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Trust-Aware Scheduling for Tasks with Precedence Constraints in Heterogeneous Distributed Computing

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Abstract: Demands for reliability in distributed computing systems have become extremely important now a days due to strong requirements imposed by the dynamic behaviour of user and resource communities. With the increasing number of entities in the distributed systems, inadequate information and unsuccessful accessibility have becoming critical factors that impact system performance. We present an adaptive scheduling which attempts to improve system reliability. Specifically, our scheduling approach combines trust-based matching scheme with robust mapping rules to deal with diverse processing requirements and heterogeneous resources. Simulation experiments proved the efficacy of our approach in achieving better system performance and implicitly help to gain reliable and cost-effective computation.

Key words: Distributed computing systems, dynamic scheduling, reliable computation, trust-based matching scheme, better system performance

INTRODUCTION

The computing paradigm of distributed computing systems poses new challenges to the reliability problem. The continuous growth of community computing in such systems has led to complex systems of behaviour from processing the large volumes of datasets to resource heterogeneity (Vasile *et al*., 2015; Hussin *et al*., 2011; Zhang *et al*., 2011; Hussin *et al*., 2013; Rosa *et al*., 2016). The resource scheduling is importance to deal with diverse nature of resources for optimizing system performance. Satisfaction on these systems towards their resource capabilities is an important indicator that reflect quality of resource scheduling (Chauhan and Joshi, 2010; Jalal and Hussin, 2014). However, resource's information in regards their capabilities are hard to determine prior in heterogeneous distributed computing environment. In many cases, if not all, the information returned by the systems is costly to obtain, inaccurate or out-dated (Singh and Chana, 2016; Antonescu and Braun, 2016). Hence, it is necessary to develop effective scheduling for dynamically evaluating resource capabilities (i.e., capacity and availability).

This motivated us to design resource scheduling that able to adapt heterogeneous and dynamic distributed computing. In large-scale distributed computing, the criteria such as execution time, waiting time, processing overhead and resource utilization are considered simultaneously to yield cost-effective processing. The task scheduling can be integrated with the notion of trust in order to achieve cost-effective processing (Xie *et al*., 2015; Tan *et al*., 2014). With the diverse processing requirements from the system's users, the trust factor becomes significant indicator to convince the continuous reputation of computational processing power. It means that by the trust factor it ensures the processing is not come at a great cost in terms of delay and latency; hence improves reliable computation. In this research, we define trust as a capability of resources for maintaining to function well and adapting to diverse processing requirements.

This research evaluates in our extensive simulations (i.e., comparison with other techniques) through varying processing capacities and a diverse set of workloads. The results obtained from our comparative evaluation study clearly show that our resource scheduling improves execution time and processing cost while meeting "at-scale" processing requirements.

Literature review: Despite of decades of research advances, resources scheduling keeps posing challenging research questions due to ever-increasing workload

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variety and scale and increasing diversity of resources and network domains. Due to uncertainties in the resource availability and cost of using resources (e.g., in clouds), scheduling mechanisms have been extensively studied in the literature (Vasile *et al*., 2015; Hussin *et al*., 2013; Righi *et al*., 2016; Alicherry and Lakshman, 2012). There has been increasing interest in addressing dynamic scheduling decisions for performance optimization that take into account computing reliability as one perspective.

The dynamic scheduling for distributed computing that proposed by Vasile *et al*. (2015) addressed the issue of resource reliability. Their resource-aware hybrid scheduling algorithm classified user's task and mapped to each group of resources. Such grouping is formed through K-Mean clustering approach that based on CPU processing power and I/O operation speed. The research achieves good balance between processing time and overload. Fu (2010) proposed the failure-aware node selection strategies by calculating node's reliability states. They defined the capacity-reliability metric and used best-fit algorithm to find the best qualified nodes to run user jobs. Zhang *et al*. (2011) modelled the resource sharing problem as constrained discrete-time optimal and used Model Predictive Control (MPC) to allow the resource controller adjusts price and capacity for future use. Their scheduling scheme dynamically adapted both supply and price to meet customer's demands while optimizing the provider revenue, energy cost and request wait times. However, the focus of the work is to allocate available virtual machine in order to meet the demand, rather than maintaining resource capacity for increasing system reliability. Alicherry and Lakshman (2012) claims that efficient algorithms for scheduling is necessary for minimizing communication costs and latency. Due to the resources are geographically located over many locations in the network, resource scheduling scheme should aims for reducing bandwidth costs. With the heuristic algorithms, their scheduling scheme performs well for assigning VMs to processing resources in the chosen data centre. However, there is no formal model to analysing the impact of cost-effective on their resource scheduling decisions. Our scheduling approach in this work explicitly takes into account both trust and cost factors in mapping strategy? to fulfil reliable computing.

