A Survey of Workflow Scheduling Algorithms and Research Issues

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ABSTRACT
Cloud Computing refers to a paradigm whereby services are offered via internet using pay as you go model. Services are deployed in data centers and the pool of data centers is collectively referred to as "Cloud". Data centers make use of scheduling techniques to optimally allocate resources to various jobs. Different scenarios require different scheduling algorithms. The selection of a particular scheduling algorithm depends upon various factors like the parameter to be optimized (cost or time), quality of service to be provided and information available regarding various aspects of job. Workflow applications are the applications which require various sub-tasks to be executed in a particular fashion in order to complete the whole task. These tasks have parent child relationship. The parent task needs to be executed before its child task. Workflow scheduling algorithms are supposed to preserve dependency constraints implied by their nature and structure. Resources are allocated to various sub-tasks of the original task by keeping into account these constraints. In this paper, various workflow scheduling algorithms have been surveyed. Some algorithms have been found to optimize cost, some have been found to optimize time, some focuses on reliability, some focuses on availability, some focuses on energy efficiency, some focuses on load balancing or some focuses on a combination of these parameters. A lot of work has already been done in the area of workflow scheduling but still, we feel that there is a need and lot of scope in applying other optimization techniques, like intelligent water drops, to schedule workflow applications.

Keywords
Cloud computing, workflow applications, workflow scheduling algorithms, intelligent water drops based algorithm.

1. INTRODUCTION
Cloud Computing enables the procurement of large amount of computational resources on demand by employing pay-per-use model. It delivers computational resources with the help virtualization technology. It shows new way to store data and run applications. Instead of storing data and running application on an individual desktop computer, everything is hosted on the Cloud. It allows us to access all the documents and run applications from anywhere in the world via the Internet.

In a Cloud, there are four main entities viz. Cloud User, Broker, Virtual Machines and Physical Machines [1]. The cloud users are the actual consumers of services and can submit their service requests from anywhere in the world. A cloud data center consists of physical machines. Using virtualization technology, virtual machines are created on the top of physical machines. Broker acts as an intermediator between cloud users and cloud datacenters. It is responsible for allocating cloud resources to user's workflow applications. It assigns virtual machines to user's workflow applications by making use a scheduling algorithm and SLA (Service Level Agreements) which is a written and agreed document between service provider and cloud user. Figure 1 represents the role of a cloud broker in a cloud environment.

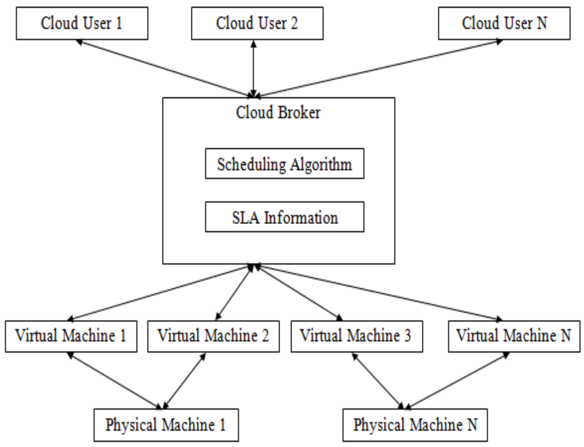

Fig. 1 Role of Broker in Cloud Scheduling

The scheduling algorithms provide benefit to both, the cloud user as well as the service provider. At one hand, scheduling algorithms can be designed in such a way that they satisfies the QoS (Quality of Service) constraints imposed by cloud users and on the other hand, they can be designed to perform load balancing among virtual machines which results into improvement of resource utilization at service provider's end.

The rest of the paper is structured as follow: The workflow scheduling is presented in section 2. The survey of important workflow scheduling algorithms is presented in section 3. Research issues in the area of workflow scheduling are presented in section 4 and section 5 concludes the work carried out.

2. WORKFLOW SCHEDULING

In workflow scheduling, different sub tasks of a bigger task are allocated resources in such a way that some pre-defined objective criteria is met. There are various problems in bioinformatics, astronomy and business enterprise [2] in which a set of sub tasks is executed in a particular sequence in order to carry out a bigger task. In general, a workflow application requires series of steps to be executed in a particular fashion. These steps have parent child relationship. The parent task should be executed before its child task. The parent task is linked to child task according to set of rules [3].

