in a real volunteer grid environment comprising of large number of resources.

Acknowledgement

Authors appreciatively acknowledge the High Performance Computing Center (HPCC) at Universiti Teknologi PETRONAS (UTP), Malaysia for providing the volunteer grid computing environment. The authors also thank ERGS grant (0153AB-I27) for partially funding the publication work.

References

[1] Chen W., Fekete K., and Lee Y., "Exploiting Deadline Flexibility in Grid Workflow Rescheduling," *in Proceedings of 11th IEEE/ACM International Conference on Grid Computing*, Brussels, pp. 105-112, 2010.

[2] Coffman J., Garey M., and Johnson D., "Dynamic Bin Packing," *SIAM Journal on Computing*, vol. 12, no. 2, pp. 227-258, 1983.

[3] Coffman J., Garey M., and Johnson D., "Approximation Algorithms for Bin Packing: A Survey," *Approximation Algorithms for NP-Hard Problems*, pp. 46-93, 1996.

[4] Ding D., Luo S., and Gao Z., "A Matrix Scheduling Strategy With Multi-Qos Constraints In Computational Grid," *in Proceedings of International Conference on Grid and Pervasive Computing*, Berlin, pp. 59-68, 2010.

[5] Guitart J., Macías M., Rana O., Wieder P., Yahyapour R., and Ziegler W., "SLA-Based Resource Management and Allocation," *Market-Oriented Grid and Utility Computing*, vol. 75, pp. 261-284, 2009.

[6] He X., Sun X., and Von Laszewski G., "Qos Guided Min-Min Heuristic for Grid Task Scheduling," *Journal of Computer Science and Technology*, vol. 18, no. 4, pp. 442-451, 2003.

[7] Hongbing L., Linping W., and Wei W., "A Multi-Constraint Preemption Algorithm for Parallel Job Scheduling," *in Proceedings of 12th International Conference on Parallel and Distributed Computing, Applications and Technologies*, Gwangju, pp. 73-78, 2011.

[8] Ioannidou M. and Karatza H., "Multi-Site Scheduling with Multiple Job Reservations and Forecasting Methods," *in Proceedings of International Symposium on Parallel and*

Distributed Processing And Applications, Berlin, pp. 894-903, 2006.

[9] Kakarontzas G. and Savvas I., "Agent-Based Resource Discovery and Selection for Dynamic Grids," *in Proceedings of 15th IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises*, Manchester, pp. 195-200, 2006.

[10] Khanli L. and Analoui M., "Grid_JQA: A QoS Guided Scheduling Algorithm for Grid Computing," *in Proceedings of 6th International Symposium on Parallel and Distributed Computing*, Hagenberg, pp. 34-34, 2007.

[11] Leinberger W., Karypis G., and Kumar V., "Job Scheduling in The Presence of Multiple Resource Requirements," *in Proceedings of the ACM/IEEE Conference on Supercomputing*, Portland, pp. 47, 1999.

[12] Leinberger W., Karypis G., and Kumar V., "Multi-Capacity Bin Packing Algorithms with Applications to Job Scheduling Under Multiple Constraints," *in Proceedings of the International Conference on Parallel Processing*, Aizu-Wakamatsu City, pp. 404-412, 1999.

[13] Li H. and Buyya R., "Model-Driven Simulation Of Grid Scheduling Strategies," *in Proceedings of 3rd IEEE International Conference on e-Science and Grid Computing*, Bangalore, pp. 287-294, 2007.

[14] Milenkovič M., *Operating Systems: Concepts and Design*, McGraw-Hill, 1987.

[15] Nouman M. and Shamsi J., "Volunteer Computing: Requirements, Challenges, and Solutions," *Journal of Network and Computer Applications*, vol. 39, pp. 369-380, 2014.

[16] Panigrahy R., Talwar K., Uyeda L., and Wieder U., "Heuristics for Vector Bin Packing," *in Proceedings of Research. Microsoft*, 2011.

[17] Parsons E. and Sevcik K., "Coordinated Allocation of Memory and Processors in Multiprocessors," *in Proceedings of ACM SIGMETRICS Performance Evaluation Review*, Philadelphia, pp. 57-67, 1996.

[18] Rubab S., Hassan M., Mahmood A., and Shah N., "Bin Packing Multi-Constraints Job Scheduling Heuristic for Heterogeneous Volunteer Grid Resources," *in Proceedings of 4th International Conference on Computer Science and Computational Mathematics*, Langkawi, pp. 644-649, 2015.

[19] Rubab S., Hassan M., Mahmood A., and Shah N., "Job Scheduling Approach Based on Quality of Service Classification in Volunteer Grid Environment," *in Proceedings of 4th International Conference on Computer Science and Computational Mathematics*, pp. 520-524, 2015.

[20] Srinivasan S., Kettimuthu R., Subramani V., and Sadayappan P., "Selective Reservation Strategies For Backfill Job Scheduling," *in Proceedings of Workshop on Job Scheduling Strategies for Parallel Processing*, Berlin, pp. 55-71, 2002.

[21] Stallings W., *Operating Systems*, Prentice Hall, 1995.

[22] Stillwell M., Schanzenbach D., Vivien F., and Casanova H., "Resource Allocation Algorithms for Virtualized Service Hosting Platforms," *Journal of Parallel and Distributed Computing*, vol. 70, no. 9, pp. 962-974, 2010.

[23] Tawfeek M., El-Sisi A., Keshk A., and Torkey F., "Cloud Task Scheduling Based on Ant Colony Optimization," *The International Arab Journal of Information Technology*, vol. 12, no. 2, pp. 129-137, 2015.

[24] Tomás L., Caminero A., Caminero B., and Carrión C., "Using Network Information to Perform Meta-Scheduling in Advance in Grids," *in Proceedings of European Conference on Parallel Processing*, Berlin, pp. 431-443, 2010.

[25] Wang C., Chen H., Hsu C., and Lee J., "Dynamic Resource Selection Heuristics for A Non-Reserved Bidding-Based Grid Environment," *Future Generation Computer Systems*, vol. 26, no. 2, pp. 183-197, 2010.

[26] Watanabe K., Fukushi M., and Kameyama M., "Adaptive Group-Based Job Scheduling for High Performance and Reliable Volunteer Computing," *Journal of Information Processing*, vol. 19, pp. 39-51, 2011.

[27] Xhafa F. and Abraham A., "Computational Models and Heuristic Methods for Grid Scheduling Problems," *Future Generation Computer Systems*, vol. 26, no. 4, pp. 608-621, 2010.

Saddaf Rubab is a Ph.D. student at Universiti Teknologi PETRONAS, Malaysia. In the context of her PhD studies, she is working on high-performance, reliable and fault tolerant grid systems. Apart from this, her research interests concern resource management issues in distributed computing infrastructure.

Mohd Fadzil Hassan obtained his PhD in Informatics in 2007 from the University of Edinburgh, UK. He is currently the Dean, Centre for Graduate Studies, Universiti Teknologi PETRONAS (UTP), Malaysia. His research interests are in the area of Artificial Intelligence, Multi-Agent Systems and Service Oriented Architecture (SOA).

Ahmad Mahmood earned his PhD in Information Systems in 2005 from the University of Salford, UK. He is currently the Dean of Faculty of Science and IT. With his research team, a number of journal articles and conference papers have been published.

Nasir Mehmood earned his PhD in Information Technology in 2012 from Universiti Teknologi PETRONAS, Malaysia. He is serving as Head Department of Computer Science and Associate Professor at Dr. A. Q. Khan Institute of Computer Sciences and Information Technology (KICSIT), Kahuta, Pakistan.