MATERIALS AND METHODS

The models: In this study, we describe the application and system models used in our research.

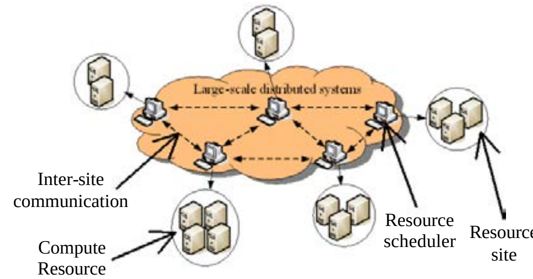

Fig. 1: The system model

The application model: The system users are considered autonomous that distributed over many distinct networks. They produced and submitted their tasks to schedulers where the tasks stayed first at the scheduler for scheduling process (matching and mapping). Each task from user is associated with the set of parameters (i.e., weight w_i and priority pr_i) that set by the user. We assume that the task's profile is available and can be provided by the user using job profiling, analytical models or historical information. Each task requires a different processing capacity to meet its priority requirement. The completion time of a task i on a particular computing resource j denote the elapsed time from the time the task arrives into the scheduler until it completes the execution entirely:

$$CT(i, j) = (wait\_t+exe\_t) \quad (1)$$

Where:

wait_t = The elapsed time between a submission and the start of execution
exe_t = Actual execution time of task, respectively

Thecompletion time of a task varies according to the performance of the resource on which the tasks is being processed.

The system model: The target system used in this work (Fig. 1) consists of several distributed resource sites given as S_x where $x = \{1, 2, ..., s\}$ which are loosely-coupled resource sites connected by a communication network. They are independently operated by different administrative domains. In each site a resource scheduler resides that handles tasks and map them onto resources.

The target resource site consists of a set of heterogeneous computing resource that is fully interconnected. Each resource j is associated with processing capacity to complete the scheduled tasks. More formally, the processing capacity of resource j is defined as:

$$PCj = speed + (L/\sum exe\_t) \quad (2)$$

Where:

speed = Relative speed of available resources
L = The total number of tasks completed within some observation period, respectively

For a given resource, its processing and availability fluctuated. Therefore, the actual completion time of a task on a particular resource is difficult, if not impossible, to determine a prior. The number of resources in this study is assumed to be relatively less than the number of tasks to be processed. The scheduler in the target system may communicate with each other to share and exchange resource's information, in the sense that there is a communication link between them. The link represents connection between sites and it might be an actual link of cable or a virtual link of the internet. The bandwidth between any two individual sites varies corresponding to realistic network; thus the inter-site communications are heterogeneous and assumed to dispute with some delays. The system performance is also affected by the inter-site communications to a certain degree due to heterogeneous communication links. In this research, the transfer rate between the schedulers through the communication link l can be expressed as in Eq. 3:

$$lc_l = (1 - dy_l) + ms_l \quad (3)$$

Where:

dy_l = Average of transaction delay in communication link
l = The within some observation periods
ms_l = The can be derived by the mean speed of the link

Note that, the execution time could be raised due to involvement of heavy loaded traffic in communication links hence, reduces the system performance. We believe that minimization of the transfer rate robustly contributes for enhancing system reliability.

