Meta-Heuristics Based Approach for Workflow Scheduling in Cloud Computing: A Survey

Poonam, Maitreyee Dutta and Naveen Aggarwal

Abstract The Cloud computing is an emerging distributed systems which follows a "pay-as-you-use" model. It is a new type of shared infrastructure able to offer several resources through the Internet. There is large number of users using the services over the cloud, which generating large volume of data. The scheduling of dependent tasks is a NP-complete problem and has become as one of the most challenging problems in cloud environment. There is a need of specifying a sequence of execution of these tasks to satisfy the user requirements in terms of QoS parameters such as cost, execution time, etc. The workflow scheduling is considered to be difficult, when it becomes a multi-objective optimization problem. In this paper, we presented a comprehensive description of the existing approaches based on meta-heuristics for workflow scheduling. On the basis of the related works, we found the Genetic algorithm as the best method for scheduling. A GA searches the problem space globally and therefore, scholars have investigated combining GAs with other meta-heuristic methods to resolve the local search problem. We feel that there is a scope of using hybrid meta-heuristics approach that combines Artificial Bee Colony algorithm and Genetic Algorithm (ABC-GA) for scheduling workflows in Cloud computing. Cross-over and mutation operators of GA can be embedded into ABC to improve scheduling strategy.

Keywords Cloud computing · Workflow · DAG · Scheduling · QoS parameters

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1 Introduction

Cloud computing is an emerging research area for the past few years and it is the transformation of the computing in which all the services are being commoditized and provided similar to traditional utilities like water, electricity, gas, and telephony. The users are allowed to access the services and resources according to their usage based on some desired quality of service. These resources are distributed and accessed the basis of Pay-as-per-use model [1]. The demand for high performance computing is growing for complex and large-scale applications in science, engineering and commerce. The elasticity feature of cloud computing is suitable for such applications because of large amount of data and computation is involved. Many complex and computation intensive applications can be modeled as workflows. These workflow applications are generally described as the sequence of tasks to be processed in well defined order to accomplish a specific goal [2]. Cloud workflow system can be regarded as a platform service that facilitates the automation of distributed large-scale applications in the cloud computing. Workflows are represented as directed acyclic graphs (DAG), which consists of nodes that are linked according to their flow dependencies: $G = (V, E)$, which G represents the graph, V represents a vertex or a node that is an operation or a task, and E represents the edge that shows the relationship between two nodes [3]. Flow dependency imposed the sequence of execution as a parent node will get executed before its child nodes always. Workflow scheduling is the key problem in cloud computing. A workflow scheduling framework is needed to optimize the performance of the resource provisioning process in a cloud system that can allocate the tasks into the appropriate resources according to certain scheduling strategies. This mapping of the tasks has an impact on the performance of workflow scheduling. The goal should be to attain an optimal trade-off between performance and cost. In general, the performance of the workflow varies depending on the nature of tasks. The users may work towards different goals, such as, the shortest possible execution time, the most inexpensive execution cost, or the optimized throughput. Moreover, some users may need to create a schedule plan that satisfies more than one goal. To achieve high performance by satisfying more than one objective makes the scheduling process difficult and such problem is termed as multi-objective optimization problem [4]. There are various scheduling strategies based on heuristics and meta-heuristics methods.

Given this motivation, we investigate meta-heuristics based workflow scheduling methods capable of being applied to complex domains. This paper gives a survey of various meta-heuristics scheduling methods used in Cloud and Grid. The remainder of the paper is organized as follows. We introduce workflow scheduling algorithms for clouds and grids in Sect. 2 with Table 1 and various scheduling parameters of existing algorithms with Table 2 and Sect. 3 gives the research challenges and finally, we conclude the paper with directions for the future work in Sect. 4.

