Extending GridSim with an Architecture for Failure Detection

Agustín Caminero [1], Anthony Sulistio [2], Blanca Caminero [1], Carmen Carrión [1], and Rajkumar Buyya [2]

[1]Department of Computing Systems
The University of Castilla La Mancha, Spain
{agustin, blanca, carmen}@dsi.uclm.es

[2]Dept. of Computer Sc. & Software Eng.
The University of Melbourne, Australia
{anthony, raj}@csse.unimelb.edu.au

Abstract

Grid technologies are emerging as the next generation of distributed computing, allowing the aggregation of resources that are geographically distributed across different locations. However, these resources are independent and managed separately by various organizations with different policies. This will have a major impact to users who submit their jobs to the Grid, as they have to deal with issues such as policy heterogeneity, security and fault tolerance. Moreover, the changes of Grid conditions, such as resources that may become unavailable for a period of time due to maintenance and/or suffer failures, would significantly affect the Quality of Service (QoS) requirements of users. Therefore, it is essential for users to take into account the effects of resource failures during jobs execution.

In this paper, we present our work on introducing resource failures and failure detection into the GridSim simulation toolkit. As we need to conduct repeatable and controlled experiments, it is easier to use simulation as a means of studying complex scenarios. We also give a detailed description of the overall design and a use case scenario demonstrating the conditions of resources varied over time.

1 Introduction

Grid systems are the next generation of distributed computing systems. They are highly heterogeneous environments and consist of a series of independent organizations sharing their resources, creating what is known as *Virtual Organization* (VO) [5]. In Grid systems, each organization keeps its own independence and autonomy, since it is an essential issue for the creation of a real Grid. Therefore, each organization can decide its own policy and whether to join/leave a VO at any time. Such decisions will certainly affect users in submitting and executing their jobs.

Another important issue concerning users is that the number of resources can fluctuate significantly over time. The availability of resources may vary due to changes in their working conditions, such as network congestion, partial failures or even the connection or disconnection of computing resources. With many resources in a Grid, the resource or network failures are the rule rather than the exception. Hence, they should be taken into account in order to provide a reliable service [11].

Supporting fault tolerance is one of the main technical challenges in designing Grid environments. This is because production Grid systems must be able to tolerate resource failures, while at the same time effectively exploiting the resources in a scalable and transparent manner. Therefore, in order to cope with these challenges, from the fault tolerance point of view, the system must have failure detection and recovery schemes. Such a scenario can be described in Figure 1. A failure detector monitors the components of the system (step 1), and notifies a local Grid Information Service (GIS) entity when a failure occurs in any of them (step 2). Then, a recovery scheme is being applied in order to restart a failed job on another computational resource dynamically. An example of such a scheme is the failure monitor notifies users that resource `Res2` is out of order (step 3). Hence, users can resubmit their jobs to other resources. As demonstrated in this example, both detection and recovery schemes must be an integral part of the Grid computing infrastructure [13, 18]. Therefore, it is important to conduct thorough study and evaluation of new reliability models, error detection and recovery techniques before they can be deployed in production Grid environments.

To test new detection and recovery schemes in a Grid environment like the above scenario, a lot of work is required to set up the testbeds on many distributed sites. Even if automated tools exist to do this work, it would still be very difficult to produce performance evaluation in a *repeatable* and *controlled* manner, due to the inherent heterogeneity of the Grid. In addition, Grid testbeds are limited and creating

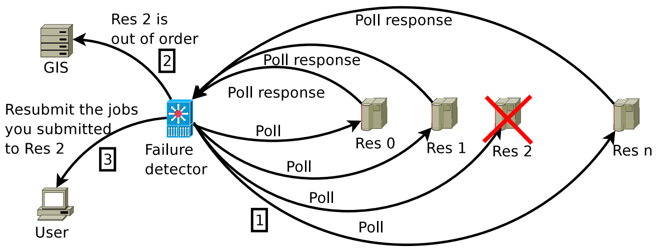


Figure 1. An example of resource failure scenario.

an adequately-sized testbed is expensive and time consuming. Therefore, it is easier to use simulation as a means of studying complex scenarios.

