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Distributed meta-scheduling in lambda grids by means of Ant Colony Optimization

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HIGHLIGHTS

- Ant Colony Optimization is a viable framework for meta-scheduling in lambda grids.
- An integrated control plane for co-allocating grid and networking resources is shown.
- Three different resource co-allocation algorithms are proposed and evaluated.
- RSVP-TE signaling protocol is extended to support advance reservation of resources.
- Local scheduling and information aggregation affect meta-scheduling performance.

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ABSTRACT

Data transport infrastructures based on wavelength-routed optical networks are appealing to the grid community because they can provide a reconfigurable and high-bandwidth network service to emerging data-intensive grid applications. Traditionally, the control plane of those optical networks is independent from the management of other resources, such as computing systems, and it is commonly limited to fulfill immediate reservation demands of lightpaths. However, the lack of network integration to grid resources and the absence of advance reservation of bandwidth are critical aspects to the widespread adoption of optical networks in grid environments. Therefore, in this work, a distributed grid meta-scheduler based on an Ant Colony Optimization (ACO) algorithm is proposed, which is capable of co-allocating both optical networking and grid resources, under an integrated, extended and distributed control plane that supports advance reservations. The blocking probability and the delay for starting the processing of a request are evaluated for the proposed meta-scheduler under different resource co-allocation algorithms and different meta- and local scheduling policies, including the influence of the information aggregation across grid nodes. In addition, the benefits of the proposed approach are shown, such as grid and networking resource integration at the control plane, and capital expenditure reductions at the deployed optical network when compared to an immediate reservation scenario.

1. Introduction

Meta-scheduling is the process of scheduling applications across different sites by orchestrating pool of resources within each local scheduler [1]. This local scheduler is commonly referred as Local Resource Management System (LRMS), since it manages the local resources. Those resources are made transparently available to its users by using network services often supported by commodity Internet, which provides a best-effort transport service.

However, some data-intensive grid applications, such as large scale scientific experiments, do require a dedicated transport infrastructure with large bandwidth associated to strict levels of Quality of Service (QoS) and predictable times, which can be provided by wavelength-routed optical networks [1,2]. When computing resources of a grid are interconnected by an optical network that allows its applications or its meta-scheduler to dynamically request lightpaths on-demand, the grid is commonly referred as a lambda grid [1,2].

In order to fulfill the needs of task requests demanded by grid applications, the grid meta-scheduler has to assure that both computing and networking resources are available at appropriate times by reserving those resources. Since a computing resource can be used only after the setup of a lightpath connection is guaranteed to connect it to the grid application, both computing

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and networking resources have to be co-allocated and then reserved by the meta-scheduler [2].

Reservation of resources in grids typically fall into two categories: immediate reservations (IR) and advance reservations (AR) [2]. The use of resources starts immediately upon the admission of an immediate reservation demand while it is delayed until a future time when an advance reservation is admitted. Note that allowing for advance reservation in a grid environment improves the performance of the scheduling process [3]. However, advance reservations make the meta-scheduling process significantly more complex [4].

Ant Colony Optimization (ACO) [5] algorithms are a promising candidate for meta-scheduling in lambda grids. They are inspired on the observation of the foraging behavior of natural ants, being specially suited for hard-to-solve combinatorial problems or situations where a distributed control is needed. Indeed, in a lambda grid environment, requests are made for lightpath connectivity from an application to a computing resource to be discovered in the grid. In ACO-based algorithms, the discovery of computing resources in the grid is a by-product of the discovery of good routes by the artificial ants. Thus, the ants can gather both resource availability and routing state information in their trips throughout the lambda grid system. In other words, the ants allow for grid and networking resource integration at the control plane of the network. Hence this information can be used in meta-scheduling and co-allocation of the lambda grid resources. In fact, the effectiveness of ACO-based algorithms has already been demonstrated for immediate reservations [6], but their support for advance reservations remained an open research issue.

In this context, the contributions of this paper are three-fold. We present an ACO-based framework for distributed meta-scheduling in lambda grids with support to distributed advance reservation and co-allocation of both computing and optical networking resources. We also present an aggregation mechanism for the information collected by the ants to keep their overhead in the lambda grid system low. In addition, we detail the use of an extended RSVP-TE signaling protocol [7], which has already been used for distributed reservation of resources on optical networks, to also reserve other grid resources and to support advance reservations.