A workflow application is generally represented as a Directed Acyclic Graph (DAG) such as G (V, E) where V is the number of tasks and E is the information regarding data dependencies among tasks. A task which does not have any parent task is called entry task and a task which does not have any child task is called an exit task.

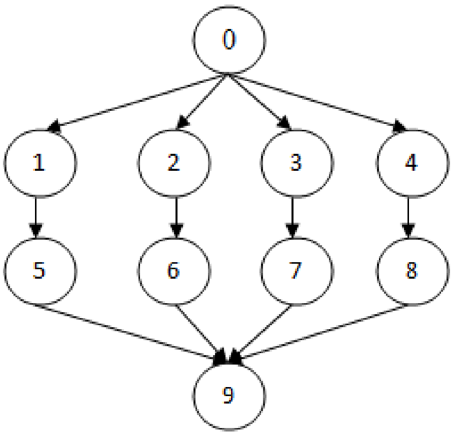

Fig. 2 A Workflow represented in the form of a graph

Figure 2 shows the dependencies among different tasks in a workflow graph G. The parent task 0 is executed before child tasks 1, 2, 3 and 4.The output of parent node acts as an input to child node. The task 0 acts as entry node and task 9 act as an exit node. Task 9 is execute after the completion of tasks 5, 6, 7and 8.

In workflow scheduling, the different tasks are allocated resources (e.g. virtual machines). The workflow scheduling decisions are taken by cloud broker, which works as an intermediator between the cloud user's workflow application and cloud provider's datacenters, as shown in Fig. 1. The scheduling algorithms are used by broker to find optimal map of workflow tasks and cloud resources (virtual machines). The role of workflow scheduling algorithm is to find the schedule which satisfies user's objectives. Users define their objectives in SLA (Service Level Agreement) document which is written between a cloud user and a cloud service provider. The user may require multiple objectives to be satisfied such as cost optimization, makespan optimization, reliability, deadline constrained, budget constrained etc. and it is the role of scheduling algorithm to find the optimal schedule which satisfies user's objectives.

3. SURVEY OF WORKFLOW SCHEDULING ALGORITHMS

Numbers of authors have done work in the area of workflow scheduling algorithms. Table 1 represents the description of work done in terms of type of scheduling algorithm, nature of scheduling algorithm, objective criteria i.e. the parameters which have been focused for optimization and the environment in which the scheduling algorithms were applied. The workflow scheduling algorithms can be heuristic or meta-heuristic in nature [4]. The heuristic algorithms are priority based and mainly problem centric. The developer can use his own experience to assign priority to workflow applications and cloud resources. Meta-heuristic scheduling algorithms are the ones which do not need human interaction and provide general solution to workflow applications. These algorithms are applicable to wider range of workflow applications but the heuristic scheduling algorithms are fit for only specific applications [4].

Authors and Year	**Nature of Scheduling Algorithm**	**Type of Algorithm**	**Objective Criteria**	**Description**	**Environment**
Rizos Sakellariou and Henan Zhao in 2004 [5]	Hybrid	Heuristic	Makespan	A novel heuristic algorithm for DAG scheduling on heterogeneous machines, which break whole problem to independent sub problems. It performs better than DLS (Dynamic List Scheduling), HEFT (Heterogeneous Earliest Finish Time), CPOP (Critical Path On a Processor), FCP (Fastest Critical Path) and LMT (Levelized-Min Time).	Grid
A. Mandal, K. Kennedy, C. Koelbel, G.Marin, J. Crummy in 2005 [6]	List Scheduling	Heuristics	Makespan, Load Balance	The heuristic based strategy is used to schedule EMAN, a bio-imaging workflow application. It results into 1.5 to 2.2 time better optimization of makespan and load balance.	Grid
Markek Wieczorek, Radu	Genetic,	Heuristic (HEFT,	Makespan	In this paper the HEFT, Genetic and Myopic algorithms were compared	Grid