To address the above issues, we have incorporated failure detection and recovery scheme into GridSim [2, 25]. We opted to work on GridSim because it has a complete set of features for simulating realistic Grid testbeds. Such features are modeling heterogeneous computational resources of variable performance, scheduling jobs based on time- or spaced-shared policy, differentiated network service, and workload trace-based simulation from real supercomputers [25]. More importantly, GridSim allows the flexibility and extensibility to incorporate new components into its existing infrastructure.

The main contribution of this work is the implementation of an extension to GridSim. This extension allows GridSim to simulate the failure of computing resources, and includes a failure detection mechanism, essential to provide a complete simulation environment. Most of the parameters of this extension are configurable, allowing researchers to simulate a wide variety of failure patterns. To evaluate our design, we simulate a failure scenario by constructing an EU DataGrid testbed into the experiment [9].

The rest of this paper is organized as follows: Section 2 reviews efforts in order to provide Grid systems with reliability. Also, existing methods for failure detections and several Grid simulation tools are mentioned. Section 3 explains the GridSim toolkit, which is a simulation tool that has been extended to provide the failure functionality. Section 4 describes the failure functionality, including the actual implementation using GridSim. Section 5 shows a use case scenario, where we demonstrate the usefulness of our work. Finally, Section 6 concludes the paper and suggests some guidelines for future work.

2 Related Work

Reliability in Grid computing is a key research topic, being covered by several research projects. Phoenix [13] detects failures by scanning scheduler log files. It can diagnose execution and data transfer errors. Moreover, it can follow different user defined failure-handling strategies. However, the applicability of Phoenix is limited to those systems in which log files can be interpreted.

Application failures can also be handled on a workflow level, where individual tasks may be run alternatively should another task fail. The system in [12] relies on information from a resource broker, but it can also be combined with heartbeat monitors. Pierre [21] utilizes the peer-to-peer (P2P) technologies to perform node management in a decentralized manner. Krepska et al. [14] present a service for a reliable application execution, which keeps track of an application's life cycle, from submission by the user to successful completion of its execution. This service uses a *push* method (explained next) in order to keep track of the execution of applications.

2.1 Existing Resource Failure Detections

In general, computing resource failure can occur in hardware, operating systems, and Grid middleware components, as well as network connections. On the failure of a resource, rescheduling and migration of jobs submitted to the failed resource should be done [11]. According to the work in [8], there are two methods for detecting resource failures, i.e. *push* and *pull*.

The *push* method uses some form of "heartbeat" messages to renew a soft-state availability registration [6]. Each monitored resource periodically sends a message to a central server indicating its availability. Missing a heartbeat after a certain time interval (timeout) T indicates that this resource has failed. Although this method is robust when the central server is running on a highly available system, it is inextricably convolving network failure and host failure. A missing heartbeat or set of heartbeats can either be interpreted as the failure in the monitored resource or the loss of network connection. A real implementation using the heartbeat method can be found at [24].

The *pull* method works by sending a message or a polling request to the monitored resources. On receiving these messages, the resources will send them back, so that the sender knows that each of them is alive. However, if T expires before the sender receives the reply message, it means that the resource is not available at this moment. Hence, the sender will keep an up-to-date list of available resources. However, the *push* and *pull* methods can not differentiate between network and resource failure. The *pull* method has been implemented in the Gridbus Broker [26] and the GridWay [11] meta-scheduler.

