Multi-agent Approach for Managing Workflows in an Inter-Cloud Environment

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Abstract. Despite the several attractive features that offers the cloud technology, managing, controlling processes and resources are among the serious obstacles that cloud service providers need to overcome. These issues increase when cloud providers intend to exploit services from several distributed platforms to satisfy client's requests and requirements. At this moment, they need to deal with some critical problems like heterogeneity, collaboration, coordination and communication between different types of participants.

In another side, the most known properties of an agent are: autonomy, pro-activity, cooperation and mobility. These features are attractive and have a great importance to design and implement software systems that operate in distributed and open environments such like cloud and grid. Our main goal through this thesis is to propose an approach and architectures to permit the integration of cloud/grid and multi-agent systems concepts and technologies for managing workflows in distributed service-oriented environments. Explicitly, in an Inter-Cloud environment.

Keywords: Cloud Computing, Workflow Management Systems, Workflow Petri Nets, Reference Nets, Multi-Agent Systems.

1 Research Issues and Objectives

Service-Oriented Computing (SOC) is the field of computer science that revolves around the concept of "service": Web services, grid services and recently cloud services. It allows the composition of loosely coupled services with different Quality of Service (QoS) constraints to achieve complex distributed applications even in heterogeneous environments [18]. Based on the Internet, cloud computing provides on-demand computing capacity to individuals and businesses in the form of heterogeneous and autonomous services.

Furthermore, we observed the emergence of the Inter-Cloud notion [8,1,20,16], which could be seen as a cloud of clouds [13]. The reason lies in the fact that one cloud infrastructure does not have unlimited resources to satisfy client's requirements and the latter may receive requested services from different cloud providers [8]. At this moment we need to deal with the problem of heterogeneity,

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communication, coordination and collaboration between all participants. Hence, the construction of complex systems remains a problem as soon as there are several independent / autonomous partners involved in the design and execution of these systems. Currently mainly data is stored in the cloud. (Web) services in the cloud are designed to be realized in a static fashion. What is missing is the support of processes in this environment. For complex systems with distributed partners, expressive and powerful software systems have to be provided.

MAS (Multi-Agent Systems) and workflow concepts are strong candidates to address this issue [23,17,7]. On the one hand, commonly accepted characteristics of agents are social ability, autonomy, pro-activity, adaptability, mobility and can be used as basic components for bringing intelligence in cloud systems to make them more adaptive, flexible in both resource management, service discovery/provisioning and in running complex applications. Also in this perspective, mobile agents are used to construct a cloud computing federation mechanism to permit portability and interoperability between different cloud platforms [3,24]. On the other hand, automation of processes and efficient coordination and collaboration between various entities are some advantages of workflow concepts.

However, WfMS (Workflow Management Systems) usually do not address the special aspects of cloud-based systems. Current inter-organizational WfMS are designed to control the autonomous entities (agents or web services) from another location. So it is not embedded within the systems. This causes problems with respect either to the autonomy of the participating partners or their efficient coordination. New concepts and constructs to overcome this problem are necessary.

In order to overcome the problems above cited, this thesis provides a conceptual and technical solution for the modeling and the design of complex systems in cloud-like environments with a special emphasis on processes. I aim to provide an agent-based WfMS, which supports definition, deployment and monitoring of distributed inter-organizational workflows for independent complex partners within cloud environments. The global objective is to investigate and propose approaches, techniques and tools that facilitate the integration between cloud environments and MAS for an efficient management and execution of workflows in environments qualified to be distributed and scalable. That means concretely, I strive to take advantage of concepts and technologies from agents and workflow domain in order to provide a powerful environment for the deployment of user's applications, which are based on multiple cloud platforms.

2 Approach and Methodology

For this research, I intend to exploit some techniques, models and tools, which are part of the Paose (Petri net-based, Agent-Oriented Software Engineering) approach (see `www.paose.net`). On the basis of high-level Petri nets the above mentioned concepts like agents, workflows or services are integrated. The Mulan/Capa (Multi-Agent Nets, see [21]; Concurrent Agent Platform Architecture, see [10]) framework and the Renew (**RE**ference **NE**ts **W**orkshop) (see `www.renew.de`) modeling tool provide the technical background for this.

The description and implementation of this research will be carried out in several steps/phases, which are iteratively applied to have several prototypes. As the first step, a state of the art is continuously elaborated, which evaluates the existing theoretical basis of my work and technological solutions. The basic research areas are: Service-oriented computing, (Inter-) cloud/grid computing, workflow management systems, modeling techniques and tools, agent systems, Petri nets etc. The next step is to define the new requirements for modeling workflow execution in complex environments. I focus on the current issues in Inter-Cloud environments such as heterogeneity, communication, coordination and collaboration between the participants.

Taking into account the new defined requirements, I propose appropriate modeling techniques and concepts that should constitute a conceptual basis for the management of Inter-Cloud applications. UML (Unified Modeling Language) and Petri nets are the major modeling approaches that will be investigated to elaborate such techniques. This step also includes provisioning semantics based constructs that allow for an efficient design of process management of Inter-Cloud applications.