Prodan and Thomas Fahringer in 2005 [7]	HEFT, Myopic	Myopic), Meta-Heuristic (Genetic)	Optimization	using balanced and unbalanced workflows on the basis of execution time. HEFT performs better as compared with Myopic and Genetic.	
Jia Yu and Raj Kumar Buyya in 2006 [8]	Genetic	Meta-Heuristic	Budget Constrained	Budget constrained genetic algorithm is used to find the schedule that minimizes the execution time while meeting a specified user budget.	Grid
Jia Yu and Raj Kumar Buyya in 2006 [9]	Genetic	Meta-Heuristic	Deadline and Budget Constrained	Genetic algorithm was used to find the schedule for workflow application that meet the user defined budget and deadline.	Grid
M. Rahman, S. Venugopal and R. Buyya in 2007 [10]	DCP (Dynamic Critical Path)	Heuristic	Resource Availability	DCP assign priority to a task in the critical path. The priority based DCP results better in performance as compared with meta heuristic algorithms where resource availability changes frequently.	Grid
Wei Neng Chen, Jun Zhang and Yang Yu in 2007 [11]	Ant Colony Optimization	Meta-Heuristic	Deadline Constrained, Cost Minimization	ACO was used to schedule workflow application. It finds the schedule that satisfies user defined deadline and minimize the cost of execution of workflow application.	Grid
Bogdan Simion, Catalin Leordeanu, Florin Pop and Valentin Cristea in 2007 [12]	Hybrid	Heuristic	Makespan and Load Balance	Improved Critical Path using Descendant Prediction (ICPDP) algorithm has quadratic polynomial time complexity. It finds the schedule that results in makespan minimization and improve the utilization of resources.	Grid
Fli Tao, Dongming Zhao, Yefa Hu and Zude Zhou in 2008 [13]	Particle Swarm Optimization	Meta-Heuristic	Makespan, Cost and Reliability	Multi-objective MGrid resource service composition and optimal-selection (MO-MRSCOS) problem is solved by PSO. It minimizes execution time, cost, and maximize the reliability.	Grid
A.K.M Khaled Ahsan Talukder, Michael Kirley and Raj Kumar Buyya in 2009 [14]	Genetic	Meta-Heuristic	Makespan and Cost Optimization	Multi-Objective Differential Evolution (MODE) that optimize both cost and makespan for workflow application. The results of MODE show better performance than PAES (Pareto-archived Evolutionary Strategy).	Grid
Wei Neng Chen and Jun Zhang in 2009 [15]	Ant Colony Optimization	Meta-Heuristic	Deadline, Budget, Makespan, Cost and Reliability	ACO finds the schedule that meets all user imposed QoS constraints. It calculates the pheromone values based on heuristics and experiments are done on ten workflow applications.	Grid
Qian Tao, Hui You Chang, Yang Yi and Chunqin Gu in 2009 [16]	Particle Swarm Optimization	Meta-Heuristic	Makespan, Cost and Load Balance	Rotary Hybrid Discrete Particle Swarm Optimization (RHDPSO) algorithm that optimize the makespan, cost and perform load balancing when scheduling workflow application. The simulation results show that the RHDPSO algorithm has fast convergence, high precision and strong robustness as compared with DPSO.	Grid