Trust factor in scheduling: Basically, the distributed systems are able to improve execution time when the computing resources are ready and available to effectively perform. However, the available resources might not always be suitable resource to execute the tasks due to resource heterogeneity. Furthermore, due to the tasks come with different processing priorities, there is also increasing interest from the users to schedule their tasks into the most reliable resource. For example, the higher priority workload is needed to be executed first. Hence, it is significant to effectively match the processing capacity with processing requirement aims for better execution time. The matching process for the resource and task is determined based on a suitability value between computing resource j, transfer rate of communication link l and weight of workload i as defined to be:

$$SF(j, i)_l = \frac{PC_j}{lc_l} + \frac{1}{w_i} \quad (4)$$

A task is assigned to a resource that gives the highest suitability value $SF(j, i)_l$. It allows the tasks to meet the processing requirement with better completion time. The tasks without any additional processing requirement are assigned into the available resources based on the preference on trustworthiness. We introduce a resource trust factor that aims to express trustworthiness of execution on the underlying resources. It is formally defined as follows:

$$T(j, l) = a_j + lc_l$$

Where:

$$a_j = \begin{cases} 1, \text{ if average wait\_t}_i \leq \text{average exe\_t} \\ 0, \text{ if average wait\_t}_i > \text{average exe\_t} \end{cases} \quad (5)$$

The resource with higher trust factor is more likely to improve user satisfaction in terms of minimizing execution time. The scheduler constantly checks and sorts the value of trust factor to indicate the most reliable resource among the available resources. That information from the resource site is publically share to other schedulers in the distributed system without any costs incurred in such discovery. It is where the hybrid scheduling mechanism comes into the picture. It provides opportunity for other schedulers from different resource sites to reschedule their tasks or performed task migration process to be executed in the available resources.

The hybrid scheduling mechanism effectively deals with performance fluctuations. The prior scheduled tasks in the queue might need to reschedule or migrate due to several reasons. In this research, the status change occurs due to two reasons, i.e., the computing resource is heavily loaded (causing unacceptable queuing delay) or the resource is unexpectedly halt in execution. Now, the scheduler of the resource site is pursued for alternative resource to be allocated for those tasks. The alternative resource with the highest trust factor is selected when there are multiple alternative resources. Due to the trust factor already considered transfer rate, the inter-site communication cost is insignificant during the reschedule/migration process. The reschedule/migration of particular tasks contributes to the improvement of reliable computation if completion time on the selected resource for migration is actually realized.

Performance evaluation: In this study, we first describe the experiment configuration. Then, experimental results are presented. We study the performance of our resource scheduling approach; name Hybrid-Adaptive Scheduling policy (HAS-policy) for system reliability that is compared with three other heuristic algorithms which are Fit-value, Max-max and Random-selection. Note that the other scheduling algorithms do not take into account the trust factor in their scheduling decisions. In the Fit-value, the suitable resource for a particular workload determined merely according to the highest suitability value SF(j, i). Max-max heuristic algorithm maps workload to the resource which gives the highest suitability value SF(j, i) from its maximum list. It allows the workload that assigned into the most suitable resource to be executedfirst in order to achieve better execution time. In Random-selection, workloads are randomly mapped to available resources. Performance metrics used for the experiment are resource utilization and processing cost. The resource utilization rate which is defined as the percentage of time a resource is busy servicing user's tasks, given by:

$$RU = \frac{L}{\sum exe\_t} \quad (6)$$

In addition to utilization rate RU, the processing cost represents the average of division between task's completion time and the processing overhead in some observation periods. The overhead refers as indirect access time to bandwidth, memory and CPU in order to accommodate the computation and it derives from the experiments. It is used to identify how well the resource scheduling approach deals with heterogeneous processing requirements and to measure the degree of cost-effective execution.

Experiment setting: We have evaluated our scheduling approach via simulation with number of resource sites ranging from five to twenty in each of which its own scheduler resides. Each resource site contains a varying number of computing powers ranging from 4-8. The relative processing power (speed) is selected within the range of 1 and 7.5. The number of tasks in a particular simulation is set between 1000 and 5000. Inter-arrival times (iat) of the task follow a Poisson distribution with a mean of three time units. Note that, iat satisfies with the mapping technique without explicitly increasing a delay in the queue. For a given $task_i$, the weight w_i is randomly generated from a uniform distribution ranging from 10^3-10^6. The task priority values are between 0 and 1 where 0 indicates the lowest priority and 1 indicates the highest priority. The speed of a communication link l is uniformly distributed within the range of 10 and 100.