Simulations are carried out to evaluate the performance of the ACO algorithm under different local and meta-scheduling policies, and different resource co-allocation algorithms. Moreover, a comparison with the immediate reservation case is provided to show the importance of supporting advance reservations in order to improve the performance of the scheduling process.

The remaining of the paper is organized as follows. Firstly, we briefly introduce the motivation of this paper and discuss some related works in: (i) ant algorithms for grid meta-scheduling, and (ii) optical network reservation in advance and co-allocation of processing and networking resources for grid environments. In Section 3, we discuss the advance reservation model and, in Section 4, the meta-scheduling architecture used throughout this work. Then, in Section 5, we present our ACO framework for distributed meta-scheduling in advance with co-allocation of computing and optical networking resources. In Section 6, we detail the simulations carried out to evaluate our proposed approach for meta-scheduling in lambda grids. The results obtained through simulations are shown and discussed in Section 7. Finally, in Section 8, conclusions are drawn.

2. Motivation and related work

To the best of our knowledge, there is no other work in the literature with explicit advance reservation and resource co-allocation using ACO-based algorithms for grid meta-scheduling. Besides, all proposed mechanisms in this work are distributed: meta-scheduling, advance reservation and co-allocation of resources.

A complete solution for an advance reservation and resource co-allocation mechanism will need to address the challenges related to the control plane protocols, albeit they are often not investigated in the literature. In this work, these protocols are carefully detailed, with a special focus on the signaling protocol RSVP-TE and its newly proposed objects, and their performance is assessed.

2.1. Ant algorithms for grid meta-scheduling

The inherent load-balancing capabilities exhibited by ant algorithms are a great attractive to job scheduling in grids. For instance, [8] shows that load balancing does improve job scheduling in grids.

In addition to a good load balancing, other important objectives can also be pursued by ant algorithms. In [9], the queue waiting time perceived by resources users is reduced, while in [10], the completion time is minimized.

An experimental validation for ant-based scheduling can be found in [11]. The authors implemented their proposed ant algorithm, which is called Balanced ACO (BACO), in 25 machines across 4 different sites of the Taiwan UniGrid platform. They demonstrated that BACO was capable of balancing the entire system load while minimizing the makespan.

The authors in [12] designed an ant-based scheduling algorithm for workflow applications in market-driven or economy-driven grids. Their algorithm considered multiple QoS parameters, including makespan, reliability, time and cost. Similarly, the ant algorithm proposed in [13], which is called Load Shared ACO (LSACO), also considered memory as a QoS requirement, in addition to the minimization of both the makespan and wait time of the tasks.

A rescheduling mechanism to migrate a task if the grid system has failures on nodes is proposed in [14]. This mechanism introduces fault tolerance in ant-based scheduling in order to improve the system utilization.

In [15], the authors propose two different ant colonies for a two-level job scheduling. The *red ants* are responsible for system state estimation while the *black ants* are responsible for decision making, i.e., the actual decision for resource allocation.

All those previously mentioned works have in common the use of a central entity that is responsible for the scheduling decisions. However, centralized solutions may suffer from scalability and reliability issues.

We believe that the first ant algorithm presented in the literature with distributed meta-scheduling was [16], which was later extended in [6]. By using the AntNet framework, those works presented a distributed meta-scheduling with co-allocation of processing and optical networking resources for immediate reservations.

Other ant algorithm with distributed meta-scheduling is presented in [17]. It also presented a co-allocation algorithm for both processing and networking resources for immediate reservations and it considered an SDH network in the simulations. Their proposed router table can become very big with a large number of resources in the network, which may pose scalability concerns. Aggregation techniques are mentioned in their work as a possible solution to reduce the size of the router table, but they are not applied.

Table 1 summarizes the reviewed ant algorithms, by presenting: the reference of the paper; the objective variable that is minimized/maximized during the scheduling; if the work considers co-allocation of processing and networking resources; and the known ACO variation used, where — indicates that this information was not available/specified at the work or the work proposes a different solution from known variations.