2.2 Simulation Tools

As we mentioned previously, simulations are essential for carrying out research experiments in Grid systems. A number of simulation tools for Grids exist, such as GridSim [2], OptorSim [1], SimGrid [16] and MicroGrid [17]. OptorSim has been developed as part of the EU DataGrid project [9], and it aims to study the effectiveness of data replication strategies. SimGrid is an event driven simulator, which provides functionality to simulate infrastructures and applications based on their features. Finally, MicroGrid provides on-line emulation of large-scale network and Grid resources. However, MicroGrid is actually an emulator, meaning that actual application code is executed on the virtual Grid modeled after Globus. To the best of our knowledge the above tools do not provide mechanisms to simulate computing resources failure.

3 The GridSim Toolkit

The GridSim toolkit [2, 25] is one of the most widely used Grid simulation tools. It has been used for simulating and evaluating VO-based resource allocation [4], workflow scheduling [22], and dynamic resource provisioning techniques [23] in global Grids.

It supports modeling and simulation of heterogeneous Grid resources (both time- and space-shared), users, applications, brokers and schedulers in a Grid computing environment. It provides primitives for the creation of application tasks, mapping of tasks to resources, and their management so that resource schedulers can be simulated to study the involved scheduling algorithms. GridSim adopts a multilayered design architecture, as shown in Figure 2 [25].

GridSim is based on SimJava [10], a general purpose discrete-event simulation package implemented in Java. Therefore, the first layer at the bottom of Figure 2 is managed by SimJava for handling the interaction or events among GridSim components. All components in GridSim communicate with each other through message passing operations defined by SimJava. The second layer models the core elements of the distributed infrastructure, namely Grid resources such as clusters, storage repositories and network links. These core components are absolutely essential to create simulations in GridSim. The third and fourth layers are concerned with modeling and simulation of services specific to Computational and Data Grids respectively. Some of the services provide functions common to both types of Grids, such as information about available resources and managing job submission. For Data Grids, job management also incorporates managing data transfers between computational and storage resources. Replica catalogues are information services specifically implemented for Data Grids. The fifth layer contains components that aid

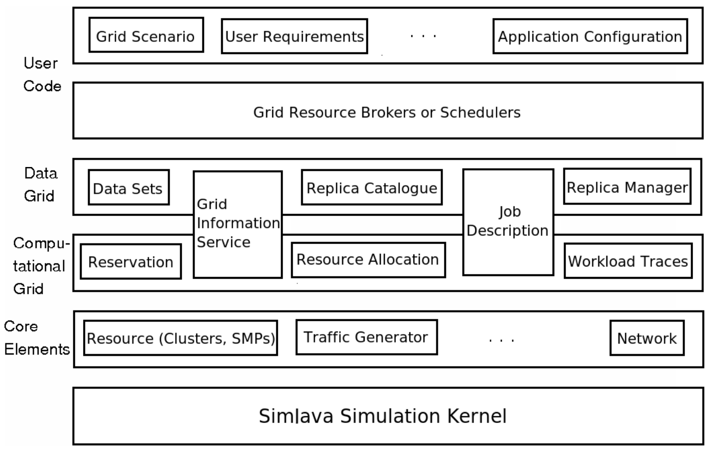


Figure 2. Architecture of GridSim.

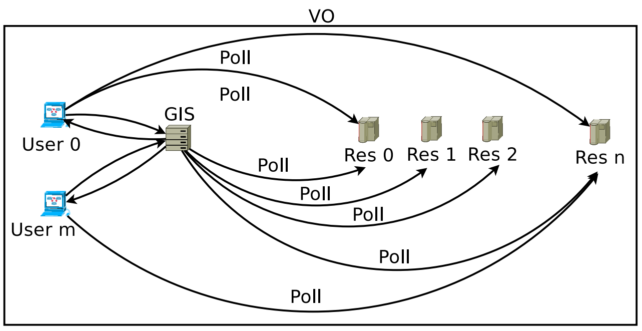


Figure 3. Interactions among entities.

users in implementing their own schedulers and resource brokers so that they can test their own algorithms and strategies. The layer above this helps users define their own scenarios and configurations for validating their algorithms.