RESULTS AND DISCUSSION

Experimental results are presented in two different ways based on resource utilization and processing cost. As shown in Fig. 2, the proposed adaptive scheduling approach outperformed others in terms of utilization rate.

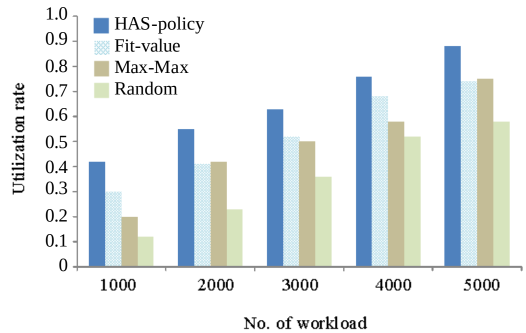

Fig. 2: Resource utilization with different scheduling approaches

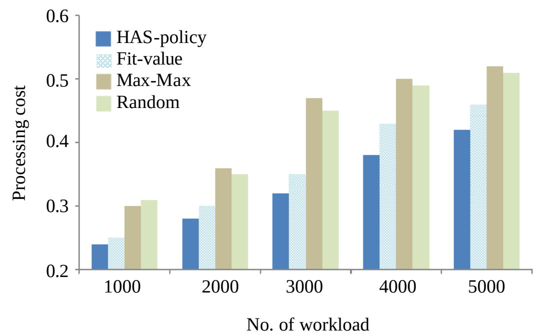

Fig. 3: Processing cost with different scheduling approaches

The superior performance of our approach is primarily achieved by scheduling policy that take into account both processing and link availabilities. Specifically, the incorporation of two different significances (i.e., suitability value and resource trust factor) into our scheduling policy leads to better completion time of user's tasks. It also observes that Fit-value is comparable with our approach. It is due to the fact that both strategies considered suitability value during their matching processes for optimal scheduling. However, it indicates that HAS-policy works 30% better in the case of more workloads coming or being processed.

Figure 3 shows the average processing cost that is plotted against number of tasks, respectively. Our scheduling approach obtains appealing processing cost compared to three other techniques with reduced considerably, about 60% on average. Although, all scheduling strategies considered communication cost during the scheduling, our HAS-policy benefits for handling various workload priorities and heterogeneous resources.

Table 1: Comparative results

Success rate	Cost rate	Divergence (%)
HAS-policy		
0.1	0.08	2
0.2	0.23	3
0.3	0.35	5
0.4	0.46	6
0.5	0.58	8
Total		28
Fit-value		
0.1	0.18	8
0.2	0.37	17
0.3	0.48	18
0.4	0.59	19
0.5	0.71	21
Total		83

We then investigate how the resource scheduling contributes for performance optimization. The experiment is set-up to measure how many workloads are completed within their processing priorities (i.e., successful workload) while effectively spending computational power for the completion (i.e., processing cost). The successful workload and processing cost in this experiment are identified based on normalization values derived from previous experiments.

Table 1 clearly shows the discrepancy of processing cost and successful workload in HAS-policy is small (by about 2% on average compared to Fit-value). It indicates that our resource scheduling approach finds amplified opportunities to reduce the processing cost while preserving better successful workload. This is can be explained by the high availability of resources either in processing powers or communication links is much preferable helps the network systems to continuously present improvement in cost-effective processing.

CONCLUSION

In this research, we addressed the reliability issue in the context of resource scheduling for distributed computing systems. We have effectively modelled adaptive scheduling decisions with minimal possible performance degradation. In addition, the adaptive nature of the resource scheduling approach benefits in handling diversity in user's processing requirements that leads for performance optimization. With the ongoing increase in the number of tasks and heterogeneous resource capacities, our approach helps in identifying the most suitable resource through suitability and trust factors. We highlight that the hybrid-adaptive scheduling strategy contributes for improving system reliability which will result in a proliferation in the performance of parallel and distributed systems.

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