Yanli Hu, Lining Xing, Weiming Zhang, Weidong Xiao and Daquan Tang in 2010 [17]	Ant Colony Optimization	Meta-Heuristic	Deadline and Budget Constrained	Knowledge based ant colony optimization algorithm which find the schedule that minimizes execution cost while meeting the user deadlines..	Grid
Suraj Panday, Linlin Wu, Siddeshwara Mayura Guru and Raj Kumar Buyya in 2010 [18]	Particle Swarm Optimization	Meta-Heuristic	Cost Optimization	PSO algorithm that allocates Cloud resources to workflow application. It consider both computation cost and data transmission cost when finding schedule. PSO achieves 3 times cost saving as compared with BRS (Best Resource Selection).	Cloud
Zhangjum Wu, Zhiwei Ni, Lichuan Gu and Xiao Liu in 2010 [19]	Particle Swarm Optimization	Meta-Heuristic	Makespan and Cost Optimization	Revised Discrete Particle Swarm Optimization (RDPSO) algorithm minimize the makespan and cost as compared with standard PSO and BRS.	Cloud
Yong Wang, R. M. Bahati and M. A. Bauer in 2011 [20]	Novel DBC (Deadline and Budget Constrained)	Heuristic	Deadline and Budget Constrained	Novel DCP is compared with DCP in GridSim simulator. The experiment results show that the workflow completion ratios of Novel DCP are higher than DCP.	Grid
Sawant and Shailesh in 2011 [21]	Genetic	Meta-Heuristic	Load Balance	Genetic algorithm uses historical data and current state of the system to ensure better load balancing and reduce the number of dynamic VM migration.	Cloud
F. Coutinho L. A. V. Decarvalho and R. Santana in 2011 [22]	HGreen	Heuristic	Energy Efficient	H-Green heuristic algorithm schedules the heavier tasks on maximum green resources. The simulation results have shown that the H-Green algorithm reduce the power consumption in global grids	Grid
Xiaofeng Wang, Chee Shin Yeo, Jinshu Su and Raj kumar Buyya in 2011 [23]	Genetic	Meta-Heuristic	Makespan, Reliability	RD (Reliability Driven) reputation is implemented to evaluate the reliability of resource in widely distributed systems. The look ahead genetic algorithm (LAGA) that utilize the RD reputation to optimize both makespan and reliability for workflow application.	Cloud
Eugen Feller, Louis Rilling and Christine Morin in 2011 [24]	Ant Colony Optimization	Meta-Heuristic	Energy Efficient	ACO achieves better server utilization and requires fewer machines for scheduling workflow application as compared with greedy algorithm.	Cloud
Rajarathinam Jeyarani, N. Nagaveni and Vasanth Ram in 2011 [25]	Particle Swarm Optimization	Meta-Heuristic	Energy Efficient	Self-adaptive PSO algorithm is used to optimally placement of VM (Virtual Machine) in Cloud. Simulation results shows that SAPSO outperforms and power aware VM provisioning in large scale, heterogeneous and dynamic Cloud environment as compared with Multi-Strategy Ensemble PSO.	Cloud
Saurabh Kumar Garg, Parmod Kongurthi and Raj Kumar Buyya	Hybrid	Meta-Heuristic	Cost Optimization	Linear programming driven genetic algorithm that minimizes the cost of all users in coordinated manner with negligible time overhead.	Grid

in 2011 [26]					
Jiandun Li, Junjie Peng, Zhou Lei and Wu Zhang in 2011 [27]	Hybrid	Meta-Heuristic	Energy Efficient and Load Balance	Hybrid scheduling approach was used to schedule workflow application in private clouds. Simulation results show that it can save more time for users, conserve more energy and achieve higher level of load balancing	Cloud
H. M Fard, R. Prodan, J. J. D Barrionuevo and T. Fahringer in 2012 [28]	List Scheduling	Heuristic	Makespan, Economic Cost, Energy Consumption, Reliability	The scheduling algorithm is implemented in ASKALON environment for Grid and Cloud Computing. It outperform as compared with bi-criteria heuristic and bi-criteria genetic algorithm.	Grid and Cloud
Timur Keskinturk, Mehmet B. Yildirim and Mehmet Barut in 2012 [29]	Ant Colony Optimization	Meta-Heuristic	Load Balance	ACO minimize average relative percentage of imbalance (ARPI) with sequence dependent setup times in a parallel machine environment. Simulation results show that ACO perform better load balancing than heuristic and genetic algorithm.	Cloud
S. H. Niu, S. K. Ong and A.Y. C Nee in 2012 [30]	Intelligent Water Drops (IWD)	Meta-Heuristic	Makespan Optimization	IWD algorithm was used to solve job shop scheduling problem in Cloud. The IWD employ five schemes to increase the diversity of the solution space as well as the solution quality.	Cloud
Salid Abrishami, Mahmoud Naghibzadeh and Dick H. J. E pema in 2013 [31]	PCP (Partial Critical Path)	Heuristic	Deadline-Constraint, Cost Minimization	PCP algorithm minimizes the execution time while meeting the user defined deadline. Two types of PCP is implemented in Cloud i.e. IC-PCP (IaaS Cloud Partial Critical Path) and IC-PCPD2 (IaaS Cloud Partial Critical Path with Deadline Distribution). The simulation results show that IC-PCP performs better than IC-PCPD2.	Cloud
Zhangjun Wu, Xiao Liu, Zhiwei Ni, Dong Yuan and Yun Yang in 2013 [32]	Genetic, Ant Colony Optimization and particle swarm Optimization	Meta-Heuristic	Makespan, Cost and Resource Utilization	GA, ACO and PSO were implemented to solve the issue of market-oriented hierarchical scheduling strategy in Cloud workflow systems. ACO perform better than other scheduling strategies	Cloud
S. Kaur and S. Singh [33]	PSO and others	Meta-Heuristic and others	Constraint-based	Grouping the jobs according to processing capabilities of available resources results in better throughput, resource utilization and low communication time.	Grid