Table 1 Survey of workflow scheduling algorithms based on hybrid heuristics and meta-heuristics methods

Paper title	Nature of scheduling algorithm	Findings	Environment	Objective parameter
A multiple-objective workflow scheduling framework for cloud data analytics [5]	Artificial bee colony algorithm	In this paper, a meta-heuristics based approach is proposed which is called artificial bee colony (ABC) for scheduling workflows with multiple objectives onto a cloud system	Java environment and Ubuntu 10.04 with Xeon E5500 CPUs	Minimizes makespan and cost
		The proposed method has been compared with HEFT/LOSS and it outperforms in both the single objective optimization with the constraint, and multi-objective optimization problem for structured workflow		
Bees life algorithm for job scheduling in cloud computing [6]	Bee life algorithm	Authors presented a swarm optimization-based bees life algorithm (BLA) has been applied to efficiently schedule computation jobs among processing resources onto the cloud datacenters	Virtual clouds	Minimizes total execution time
Honey bee behavior inspired load balancing of tasks in cloud computing environments [7]	Honey bee behavior	A honey bee behavior inspired load balancing (HBB-LB) algorithm is proposed, which balanced the load across virtual machines for maximizing the throughput. It balances the priorities of tasks on the machines in such a way that the amount of waiting time of the tasks in the queue is minimal	CloudSim	Load balancing minimum queue waiting time
Dynamic task scheduling with load balancing using hybrid PSO [8]	Hybrid PSO	Hybrid PSO is applied to dynamically schedule heterogeneous tasks on to heterogeneous processors in a distributed setup	Heterogeneous systems	Minimizing total execution time, communication cost
A particle swarm optimization-based heuristic for scheduling workflow applications in cloud computing environments [9]	PSO	PSO based approach is used which optimizes the cost of computation, based on the current network and resource conditions by updating the communication costs and also re-computes the task-resource mapping	Amazon EC2	Total execution cost load balancing

(continued)

Table 1 (continued)

Paper title	Nature of scheduling algorithm	Findings	Environment	Objective parameter
Quantum PSO technique for load balancing in cloud computing [10]	QPSO	A scheduling based on quantum particle swarm optimization technique for load balancing in cloud computing has been proposed. The work presented a load balancing algorithm in order to balance the entire load of the system. The optimal resources have been selected to perform task according to resources status and the size of given task in the cloud environment	CloudSim	Minimizes makespan and execution time Load balancing
An optimized scheduling algorithm on a cloud workflow using a discrete particle swarm [11]	PSO	To solve the problems of security threats on workflow scheduling in cloud computing environments, an optimized cloud workflow scheduling algorithm is proposed using a discrete particle swarm. This paper designed a cloud model to describe its security in the cloud workflow scheduling system	CloudSim	Minimizes completion time and cost Maximized security satisfaction
Deadline Based resource provisioning and scheduling algorithm for scientific workflows on clouds [12]	PSO	In this paper, authors developed a static cost-minimization, deadline-constrained heuristics for scheduling a scientific workflow application	CloudSim	Minimizes total Execution cost
Bacterial foraging based hyper-heuristic for resource scheduling in grid computing [13]	BFO	This paper presented a bacterial foraging optimization to schedule the resources in grid and it has been used for the practical application of protein sequence analyzer	GridSim	Minimizes makespan Resource utilization
Cloud task scheduling based on load balancing ACO 2011 [14]	LBACO	In this paper, load balancing ant colony optimization (LBACO) algorithm is proposed to find the optimal resource allocation for each task in the dynamic cloud system. The tasks are mutually independent	CloudSim	Minimizes makespan Dynamic load balancing

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Table 1 (continued)