In order to evaluate and validate my results, I propose a direct modeling tool support, which will be implemented on the basis of Renew for the elaborated techniques. The first version is based just on Renew in terms of a drawing and simulation tool for Petri nets and UML models (see [6]). In this version, many refinements and extensions are proposed, in order to allow the future agent-based WfMS to manage interactions with the cloud. One of the main refinements is the introduction of a specialized *Cloud Task Transition* (CTT) (see Fig. 1).

Workflow modelers specify their requirements as parameters to the CTT in form of tuples (S, Q, I), which correspond respectively to the cloud service (S) to be used (it can be a storage or a compute service), the QoS constraints (Q) consisting of deadlines or costs and input data (I) consisting either of required files in case of a storage or scripts if modelers want to execute their codes on the cloud. Synchronous channels are used to make the connection with the WfMS, which controls the completion of the task. It either initiates the firing or cancels it and all input parameters are put back onto the input places.

The second version is based on Mulan and Capa, which allow the simulation and the execution of agent-based systems. Due to the FIPA compliance also distributed execution is possible. An extension for workflows is provided by [12] for Petri nets and by [19] for workflow and WfMS. The third version is based on WfMS implemented on Grid/Cloud either using the Globus Toolkit[1] or existing cloud-based frameworks with a perspective to a future Inter-Cloud environments.

As a prove of concept for the conceptual solution proposed in the dissertation, a prototype distributed over above mentioned prototypes will allow for the investigation of heterogeneous implementation of the approach for the management of workflow in an Inter-Cloud environment. The solution is named Inter-Cloud Agent-based WfMS (IC-AgWfMS). The architecture that we propose is depicted in Fig. 2. It includes three basic layers from top to bottom:

[1] `http://www.globus.org/toolkit/`

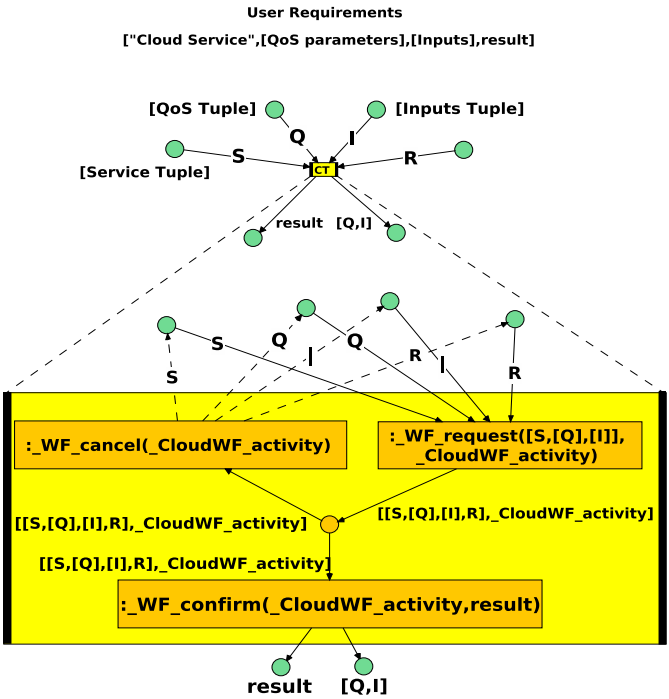

Fig. 1. The Cloud Task Transition

- *The User applications layer* (Ul): permits both managing users (access to the system) and monitoring deployed workflows,
- *The Middleware layer* (Ml): composed mainly of the workflow engine as well as the task dispatcher module (see step 4).
- *The Resource layer (Cloud infrastructure)* (Rl): This layer represents the resources used to excute the workflow tasks. They can be either compute or storage services. This depends on the workflow requirements.

As shown in Fig. 2, managing workflows can be broken down into a series of steps (indicated by numbered circles) and carried out by several components. More details about these steps can be found in [5].

3 Related Work

Much interesting work has been devoted to investigate the possible integration of agent paradigm, workflow concepts and cloud computing. For example, Pandey et al. [17] present a high-level architecture of a workflow management system for developing distributed applications on the cloud. Key components of the presented architecture are: A *Market-Maker broker* and a *workflow engine* to