Table 1: A brief description and comparison among various workflow scheduling algorithms

4. RESEARCH ISSUES OR CHALLENGES IN WORKFLOW SCHEDULING ALGORITHMS

Workflow scheduling in a cloud environment is a challenging task because of the following reasons:

- The resource pool is central which caters to the needs of all the jobs. So it is difficult to predict which resources will be available at the time of actual execution of the jobs.
- It is difficult to apply access control enforcement while the workflow is being executed, if the access rights of jobs change dynamically.
- It is difficult to handle the dynamic workflow applications in which the structure of workflow graph changes with time.
- It is difficult to reduce overhead involved while generating schedules for multiple workflows because there can be many users competing for common resources and decisions must be made in possible shortest time.
- It is difficult to achieve maximum possible utilization of resources while scheduling levelized workflow applications because of dependencies, and different load and resource requirements among different levels.
- The scheduling decisions for workflow applications become complicated when made by multiple distributed schedulers in hybrid Cloud.
- The virtual instances run on physical machines. When physical machine fails due to hardware failure or any other reason, the entire workflow application may need to be restarted. It is difficult to migrate one workflow application running on one virtual machine to another virtual machine.
- It is difficult to achieve multi-objective criteria imposed by certain workflow applications. Different techniques produce different results in such situations and it becomes difficult to select a particular scheduling technique for a generalized class of applications.

All the points mentioned above make workflow scheduling a complex and challenging task. Each of the challenge mentioned above require new techniques, new methodologies and new models or frameworks to effectively address that challenge.

Besides this, six workflow scheduling algorithms viz. List Heuristic, Genetic, Ant Colony Optimization, Particle Swarm Optimization, Hybrid and Intelligent Water Drops scheduling algorithms have also been studied. We felt that there is a need to explore Intelligent Water Drops based scheduling algorithm for workflow applications. The IWD may results into better performance than existing workflow scheduling algorithms. Very less work has been done in exploring intelligent water drops based algorithm for scheduling workflow applications.

Table 2 shows the work which require further attention as well as the work which has already been attempted by different researchers in the area of workflow scheduling. Two signs have been used in Table 2. Following is a brief description of these signs:

- ✓ : Tick sign means that work has already been done in that area and there is a workflow scheduling algorithm for solving that type of problem.

? : Question mark sign means that there is a need to explore workflow scheduling algorithm for that particular domain focusing on different aspects like cost optimization, deadline constrained, budget constrained, reliability, load balance, availability and energy efficient.

For example, tick signs exits under makespan in intelligent water drop algorithm row shows that there is an IWD based algorithm that optimizes makespan for workflow applications. Question mark sign under other columns of IWD row means that there is a need to explore those aspects i.e. cost, deadline and budget constrained, reliability, load balance, availability and energy efficient using IWD to schedule workflow applications.

QoS Constraints → / Scheduling Algorithms ↓	Make span	Cost	Deadline Constrained	Budget Constrained	Reliability	Load Balance	Availability	Energy Efficient
List Heuristic	✓	✓	✓	✓	✓	✓	✓	✓
Genetic	✓	✓	✓	✓	✓	✓	✓	?
Ant Colony Optimization	✓	✓	✓	✓	✓	✓	?	✓
Particle Swarm Optimization	✓	✓	✓	✓	?	✓	?	✓
Hybrid	✓	✓	✓	✓	?	✓	?	✓
Intelligent Water Drop	✓	?	?	?	?	?	?	?

Table 2: Table showing different areas which require further attention and the areas which have already been explored

5. CONCLUSIONS

In this paper, we surveyed various existing workflow scheduling algorithms and tabulated them on the basis of nature of scheduling algorithm, type of algorithm, objective criteria and the environment to which the workflow scheduling algorithm was applied. From the literature reviewed, it is clear that lot of work has already been in the area of workflow scheduling but still there are many areas which require further attention e.g. there is a need to explore energy efficient genetic algorithm for workflow application whereas cost and deadline constraints have already been addressed using genetic algorithms. These areas have been marked in Table 2. We also conclude that there is a need to explore intelligent water drops based algorithm for workflow scheduling applications.

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