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# Fault-Tolerant Scheduling Using Primary-Backup Approach for Optical Grid Applications

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**Abstract:** Fault-tolerant scheduling is an important issue for optical grid applications because of various grid resource failures. To improve the availability of the DAGs (directed acyclic graphs), a primary-backup approach is considered when making DAG scheduling decision. Experiments demonstrate the effectiveness and the practicability of the proposed scheme.

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## 1. Introduction

Optical grids have emerged as a powerful and cost-effective platform for solving distributed computing applications [1]. These applications involve dispersed grid resources such as supercomputers, experimental facilities and massive storage systems, which are interconnected by optical networks. Running DAG applications in such environments is fragile as a wide range of grid resource failures, which include hardware failures (e.g., host crash), software errors (e.g., immature middleware), and other failure sources (e.g., machine removed by the owner) [2]. However, the issue of handling grid resource failures in optical grids has not been studied although they are very critical.

This paper proposes a Grid Resource Protection (GRP) scheme for directed acyclic graphs (DAG) [3] scheduling, in which a primary-backup approach is used to allocate two copies of each computing task to two different grid resources. This problem is an NP-complete problem because the common DAG scheduling without fault tolerance is NP-complete [3]. The simulation results illustrate the good performance of the proposed algorithm.

## 2. DAG scheduling without Grid Resource Protection

A DAG application contains a set of inter-dependent computing tasks  $T$  and a set of weighted and directed edges  $E$ , which represent communication tasks among computing tasks. An optical grid system is composed of a set of optical switch nodes and a set of multiple-wavelength optical links. We assume that each grid (computing) resource is attached to one switch node via a dedicated access link.

Based on the above model and assumptions, the existing DAG scheduling algorithm jointly allocates each computing task to an available grid node for data process and each communication task to a lightpath for data transfer. The following constraints must be satisfied: 1) *Precedence constraint*, 2) *Grid resource constraint*; 3) *Network resource constraint* [3]. An extended list scheduling (ELS) is proposed to fulfill the DAG scheduling in optical grids [3]. The basic idea of ELS is that the computing tasks are ordered according to certain priorities (bottom levels in this study) and then scheduled one by one to achieve the objective in a greedy manner.

## 3. Grid Resource Protection in Optical Grids

To improve the DAG application availability, a primary-backup approach is applied and each computing task  $t$  has two copies,  $t^p$  and  $t^b$ , executed simultaneously on two different grid resources. There are two important parameters to be derived: 1)  $eat(t)$ , which is the earliest available time for computing task  $t$ , and 2)  $est(t)$ , which is the earliest start time for computing task  $t$ . The former indicates the time when all data from  $t$ 's predecessors have arrived; the latter additionally signifies that the grid node  $g(t)$  (to which  $t$  is allocated) is now available to start execution.

To quantify the availability benefit gained by a DAG, we partition a DAG into many subsets. Each subset contains both one computing task node and its incoming communication links. The availability of each subset  $s_i$  is given by:  $AL(s_i) = AL(s_i^p) + (1 - AL(s_i^p)) \times AL(s_i^b)$ , where  $AL(s_i^p)$  and  $AL(s_i^b)$  are the availability of primary copy subset and backup copy subset, respectively, which are determined by the following expression:

$$AL(s_i^*) = \begin{cases} AL(t_i^*), & \text{if } g(t_i^*) \in \{g(t_j^p), g(t_j^b)\} \\ AL(t_i^*) \times \prod [AL(R_{ji}^{PT^*}) + (1 - AL(R_{ji}^{PT^*})) \times AL(R_{ji}^{BT^*})], & \text{if } g(t_i^*) \notin \{g(t_j^p), g(t_j^b)\} \end{cases}$$

where the superscript \* represents either primary copy or backup copy; node  $j$  is the predecessor of node  $i$ ,  $AL(t_i^*)$  is the availability of computing task  $t_i$ ; and  $AL(R_{ji}^{PT^*}) + (1 - AL(R_{ji}^{PT^*})) \times AL(R_{ji}^{BT^*})$  is the availability of

route  $R_{ji}$  from node  $j$  to node  $i$ , when  $g(t_j^*) \notin \{g(t_j^p), g(t_j^b)\}$  is satisfied.