Paper title	Nature of scheduling algorithm	Findings	Environment	Objective parameter
A novel energy efficient resource allocation algorithm based on Immune clonal optimization for green cloud computing [15]	Improved clonal selection algorithm	An effective energy efficient optimization model for resource allocation has been proposed based on artificial clonal selection algorithm	CloudSim	Minimizes response time and makespan, energy efficient
Multi-objective scheduling of many tasks in cloud platforms [16]	Ordinal-optimization workflows scheduling	The authors proposed the vectorized ordinal-optimization approach to achieve multi-objective scheduling for optimal resource allocation in the cloud computing	Virtualized cloud platform	Reduces scheduling overhead Optimizes resource allocation
Hybrid ant colony algorithm clonal selection in the application of the cloud's resource scheduling [17]	ACO-CS	Authors used a general method of clonal selection ant colony algorithm to solve the task scheduling in cloud computing. This algorithm combined global optimum advantage of the convergence of the clonal selection algorithm (CSA) into every ACO iterations	CloudSim	Improves resource utilization
Job scheduling model for cloud computing based on multi-objective genetic algorithm 2013 [18]	GA	A job scheduling algorithm based on Multi-Objective Genetic Algorithm (MO-GA) is presented in this paper that considers the energy consumption and the profits of the service providers, and provides a dynamic selection mechanism of the most suitable scheduling scheme for users according to the real-time requirements	CloudSim	Consumes less energy and higher profit
Hybrid job scheduling algorithm for cloud computing environment [19]	Modified genetic algorithm with fuzzy theory	In this paper, a hybrid job scheduling approach is presented with the aid of genetic algorithm and fuzzy theory. The idea is to assign the jobs to the resources with considering the VM MIPS and length of jobs	CloudSim	Load balancing Minimizes execution cost and time

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Table 1 (continued)

Paper title	Nature of scheduling algorithm	Findings	Environment	Objective parameter
Scheduling scientific workflow applications with deadline and budget constraints using genetic algorithms [20]	GA	This paper presented genetic algorithm based scheduling heuristic to solve performance optimization problems based on two typical QoS constraints, deadline and budget, for the workflow execution on "pay-per-use" services	GridSim	Minimizes the monetary cost while meeting user's budget constraint
				Minimizes the execution time while meeting user's deadline constraints
Immune genetic algorithm for scheduling service workflows with QoS constraints in cloud computing [21]	IGA	Authors proposed to optimize several objective functions simultaneously, depending on the requirements of the users and providers: makespan, cost, reliability, and resource utilization. When physical resources are involved, they discussed a way to monitor energy consumption. A new fitness function model for faster convergence is used and an immune genetic algorithm has been adopted efficiently to solve the constraint satisfaction problem linked with the task scheduling constraints	Amazon EC2	Optimizes makespan, cost and reliability
HSGA: a hybrid heuristic algorithm for workflow scheduling in cloud systems [22]	HSGA	This paper proposed a hybrid heuristic method based on genetic algorithm (HSGA) for scheduling workflow graph. The algorithm tried to decrease the number of GA operation iteration with starting the algorithm by an optimized initial population, considering load balancing of task on resources. The solutions are derived from two evaluation functions, one measured priority of each task in workflow, based on their influence on the others, and another function evaluate the value of the produced solutions. It focused to minimize the completion time of application as makespan and failure rate, and increasing the load balancing	CloudSim	Minimizes makespan and failure rate
				Load balancing

(continued)

Table 1 (continued)

Paper title	Nature of scheduling algorithm	Findings	Environment	Objective parameter
A hybrid metaheuristics algorithm for job scheduling on computational grids [23]	GGA	This research has combined the features of a genetic algorithm (GA) and the gravitational emulation local search (GELS) algorithm. As genetic algorithm is strong for global searches and GELS is a local search algorithm that imitates gravitational attraction and is therefore strong for local searches and weak for global searches. Combining the benefits of these two algorithms a static scheduling algorithm has been discussed in this paper	Java	Minimizes makespan
Simulated-annealing load balancing for resource allocation in cloud environments [24]	SA	In this paper, a simulated-annealing load balancing algorithm is presented for solving the resource allocation and scheduling problem in a cloud computing environment	CloudSim	Load balancing
Hybridization of modified ant colony optimization and intelligent water drops algorithm for job scheduling in computational grid [25]	IWD-ACO	The authors have presented a hybrid technique using Intelligent water drops with Ant colony optimization approach to solve the scheduling problem in grid environment. This method has found the optimal schedule for the job that minimized the makespan of the executing jobs and the load balancing of jobs among resources	GridSim	Minimizes makespan Load balancing Resource utilization
Hybrid ACO-IWD optimization algorithm for minimizing weighted flow time in cloud based parameter sweep experiments [26]	IWD-ACO	A hybrid meta-heuristics approach is used based on IWD and ACO algorithms for scheduling jobs. Resources are matched based on the job requirements by the IWD algorithm and then ACO is used to select the best one among the matched resources	CloudSim	Minimizes makespan Load balancing