In this paper, we incorporate failure detections to all layers of the GridSim architecture, except for the first layer (SimJava kernel) and the third layer (Data Grids). Work on introducing resource failures for Data Grids components will be considered as a future work. The discussion related to the failure architecture will be presented next.

4 Designing and Implementing Resource Failures into GridSim

4.1 Designing Resource Failures

In our model, we use the *pull* method, and the interactions among entities are depicted in Figure 3. These entities are briefly described as follows:

Computing resources: execute users' jobs.

Algorithm 1 Resource Failure Detection Algorithm used by GIS.

```
repeat
    poll the resources in my list of available resources
    if a resource does not respond then
        remove it from the list
        inform other GIS entities about the failure
    end if
    wait for $T^{GIS}_{polling}$ seconds
until simulation is over
```

Algorithm 2 Resource Failure Detection Algorithm used by Users.

```
repeat
    poll the resources which are running my jobs
    if a resource does not respond then
        ask the GIS for a list of resources
        choose one of them
        resubmit the jobs
    end if
    wait for $T^{user}_{polling}$ seconds
until all my jobs have been successfully executed
```

GIS: maintains an up-to-date list of available resources. GIS entities of the same VO can interact and exchange the information of available resources. This process can be summarized in Algorithm 1.

Users: contact a GIS entity for a list of available resources in order to know where to run their jobs. The functionality of this entity can be summarized in Algorithm 2.

For enabling an efficient polling mechanism, User Datagram Protocol (UDP) is used by these entities. This is due to the fact that UDP requires a less significant network latency in comparison with a Transmission Control Protocol (TCP), although UDP does not provide retransmission of lost packets.

Figure 4 shows a scenario of a user that has a job in execution prior to a resource failure. The sequential steps are shown in a box with a number inside. First, *Resource_1* and *Resource_2* register to *GIS* (step 1). Then, *GIS* creates a list of available resources. In order to keep that list up-to-date, *GIS* polls the resources periodically (step 2). When *User* wants to run a job, he/she contacts *GIS* in order to get a list of available resources (step 3). Upon receiving the user's request, *GIS* returns its list. In that moment, *User* will choose *Resource_1* for example, based on the features of the resource and the job specification. When *User* has chosen the resource, he/she submits the job to *Resource_1* and starts a regular polling mechanism.

In the event of a failure affecting *Resource_1*, *GIS* is able to detect this problem due to the polling mechanism in place (step 4). Hence, *GIS* removes the failed resource from the list. During a routine poll, *User* discovers that *Resource_1* has failed. As a result, *User* ask *GIS* for a list of resources (step 5). When *Resource_1* recovers, it registers itself again to *GIS* (step 6). With this approach, *GIS* is able to maintain an up-to-date list of available resources.