Now, we can define an availability-level function for a DAG application:  $AL(DAG) = \sum_{i=1}^{|E|} w(s_i) \times AL(s_i)$ . The  $w(s_i)$  is the weight of the  $i^{th}$  subset. The weight is chosen as the ratio of the sum of the costs of the considered subset (computing node and its incoming links) over all the cost (computing and communication costs) of the DAG.

#### 4. Simulation Results and Analysis

In this section, we evaluate the performance of the Extended List Scheduling with Grid Resource Protection (ELS\_GRP) scheme for randomly generated DAGs for different network topologies: 2-node network, 16-node NSFNET and Mesh Tours [3]. The MTTR (Mean Time To Failure) is assumed to be 12 hours and 1/MTTF (Mean Time To Repair) is 300 FIT/km. We assume that each optical switch is equipped with all-wavelength converters and has only one grid resource connected, which has one unit data processing capability. There are three available wavelengths in each link. The grid resource's availability randomly varies from 0.32 up to 0.98 [4]. The availability of the grid resources for 2-node network is assumed to be 0.74 and 0.86, respectively. The communication computing ratio (CCR) is defined as the sum of all the communication task costs divided by the sum of all the computation task costs in a DAG. The computation task cost per each node in a DAG are taken randomly from a uniform distribution from 6 to 14 centered around 10. The average node degree is assumed to be 4.

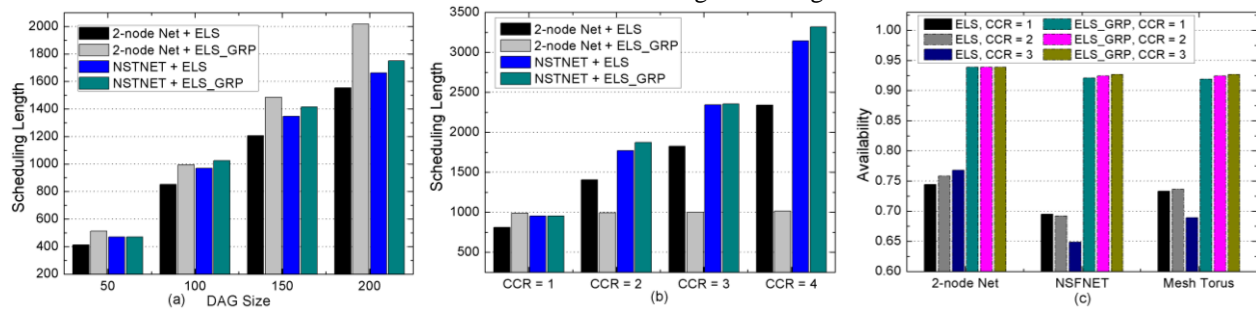


Fig. 2 Scheduling Length versus (a) DAG size, (b) CCR value with ELS and ELS\_GRP scheme in different network topologies, (c) Availability versus different network topologies, scheduling scheme and CCR value.

As we can see in Fig. 1(a) when the CCR is 1, the scheduling length is rising proportionally to the DAG size for both scheduling schemes. The scheduling length difference between ELS and ELS\_GRP with the 2-node network is larger than with NSFNET as DAG size increases. That is because more grid resources are available for allocating two copies of each computing task in NSFNET. Fig. 1(b) depicts the scheduling length with respect to different CCR values when the DAG size is 100. As the CCR is increasing from 1 to 4, the communication load in a DAG is heavier. The scheduling length increases proportionally for ELS, but it remains identical for ELS\_GRP with the 2-node network. The reason is that only two grid resources are served for two copies of each computing task in the same time and there is no communication task to be executed when the ELS\_GRP is applied. However, Fig. 1(c) shows that the ELS\_GRP greatly improves the DAG availability, because the two copies of each computing task are scheduled in two different grid resources. For ELS, we observe that the more the involved grid resources, the lower the DAG availability for any of the network topologies. This is due to the fact that the grid resource's availability is lower generally and when there are more and more the grid resources for a DAG, the availability of the whole DAG becomes lower. Another observation is that the impact of the CCR variation on the DAG availability for ELS\_GRP can be ignored. It is because the DAG availability improvement mainly comes from the primary-backup technique of the grid resource rather than from the lightpath protection for communication tasks.

#### 5. Conclusion

This paper presents a fault-tolerant DAG scheduling scheme using a primary-backup approach in optical grids. We extend a joint DAG scheduling mathematical model and construct the DAG's availability model. The simulation results show that the ELS\_GRP greatly improves DAG availability and induces less overhead in the scheduling length when more network resources are available.

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