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Table 1 (continued)

Paper title	Nature of scheduling algorithm	Findings	Environment	Objective parameter
Job scheduling in grid computing with cuckoo optimization algorithm [27]	Cuckoo optimization algorithm	In this paper, a scheduling algorithm based on COA is implemented for job scheduling problem on computational grids. This approach generated an optimal schedule that completes the jobs in a minimum time	GridSim	Minimizes execution time
A Meta-heuristic algorithm for job scheduling in grid computing [28]	CUckoo-Generic algorithm	Authors proposed a CUckoo-Genetic Algorithm (CUGA) as a meta-heuristic algorithm to solve job scheduling problem in grid environment. CUGA is inspired by cuckoo search optimization and genetic algorithm	Matlab	Minimizes execution time Resource utilization
A Multi-objective Cat Swarm Optimization algorithm for workflow scheduling in cloud computing environment [29]	CSO	In this paper, Cat Swarm based approach is used for multi-objective optimization for workflow scheduling in cloud computing	Matlab	Minimizes execution time, cost and CPU idle time

Table 2 Scheduling parameters considered by existing workflow scheduling algorithms

References	Makespan	Cost	Scheduling overhead	Load balancing	Security	Reliability	Resource utilization	Failure rate	Energy efficient
[5]	√	√	X	X	X	X	X	X	X
[6]	X	√	X	X	X	X	X	X	X
[7]	√	X	X	√	X	X	X	X	X
[8]	√	√	X	X	X	X	X	X	X
[9]	X	√	X	√	X	X	X	X	X
[10]	√	X	X	√	X	X	X	X	X
[11]	√	√	X	X	√	X	X	X	X
[12]	X	√	X	X	X	X	X	X	X
[13]	√	X	X	X	X	X	√	X	X
[14]	√	X	X	√	X	X	X	X	X
[15]	√	X	X	X	X	X	X	X	√
[16]	X	X	√	X	X	X	X	X	X
[17]	X	X	X	X	X	X	√	X	X
[18]	X	X	X	X	X	X	X	X	√
[19]	√	√	X	√	X	X	X	X	X
[20]	√	√	X	X	X	X	X	X	X
[21]	√	√	X	X	X	√	X	X	X
[22]	√	X	X	√	X	X	X	√	X
[23]	√	X	X	X	X	X	X	X	X
[24]	X	X	X	√	X	X	X	X	X
[25]	√	X	X	√	X	X	√	X	X
[26]	√	X	X	√	X	X	X	X	X
[27]	√	X	X	X	X	X	√	X	X
[28]	√	X	X	X	X	X	√	X	X
[29]	√	√	X	X	X	X	X	X	X

2 Related Work

2.1 *Workflow Scheduling in Cloud Computing: A State-of-the-Art*

Initial study has been carried out on understanding scheduling algorithms for executing workflows in cloud computing systems. A lot of work has been done in the area of workflow scheduling [2, 3]. To solve the optimization problem of scheduling, several solutions have been proposed in the literature. There are heuristic-based and meta-heuristic based scheduling strategies to achieve near-optimal solutions within polynomial time, as workflow scheduling is an NP-complete problem. The meta-heuristics based scheduling strategies can deal with massive search space and find a near-optimal solution within polynomial time for all workflow structures. Some of these approaches are based on Genetic Algorithms (GA) [18, 19]. In [20], the authors run the genetic algorithm starting with an initial population consisting of randomly generated solutions. The genetic algorithm started with an initial population consisting of a solution produced by one of the simple heuristics together with other randomly generated solutions. This proposed algorithm either minimized the monetary cost while meeting user's budget constraint, or minimized the execution time while meeting user's deadline constraints. Artificial Bee Colony algorithm for multivariable, multimodal function optimization have been used in [5, 30]. The use of Intelligent Water Drops (IWD) algorithm for solving multi-objective job shop scheduling has been discussed in [31], which optimized the makespan, tardiness and mean flow time of the schedules in job shop. Similar to this, authors in [25] has employed IWD with ACO algorithm to optimize the makespan and load balancing of the jobs in grid environment. The paper [26] showed the use of IWD as a hybrid meta-heuristics with ACO to optimize the mean flow time of the jobs in cloud systems. There is also work in which particle swarm optimization (PSO) is used for the scheduling of workflow in Cloud environment [8–11]. CSO based multi-objective optimization approach has been used in [29] to schedule workflow in a cloud computing environment. Researches show that ant colony optimization (ACO) is considered as one of the best meta-heuristic for scheduling workflow in Cloud computing [14]. Most of these researches focus only on one or two optimization objective most often cost or time.

