



Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

BNQM: A Bayesian Network based QoS Model for Grid service composition



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ARTICLE INFO

Article history:

Available online 11 May 2015

Keywords:

Grid computing
QoS-aware service composition
Bayesian network

ABSTRACT

The QoS attributes of Grid services play important roles in several tasks in Grid computing such as QoS-aware service composition, service negotiation, resource management, service discovery and scheduling. By considering the dynamic aspects of the Grid environments and also the uncertainty related to Grid services, in this paper, we present BNQM, a Bayesian network based probabilistic QoS Model for Grid service composition. Application of Bayesian network in QoS management makes it possible to indicate the conditional independence relationships among QoS attributes and to provide an effective probabilistic approach to predict new values for some QoS attributes while others are changed. Furthermore, we propose a framework for QoS-aware Grid service composition algorithms to use BNQM. This framework enables the QoS-aware Grid service composition algorithms to use up-to-date QoS values in the composition process. Several experiments conducted using the proposed framework and the achieved results indicate that BNQM is efficient in predicting the QoS values. Also, experiments reveal that using BNQM allows the QoS-aware Grid service composition approaches to use more precise and accurate QoS values, resulting in more precise composite Grid services from the QoS points of view.

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1. Introduction

Grid computing has emerged as a promising next-generation distributed computational platform that focuses on large-scale resource sharing, innovative applications and high-performance orientation (Foster, 2001; Foster & Kesselman, 2004). Open Grid Services Architecture (OGSA) is a refinement of Grid computing architecture that addresses Service Oriented Architecture (SOA) principles and adopts the Web services approach to enhance the capabilities of the Grid environment. OGSA describes a Grid as an extensible set of Grid services that may be integrated in different manners to satisfy the needs of virtual organizations (Foster, Kesselman, Nick, & Tuecke, 2003). Different Grid services, combined with other Grid services from different virtual organizations, can be orchestrated into composite services. Grid users usually submit composition requests as workflows. A usual representation of a workflow is the Directed Acyclic Graph (DAG) in which the nodes represent individual tasks and the directed edges represent inter-task dependencies (Shi & Dongarra, 2006; Yu & Buyya, 2006).

Given a specific task in workflow (*Abstract Service*), several Grid services (*Concrete Services*) which can realize such a task may be provided by different Grid service providers (GSP). In fact, all concrete services corresponding to an abstract service are functionally equivalent and can be replaced by each other. QoS-aware Grid service composition deals with selecting superior individual concrete Grid services from several candidates with different non-functional properties that meets some user requirements.

With regard to the widespread use of SOA and OGSA, the Quality of Service (QoS) has received significant attention. Quality of Service is used to express the non-functional properties of a Grid service such as reliability, availability, response time, cost, etc (Rosenberg, Celikovic, Michlmayr, Leitner, & Dustdar, 2009). User QoS requirements are formulated as a set of constraints which are referred to as *global QoS constraints*. Global QoS of a composite service is computed from the QoS attributes of the components services based on aggregation rule (Rosenberg, 2009; Rosenberg et al., 2009). QoS-aware Grid service composition problem is the selection of the best set of Grid services to compose in a way that global QoS constraints are met. This problem is generally modeled as a Multi-choice Multidimensional Knapsack Problem (MMKP) which is known as NP-hard (Ardagna, Giunta, Ingrassia, Mirandola, & Pernici, 2006; Canfora, Penta, Esposito, & Villani,

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2005; Mabrouk, Beauche, Kuznetsova, Georgantas, & Issarny, 2009; Rosenberg, 2009). By considering the NP-hard nature of the MMKP problem, researchers have proposed different heuristic and non-heuristic approaches for solving it in the Web service and Grid computing contexts.

To the best of our knowledge, almost all these composition approaches assume that the QoS information for candidate Grid services is readily available. Also, these composition algorithms consider the QoS parameters of a Grid service to be fixed and deterministic (Aggarwal, Verma, Miller, & Milnor, 2004; Canfora et al., 2005; Cardoso, Sheth, Miller, Arnold, & Kochut, 2004; Canfora & Penta, 2004; Harney & Doshi, 2007; Jaeger, Rojec-Goldmann, & Muhl, 2004; Yu, Zhang, & Lin, 2007; Zeng et al., 2004). While considering QoS values for Grid services as deterministic can simplify the composition process, nevertheless, it has some shortcomings and hence can lead to inaccurate composite Grid services form the QoS points of view (Wan & Wang, 2007). There exist several reasons which make Grid services uncertain at run time such as server load, number of concurrent users, performance of back end systems such as databases, external factors such as network latency, network throughput, as well as issues like security (Treiber, Truong, & Dustdar, 2009). For example, due to some uncertain factors such as the current load of the machine where the Grid service is implemented, the response time parameter may have different values in several invocations of the Grid service. Therefore, a Grid service selected as a component service in a QoS-aware Grid service composition process may no longer provide the same QoS when it is actually invoked at run-time (Mabrouk et al., 2009).