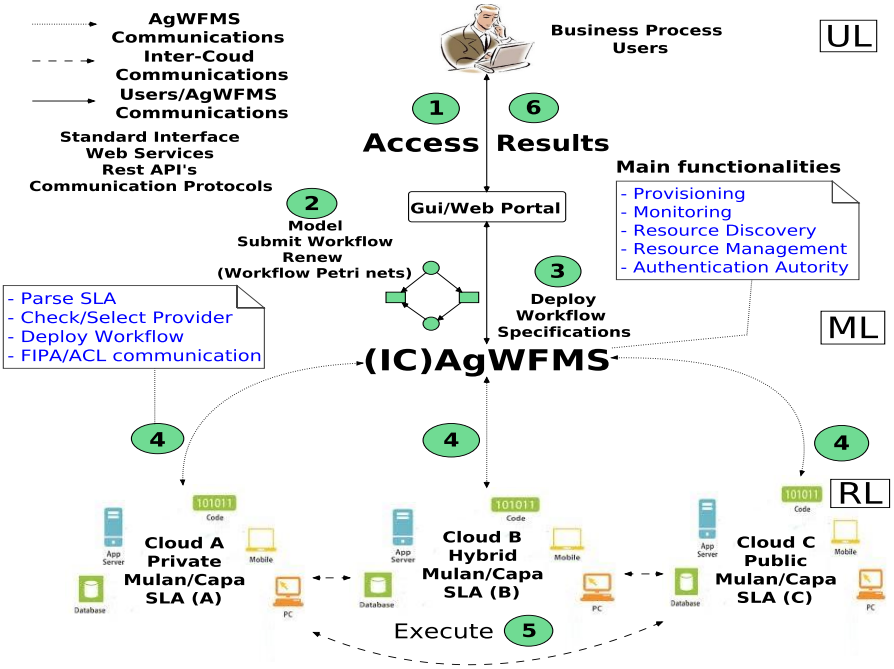

Fig. 2. Inter-Cloud Agent-based WfMS

schedule workflow tasks to the resources based on the QoS constraints. Liu et al. [15] outline three key issues in the design of cloud workflow systems: *system architecture* that decides how the system components are organized and how they interface with each other, *system functionality* that realizes the basic workflow system's functionality and manages the cloud resources, and finally *QoS* management. In [14], *SwinDeW-C*: a peer-to-peer workflow management system for cloud is proposed.

Concerning the Inter-Cloud, Buyya et al. [8] present the notion of federated cloud (Inter-Cloud) that facilitates scalable provisioning of services under variable conditions. In [11], the authors provide a classification of Inter-Cloud delivery models, which are *federated cloud* and *multi-cloud*. The EU-funded RESERVOIR[2] project [20] is the first initiative intending to provide open source technology to enable deployment and management of complex services across different administrative domains. The EU-funded mOSAIC[3] project [16] proposes a complementary solution based on software agents and semantic data processing. The mOSAIC approach is based on a *Cloud Agency* gathering client and provider agents in a brokerage process working with service level agreements. It is used as a Multi-Cloud resource management middle-ware, it plays

[2] `http://www.reservoir-fp7.eu/`
[3] `http://www.mosaic-fp7.eu/`

the role of run-time environment in the model-driven engineering project named MODAClouds [2].

In [24], the Mobile Agent Based Open Cloud Computing Federation (MAB-OCCF) is presented, where data and code are transferred from one device to another via mobile agents. Each mobile agent is executed in a virtual machine called Mobile Agent Place (MAP), and the mobile agents are able to move between MAPs, and also to communicate and negotiate with each other, realizing portability among heterogeneous cloud computing service providers. In [22], the concept of agent-based cloud computing is introduced. This concept is introduced to aid the development of software tools for service operations in the cloud using agent-based cooperative techniques. WADE (Workflow and Agent Development Environment) [9] is a domain independent platform built on top of JADE[4], it allows to develop distributed and decentralized applications based on the agent paradigm and the workflow metaphor.

4 Conclusion and Future Work

The first phase of the thesis is related to establish a study about the related work and the concepts, techniques and tools that are utilized to achieve the objectives. When some parts are well studied such as workflows and Petri nets, other domains still in their infancy and there is a lack of literature and standardizations. Therefore, they need more investigation such as the Inter-Cloud computing notion and agent-based workflow management in the cloud. Concerning the state of the art, many domains related to this research are investigated. This includes: Service Oriented Computing, web services, (Inter-) cloud/grid computing, Workflows, agent and Multi-agent systems, Paose approach, Mulan/Capa framework and Renew, A study about various modeling and composition techniques such as Petri-Nets, BPEL (Business Process Execution Language), Service-Oriented Architecture, WSCI (Web Service Choreography Interface), BPML (Business Process Modeling Language), BPMN (Business Process Model and Notation), WSCL (Web Service Choreography Language), etc.

The implementation of the several prototypes is in progress, this concerns at the first level the ability to invoke cloud services from Petri net models. The solution is based on the use of RESTful web services and cloud APIs. Many refinements and extensions are proposed to achieve this objective [6], which will allow the future agent-based WfMS to manage interactions with the cloud. An approach named Inter-Cloud Workflow Petri Nets (IC-WPN) is proposed [4], for enabling workflows in an (Inter-) Cloud environment. My future work includes finishing the prototypes of the proposed approach along two directions. The first direction is to provide the support modeling tool in Renew. This allows users to specify their workflows and the related QoS constraints through Petri net models. Second, I will use the latter results to implement the proposed models (see [4] for the IC-WPN and [5] for IC-AgWfMS).

[4] `http://jade.tilab.com/`

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