However, current state-of-the-art studies tackle different scheduling problems in cloud workflow systems by focusing on general QoS optimization constraints as described in a Table 1. It is clear that most of the scheduling algorithms have focused on optimizing makespan and cost [5, 6, 8, 10, 11, 21]. Some of the algorithms have considered makespan and load balancing [10, 14, 16, 19, 22, 25], while others have taken care of optimizing makespan and security [11]. Optimization of resource utilization is considered in [13, 17, 25, 27] in addition to makespan and load balancing. Some have also considered the issue of reliability

along with makespan and cost [21]. Also the papers [11, 15, 18] based on meta-heuristics approaches considered the energy efficiency parameter for scheduling of the workflow tasks.

2.2 Scheduling Parameters

The scheduling decision during workflow scheduling must be guided by user's QoS constraints [1]. There are different parameters which need to be considered when developing a scheduling algorithm for workflows. It is not possible for an algorithm to consider all the parameters in a single solution because it depends on many factors like nature or size of the job, resource availability, working environment etc. Some of the parameters considered in the existing workflow scheduling algorithms in Table 2 are explained as below:

Makespan Makespan, M, is the total elapsed time required to execute the entire workflow. The makespan of the workflow is computed as M = finish time − submission time. It represents the duration from the user submitting a workflow to the time it completes and receives the results.
Cost The cost is the monetary value which incurred while running a cloud workflow. It consists of the processing cost and the data transfer costs.
Security Security is an essential requirement in the cloud computing as there is a risk of sensitive data being leaked or tampered in the process of transmission or execution.
Scheduling overhead There can be the situation when numbers of tasks demand for the same resource. Such tasks then need to be queued up waiting for the desired resource which creates a problem of scheduling overhead.
Resource utilization Scheduling refers to the appropriate assignment of tasks to the resources available like CPU, memory and storage, such that there is a maximum utilization of resources.
Failure rate Many discrete events may lead to failures of an application such as non-availability of required services or overloaded resource conditions. The failure density function is defined as:

$$f(t) = \lambda e^{-\lambda t} (t \geq 0) \tag{1}$$

where λ is the failure rate of a resource [32]. If $\text{num}_{\text{fails}}$ be the number of failures within a resource during the job execution period run_{time} then the failure rate can be calculated as: $\frac{1}{\text{MTTF}} = \frac{\text{num}_{\text{fails}}}{\text{run}_{\text{time}}}$, which is the inverse of mean time to failure (MTTF).

Reliability Reliability represents the probability that the workflow will be executed successfully and it is to be maximized. A schedule is an assignment of the tasks to the virtual machine and the reliability of a schedule is defined as the probability that it finishes correctly and is given by the probability that all the VMs be functional during the execution of all their assigned tasks.
Energy efficiency Data centers consist of huge numbers of heterogeneous servers which both consume and simultaneously waste massive power to execute numerous assigned tasks due to poor task assignment optimization. So, scheduling plays a very important role in determining the efficient execution of tasks in virtualized environments. Tasks are to be mapped to the virtual machines in such a way that the energy consumption should be reduced.

3 Research Challenges

Based on the related literature, we find that the following issues have not been sufficiently solved. These issues can give the directions for future work.