With respect to the dynamic essence of Grid computing environment and the uncertainty related to Grid services, it is more realistic to assume the QoS values of Grid services as random variables. The concept of probabilistic QoS values has been researched in some former works (Geebelen et al., 2014; Hwang, Wang, Tang, & Srivastava, 2007; Klein, Ishikawa, & Bauer, 2009, 2010; Rosario, Benveniste, Haar, & Jard, 2008; Wiesemann, Hochreiter, & Kuhn, 2008; Zheng, Yang, & Zhao, 2011). The main focus of these works was the estimation of probability distribution functions for QoS values with the assumption that the QoS parameters of component services are independent of each other, which is not the case in reality. In the real-world Grid services, there may exist dependencies among different QoS parameters. For example, slower response time may infer lower throughput. Overlooking these dependencies among QoS parameters can lead to incorrect inference and estimation of QoS values. Considering the aforesaid aspects of the QoS values, algorithms needed to estimate the QoS values of Grid services probabilistically, taking into account the dependencies among them.

Over the last two decades, Bayesian network has become a popular and dominant representation for encoding uncertain expert knowledge in expert systems. It is a probabilistic model that is developed in the artificial intelligence community as a systematic formalism for data representation and reasoning under conditions of uncertainty. A Bayesian network is a graphical model that encodes probabilistic relationships among variables of interest in an uncertain-reasoning problem. Bayesian networks have been developed and used for expert systems in areas such as quality evaluation (Correa, Bielza, & Pamies-Teixeira, 2009), medicine (Arizmendi, Vellido, & Romero, 2012; Arsene, Dumitrache, & Mihu, 2015; Mani, Valtorta, & McDermott, 2005; Sun, Tang, Ding, Lv, & Cui, 2011), financial analysis (Häger & Andersen, 2010; Kirkos, Spathis, & Manolopoulos, 2007; Lu, Bai, & Zhang, 2009), risk management (Lee, Park, & Shin, 2009; Trucco, Cagno, Ruggeri, & Grande, 2008), project management (de Melo & Sanchez, 2008; Lu et al., 2009; Perkusich, Soares, Almeida, & Perkusich, 2015) and etc.

Comparing with other probabilistic models, Bayesian networks have some advanced features (Heckerman, 2008). First, Bayesian networks can handle incomplete datasets by encoding dependencies among all domain variables. Second, a Bayesian network makes it possible to learn causal relationships, and therefore can be used to gain understanding about a problem domain and to predict the consequences of intervention. Third, Bayesian network is an ideal representation for combining prior knowledge and data because it has both a causal and probabilistic semantics. Finally, Bayesian methods in conjunction with Bayesian networks and other kinds of models offers an efficient approach for avoiding the over fitting of data.

Considering the above-mentioned features of Bayesian networks, in this paper, BNQM, a Bayesian Network-based QoS Model, is proposed for QoS-aware Grid service composition. In the proposed model, QoS parameters of the Grid services are considered as random variables of the Bayesian network. BNQM uses the Bayesian network to take the uncertainty of Grid services into account and estimate the QoS values of Grid services probabilistically. To achieve this, inference algorithm used to compute the probability distribution for any subset of QoS parameters. This paper also proposes a framework for QoS-aware Grid service composition approaches to use the BNQM. This framework uses the Ant Colony Optimization (ACO) algorithm mentioned in our previous work for QoS-aware Grid service composition (Pourhaji Kazem, Pedram, & Abolhassani, 2011). The proposed framework is also used to evaluate the BNQM.

With regard to the aforementioned issues, the core contributions of this paper are summarized as follows:

- Proposing a new probabilistic QoS model for QoS-aware Grid service composition using Bayesian network
- Proposing a framework for QoS-aware Grid service composition approaches to use the proposed QoS model

The remaining sections of this paper are organized as follows: Section 2 describes the background on Bayesian networks and presents a formal definition of QoS-aware Grid service composition. In Section 3, the relevant research concerning the QoS models for QoS-aware Grid service composition is presented. Section 4 describes different parts of the BNQM in brief. In Section 5, evaluation methods and the results of several experiments are presented. Finally, Section 6 concludes this paper and discusses future works.

2. Background

2.1. Bayesian networks

A Bayesian network is a probabilistic graphical model that is formally consists of two components $B = (G, P)$. The first component G is a DAG $G = (V, E)$, where V is the set of random variables from the domain $V = \{X_1, X_2, \dots, X_n\}$ and E is the set of edges that represents the conditional dependencies between variables (Korb & Nicholson, 2011). The lack of possible edge between two nodes in G encode conditional independence (Heckerman, 2008). The second component P represents a joint probability distribution for each node of G that satisfies the Markov condition. Assuming the V , the joint probability distribution P can be calculated as:

$$P(X_1, X_2, \dots, X_n) = \prod_{i=1}^n P(X_i | Pa(X_i)) \quad (1)$$

where $Pa(X_i)$ denotes the set of parents of X_i in G .

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