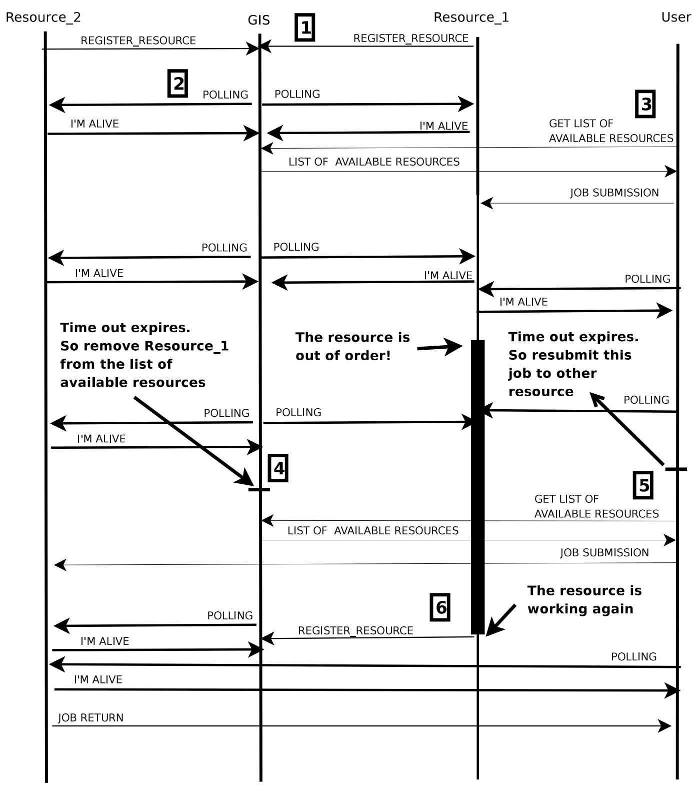

Resource_2
GIS
1
Resource_1
User
REGISTER_RESOURCE
REGISTER_RESOURCE
2
POLLING
POLLING
3
I'M ALIVE
I'M ALIVE
GET LIST OF AVAILABLE RESOURCES
LIST OF AVAILABLE RESOURCES
JOB SUBMISSION
POLLING
POLLING
I'M ALIVE
I'M ALIVE
POLLING
I'M ALIVE
Time out expires. So remove Resource_1 from the list of available resources
The resource is out of order!
Time out expires. So resubmit this job to other resource
POLLING
POLLING
POLLING
I'M ALIVE
4
5
GET LIST OF AVAILABLE RESOURCES
LIST OF AVAILABLE RESOURCES
JOB SUBMISSION
The resource is working again
6
POLLING
REGISTER_RESOURCE
I'M ALIVE
POLLING
I'M ALIVE
JOB RETURN

Figure 4. A sequence diagram showing a scenario of a failure detection.

If the failure only affects some of the machines in a resource, what happens next depends on the allocation policy of this resource. If the resource runs a *space-shared* (first come first serve) allocation policy, the jobs that are currently running on the failed machines will be terminated and sent back to users. However, when the resource runs a *time-shared* (round-robin) allocation policy, no jobs will be failed, as their execution will continue in the remaining machines of the resource. For both allocation policies, the remaining machines are responsible for responding to polling requests from users and GIS. Moreover, they are required to inform the GIS about such failure. This way, the GIS can have accurate information on the current status of the resource.

4.2 Implementing Resource Failures into GridSim

We have implemented the computing resource failure functionality on GridSim version 4.0 [7]. In order to provide GridSim with this new functionality, several new classes have been developed. The new classes are depicted in Figure 5 in italic-bold font. We will explain them next:

GridUserFailure: as its name suggests, this class implements the behavior of the users of our grid environment. Its functionality can be summarized as follows: (1) creation of jobs; (2) submission of jobs to resources; (3) poll the resources used to run its jobs; (4) on the failure of a job, choose another resource and re-submit the failed job to it; (5) receive successful jobs.

GridResourceWithFailure: based on GridSim's GridResource class, this class interacts with RegionalGISWithFailure to set machines as failed or working. It also interacts with classes implementing AllocPolicyWithFailure to set jobs as failed.

AllocPolicyWithFailure: it is an interface class, which provides some functions to deal with resource failures. Each allocation policy implementing this interface will have a different behavior with regard to the failures.

SpaceSharedWithFailure: based on the SpaceShared class, one of the allocation policies available in GridSim. It extends AllocPolicy and implements AllocPolicyWithFailure. It behaves exactly like First Come First Serve (FCFS), and executes each job to one Processing Element (PE).

If there are *still* working machines in a resource on an event of a failure, then only running jobs in the failed machines will be sent back to their users. Moreover, these jobs will be marked as failed. If there are *no* working machines, then all jobs in this resource will be marked as failed and sent back to their users with a special tag. This tag is used to notify the affected users that this resource is out of order. In a real grid, a more realistic behavior would be not sending failed jobs back to their users. However, GridSim does not deal well with entities or users in this case, waiting for an event or a job that never arrives. Therefore, to overcome this problem, we introduce this special tag.