Scheduling overhead There are number of resources available and it may possible that more than one user demand the same resource. This creates a scenario of multiple jobs waiting in a queue, which leads to the problem of scheduling overhead. Some mechanism needs to be discussed to reduce such overhead while generating schedules in a workflow. In [33] the authors presented different clustering techniques incorporated into the Pegasus workflow mapping system on the TeraGrid and results showed significant reduction of overall workflow runtime. Similar thing can be thought in the clouds systems also.
Scheduling with Fault tolerance There is a need of defining a method to integrate fault tolerance with scheduling algorithm based on some meta-heuristics approach. There is no evidence of such work done in the related literature. There are various fault tolerance techniques that reduce the effect of failures on application execution when the failure occurs. Check point recovery, over-provisioning or task replication and task resubmission schemes can be integrated with scheduling as discussed in [34].
Storage cost and performance trade-off workflow scheduling that takes both storage cost and execution time into consideration has not been studied as extensively. The tasks of a workflow are to be mapped to the VM-instances (Virtual Machine) in the cloud. Every available virtual machine is associated with both cost and performance related attributes like processor speed, bandwidth. Reducing the storage cost has also become a challenge for the scientists while optimizing the workflow performance [35].

4 Conclusion and Future Directions

In this paper, we have discussed various workflow scheduling algorithms in clouds and Grids. Scheduling criteria should include multiple constraints to be satisfied based on the user's requirements. There can be heuristics approach or meta-heuristics approach for optimizing the various scheduling criteria. We discussed both approaches but focus of our survey is meta-heuristics based methods. Some of the algorithms are based on Artificial Bee colony algorithms (ABC) [5, 7]. There are some work in which Genetic Algorithm (GA) is combined with other heuristic method [18–23]. Also, the use of Particle Swarm Optimization (PSO) discussed in [8, 9, 11, 12] for the scheduling of workflow in Cloud environment. Clonal selection algorithm is also being used for scheduling workflow in cloud environment [15, 17]. In [17], authors combined ACO with Clonal selection algorithm for scheduling the resources in the clouds. ACO is also combined with intelligent water drops algorithm in [25, 31] to improve the scheduling. In [27, 28], a new method based on Cuckoo Optimization has been used to generate optimal schedules in a Grid environment. Researches show that Genetic Algorithm is one of the best meta-heuristic for scheduling workflow in Cloud computing [18, 20]. In [29], Cat Swarm Optimization has been used to minimize the cost, makespan, and CPU idle time. Discrete CSO [36, 37] can also be used in combination with other heuristics method to achieve the better performance. As there is no evidence of using Discrete CSO based approach for workflow scheduling in cloud systems.

Most of the above stated researches focus only on one or two optimization objective such as cost or time and do not consider the energy efficiency and failure rate while scheduling the workflows. But, there is need to consider the failure rate and security also. The efficient scheduling will give better optimized results if energy efficiency factor is also considered. A hybrid heuristic-based scheduling [22] considered the failure rate while scheduling the tasks in workflow which is shown as in a Table 2 given. Also, the papers [15, 18] based on meta-heuristics approaches considered the energy efficiency parameter for scheduling of the workflow tasks. There is need to develop scheduling algorithms that would focus on failure rate, reliability, and energy efficient parameters.

Also, we found that the Artificial Bee Colony has not been used for optimization in workflow scheduling. The experimental results of various research works [5, 30, 38, 39] reveal that the ABC algorithm is having potential to solve optimization problems and more research is required to adapt it to other engineering problems. After getting inspiration from its successful implementation in [18] to solve Job scheduling problem in cloud computing, we feel that there is a scope of using hybrid meta-heuristics approach that combines Artificial Bee Colony algorithm and Genetic Algorithm (ABC-GA) for multi-objective optimization workflow scheduling problems. Cross-over and mutation operators of GA can be embedded into ABC to improve scheduling strategy. A hybrid meta-heuristics based energy

efficient workflow scheduling can be considered for future work, which schedules the tasks on the resources by minimizing the cost and that consider the failure rate of the resources.

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