TimeSharedWithFailure: this class is based on the TimeShared class, another allocation policy that exists in GridSim. It extends AllocPolicy and implements AllocPolicyWithFailure. It behaves similar to a round robin algorithm, except that all jobs are executed at the same time. On the event of a failure, if there are *still* working machines in this resource, then no jobs will be marked as failed, since they are not allocated to a specific machine. However, if there are *no* working machines in this resource, then its behavior will be the same as explained for the previous class.

RegionalGISWithFailure: this class is based on GridSim's RegionalGIS class. However, the only difference is that RegionalGISWithFailure provides a support for resource failures, with new parameters: NumResPattern, ResPattern, TimePattern and LengthPattern. These parameters are used to generate number of resources that will fail, which resource will fail, when and how long the failure will be respectively. The NumResPattern can also be reused to choose number of machines that are failed on each resource. These parameters are random number generators based on either continuous, discrete or variate distributions. As a result, a wide variety of failure patterns can be studied.

AvailabilityInfo: This class is used to implement the polling mechanism. The user and GIS send objects of this class to resources, which in turn send them back, as mentioned previously. When a resource still has some working machines left, it will send these objects back with no delay. However, when all machines are out of order, the resource sends these objects back with some delay with a special tag. This is done to simulate a situation, where if a resource does not reply to the given poll before a specified time out, then it is interpreted as not available. This method is used to overcome the same problem in GridSim, i.e. waiting for events that never arrive, as mentioned previously.

GridletSubmission: This class is used to keep track of each job, so that the user knows whether this job has already been submitted or not.

FailureMsg: This class is used as a communication message between RegionalGISWithFailure and GridResourcesWithFailure.

Variate, **LCGRandom**, **HyperExponential** and **Weibull**: These classes are random number generators, adapted from JSIM [19] simulation tool.

5 Use Case Scenario

In this section, we provide a scenario of the new resource failure functionality. We have created an experiment based on the EU DataGRID Testbed 1, as shown in Figure 6 [9].

Table 1 summarizes the characteristics of simulated resources, which were obtained from a real LCG testbed [15]. The parameters regarding to a CPU rating is defined in the form of MIPS (Million Instructions Per Second) as per SPEC (Standard Performance Evaluation Corporation) benchmark. Moreover, the number of nodes for each resource have been scaled down by 10, because of memory limitation on the computer we ran the experiments on. The complete experiments would require more than 2GB of memory. Finally, each resource node has four CPUs.

For this experiment, we have five VO domains and each resource belongs to one of them as shown in Table 1. The VO mapping is done by taking into account a geographical

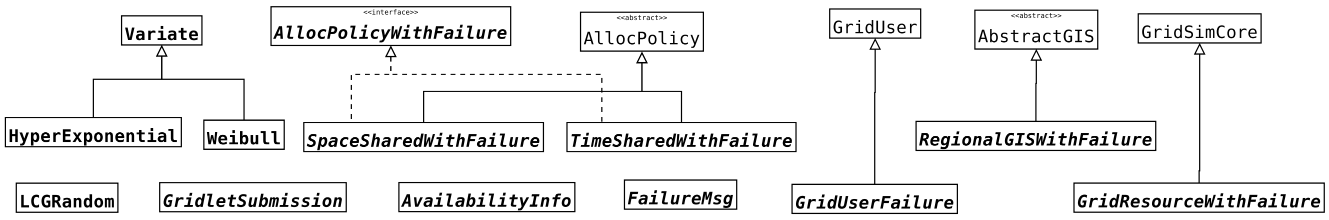


Figure 5. Classes created for the failure functionality.

Resource Name (Location)	# Nodes	CPU Rating	Policy	VO
RAL (UK)	41	49,000	Space-Shared	2
Imp. College (UK)	52	62,000	Space-Shared	2
NorduGrid (Norway)	17	20,000	Space-Shared	3
NIKHEF (Netherlands)	18	21,000	Space-Shared	3
Lyon (France)	12	14,000	Space-Shared	0
CERN (Switzerland)	59	70,000	Space-Shared	0
Milano (Italy)	5	70,000	Space-Shared	1
Torino (Italy)	2	3,000	Time-Shared	1
Rome (Italy)	5	6,000	Space-Shared	1
Padova (Italy)	1	1,000	Time-Shared	4
Bologna (Italy)	67	80,000	Space-Shared	4

Table 1. Resource specifications.

User (Location)	# Users	Primary VO	Secondary VO
RAL (UK)	12	2	4
Imperial College (UK)	16	2	0
NorduGrid (Norway)	4	3	2
NIKHEF (Netherlands)	8	3	4
Lyon (France)	12	0	1
CERN (Switzerland)	24	0	1
Milano (Italy)	4	1	2
Torino (Italy)	2	1	3
Rome (Italy)	4	1	4
Padova (Italy)	2	4	3
Bologna (Italy)	12	4	0

Table 2. Allocation of VO domains to users.

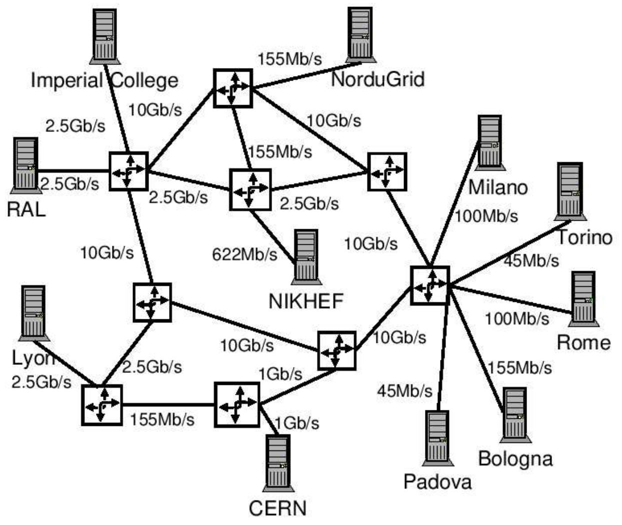


Figure 6. EU DataGRID Testbed 1.

proximity among the resources. We created 100 users and distributed them among the VOs, as shown in Table 2. Each user has 10 jobs and each job takes about 10 minutes if it is run on the CERN resource. Each user belongs to two different VOs and submits jobs to resources from the primary VO. The secondary VO is chosen at random and it is used only when all of resources from the primary VO have failed.

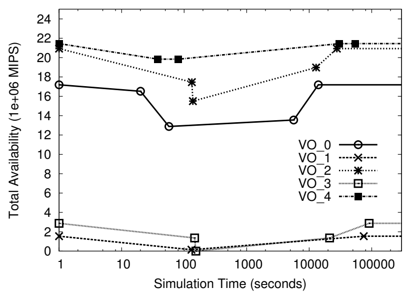
To simplify the experiment setup, some parameters are identical for all network elements, such as the Maximum Transfer Unit (MTU) of links is 1,500 bytes and the latency is 10 milliseconds.

As mentioned previously, the GIS uses a probabilistic distribution on deciding how many resources fail. Therefore, we use a hyperexponential distribution for generating a failure model, since it is suitable for representing availability of resources in different computing environments [20]. The mean of this distribution is set to be a half of the total CPUs of each VO domain. We assume that each VO contains only one GIS entity.

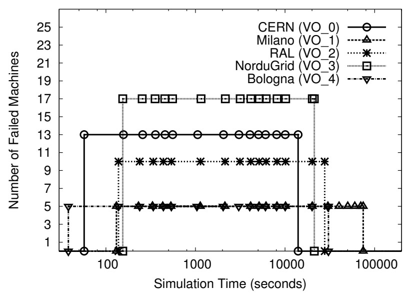
We have modeled the dynamic behavior of the Grid system, as shown in Figure 7 (a). This figure depicts the total availability for each VO varied throughout the simulation time due to resource failures. `VO_0` and `VO_1` suffered a big drop compared to others due to a fact that powerful CPUs suffered a failure.

Figure 7 (b) shows the period of a resource failure on each VO. For simplicity, we assume that failed machines in the same resource have the same start and finish period. In addition, each resource has given a failure notice only once.

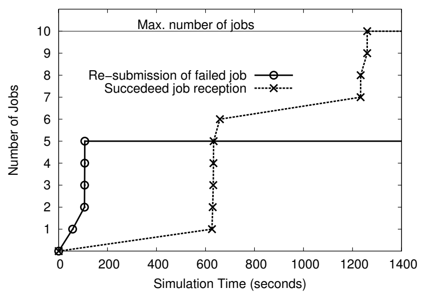
Figure 7 (c) shows an event from `User_0` of `VO_0`. Ini-



(a) Total availability of each VO domain



(b) Period of a resource failure in each VO



(c) Time-line of `User_0`

Figure 7. Time-lines showing the progress of resources and `User_0` from `VO_0`.

VO	# CPUs	# Failed CPUs	# Jobs	# Failed Jobs	MFT
VO_0	71	25	360	219	2.76 hours
VO_1	12	5	100	20	103.36 hours
VO_2	93	24	280	96	5.25 hours
VO_3	35	35	120	120	15.82 hours
VO_4	68	6	140	96	9.50 hours

Table 3. Resource failure statistics.

tially, the user submits 10 jobs to resources from `VO_0`. At around 100 seconds of simulation time, a failure is happening at CERN and the user detects this problem. Unfortunately, one of the failed machines is running the user's job. Hence, this job is being migrated to another machine. The same scenario applies to other four jobs. In the end, all jobs are completed successfully, where some of them finished at time 600 seconds and the rest at time 1200 seconds. The time difference is because the last four jobs were resubmitted to a busy resource, hence they were queued.

Table 3 presents statistics regarding the number of failed machines, Mean Failure Time (MFT), and how many jobs have failed because of that. For `VO_4`, there is a large number of failed jobs compared to the number of failed machines. This is due to a failure of the whole resource that belongs to this VO. More precisely, all the machines in Padova failed, hence all the jobs waiting or being executed in Padova also failed. Similarly, we can see that for an exact period of time, all NorduGrid and NIKHEF machines failed in `VO_3` (also shown in Figure 7 (b)). Hence, users of `VO_3` have to submit all of their affected jobs to their secondary VO. In the end, all jobs were successfully executed.

6 Conclusion and Future Work

Grid systems is a hot topic in distributed systems research at this moment. In order to carry out this research efficiently, simulations are absolutely essential. Hence, simulation tools should cover the main features of real Grid systems, but up to now it is not easy to find a simulation tool covering resource failures and detection mechanisms.

Failures can be modeled in several levels. At a resource broker level, where historical data are kept so that resources which were reliable in the past will be rated highly. At a task level, where repetition, replication and checkpointing are used. Finally, at a workflow level, where execution of alternative tasks, workflow-level redundancy and user-defined exception handling are introduced [12].

In this paper, we have presented an extension to GridSim, which is one of the most widely used simulation tools. Failure models are created by means of probabilistic distributions with fully configurable parameters, so that researchers will be able to decide how these failures take place. By means of this new functionality, researchers will be able to create more realistic Grid models. In turn, this will help them exploring their research projects to different fields of Grid computing, such as Grid scheduling, fault tolerance, and resource discovery. To support the usefulness of our work, we have presented simulation results based on a real Grid testbed. The results show that we have been able to efficiently simulate failure of computing resources.

As for future work, we are planning to use the improved simulation tool to carry out research aimed at providing network QoS in Grids. This will be done by integrating this functionality into the network broker outlined in [3]. Also, in order to make our research more realistic, new extensions regarding network link failures and finite buffers will be added to GridSim.

Software Availability

The latest GridSim toolkit with the resource failure functionalities can be downloaded from the following website:

`http://www.gridbus.org/gridsim/`

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