Application of Stable Marriage Algorithms and Cooperative Game Theory to the Building of Cloud Collaborations

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Abstract. Today's cloud environments are very heterogeneous. This cloud heterogeneity, as the consequence of lacking cloud standards, builds technical and security barriers between cloud providers and blocks them from intended cloud collaborations within cloud marketplaces. A cloud broker, who acts on behalf of cloud providers, matches compatible collaborative partners according to their requirements and attempts to support the optimal exchange of cloud resources between them. The cloud brokerage matchmaking process must also consider security aspects. The fulfillment of security requirements in cloud collaborations usually involves providing risk assessments, which are still very time-consuming. In our research we aim at the developing of appropriate optimal mechanisms for cloud provider selection for building cloud collaborations with respect to security requirements. In our paper, we present our initial ideas of the application of the cooperative game theory and stable marriage algorithms in order to provide a solution for proper cloud provider selection.

Keywords: cloud collaborations, cloud provider selection, stable marriage problem, cooperative game theory, cloud market supervision

1 Introduction

Today's cloud environments are built up of heterogeneous landscapes of independent clouds. The heterogeneity of clouds, as a consequence of still nonexistent technology, security and audit standards, presents a hurdle for a proper collaboration between clouds, necessary for the building of the cloud ecosystem and cloud marketplaces [1].

The reasons for cloud collaborations can be very different: enterprise acquisitions, storage and compute power extensions, disaster recovery plans, sub-contracting and service outsourcing, the necessity for a wider spectrum of services, etc. Such cloud collaborations bring cloud providers further advantages. Besides the eco-efficiency, due to shared usage of data centers and technologies [2], a better scalability and cost reduction can be achieved by the ad hoc selling of free resources and buying of additional external resources. This exchange of cloud resources forms the basis of the cloud brokerage service model [3]. Cloud brokerage enables cloud providers to find an optimally suitable match for each other, i.e., to find a collaborative partner that meets all requirements of intended cloud collaboration. These requirements may include business aspects (pricing, timelines), technical aspects (compatibility, interoperability, availability), and of course legal and security aspects (level of data protection, security measures, compliance with different industrial regulations, etc.) [3, 4, 5]. The cloud broker is the main actor in the cloud brokerage service model, and acts as a mediator between cloud service providers and cloud service consumers, providing matchmaking, monitoring and governance of cloud collaborations [6].

The matchmaking of security and legal requirements and especially monitoring of their fulfillment during the cloud collaboration is not trivial. The security risks tend to accelerate by entering into cloud collaborations within cloud marketplaces, because collaborative partners may have different implemented security policies and standards [7]. Therefore, two main requirements must be met to provide secure and compliant cloud collaboration - the cloud broker must perform an optimally reliable security risk assessment prior to the collaboration, or on-demand; and the cloud broker must provide the security governance during the collaboration.

The security risk assessments of cloud providers are widely discussed in the recent research, but, to the best of our knowledge, these assessments are still very time-consuming and cannot be applied to ad hoc cloud collaborations [8]. In this context the following research question need to be answered:

What are appropriate optimal mechanisms for cloud provider selection for building cloud collaborations with respect to security requirements?

The remainder of the paper is organized as follows. In Section 2, we discuss the current cloud market environments and their supervision. In Section 3, we present the principles of the stable matching problem and the cooperative game theory. Section 4 provides our initial idea of application of the stable matching and cooperative game principles to the building of cloud collaboration and the cloud provider selection process. Finally, in Section 5, we outline steps of our future work.

2 Supervision of Cloud Collaborations within Cloud Marketplaces

The current cloud market environments consist of heterogeneous clouds, cloud providers who sell services, customers who buy services, and cloud brokers who help to find the perfect match for their clients. In other words, cloud markets present the aggregate of possible buyers and sellers of cloud services and cloud resources and the transactions between them [9]. But the current cloud markets are still not organized and supervised, if compared to financial or energy markets [10].

The financial and energy markets are supervised by exchanges or other organizations that facilitate and oversee the trade, using *physical locations* (e.g., New York Stock Exchange (NYSE), Deutsche Börse (German Stock Exchange in Frankfurt), or European Energy Exchange (EEX) in Leipzig), or *electronic systems* (e.g., NASDAQ

- National Association of Securities Dealers Automated Quotations, XETRA - Xchange Electronic Trading). These are also regulated by different national and international authorities, e.g., U.S. Securities and Exchange Commission, Monetary Authority of Singapore, Energy Market Authority (EMA) in Singapore, Energy Community (EC) in Europe, etc [11].

Lack of control or supervision is one of main concerns of cloud collaborations within cloud marketplaces. The development of market supervision techniques and approaches for the current cloud marketplaces, to provide *a fair and orderly cloud market*, is still at an embryonic stage. Recently rolled-out Deutsche Börse Cloud Exchange is the next attempt to bring more transparency and safety for cloud market participants and to narrow the gap in cloud market supervision [12].

The trading of cloud resources within predefined cloud collaborations can be seen as *an interim solution* to provide desired supervision and information security governance in cloud markets [9].

Two main principles in the market design theory for the establishment of any fair and orderly market are *stability* and *incentive compatibility* [13]. Both principles are derived from *the cooperative game theory* [13, 14] and *the stable marriage problem* [13, 15] and found very wide application in economics. *Coalitions* building between game players in the cooperative game theory with the purpose of increasing their benefit (only if they play together and not individually) appears to be very similar to the idea of cloud collaborations building. Stability is one of the important drivers for involving new market participants and building collaborations. Incentive compatibility is necessary to prevent manipulations on the market and within collaborations.

In our research we aim at clarification in which way and in what extent the principles of the cooperative game theory and the stable marriage problem can be applied to provide a solution for proper cloud provider selection in the building of cloud collaborations.

3 Principles of the Stable Marriage Problem and the Cooperative Game Theory

Stable Marriage Problem

The stable marriage problem (in its classical form) is a matching problem of two finite disjoint sets $M = \{m_1, ..., m_n\}$ of men and $W = \{w_1, ..., w_n\}$ of women. Each man and each woman has ordered preference lists with the names of preferred partners. The solution is a set of *n* monogamous marriages between *M* and *W*, i.e., bijection of *M* onto *W*, with considering of their preferences. The matching is called *stable* if all partners are married and there are no two people who would both prefer each other than their current partners [15]. Existing algorithms to this problem (e.g., Gale-Shapley algorithm [15], extended algorithms from Donald E. Knuth [16]) solve the problem in *polynomial time*. These algorithms found their application in very different industries to solve real-world situations, such as the assignment of medical graduates to hospitals, children to schools and other National Resident Matching Programs [17]. More complex problems, such as simultaneous assignment of *married couples of medical graduates* to hospitals or the student assignments to universities with predefined *student quota*, are *NP-complete* [16].

Introduced by Alvin E. Roth *the New England Kidney Exchange Program* is another real-world application of stable matching and game theory [17].

Cooperative Game Theory

The cooperative game theory (mostly developed by Lloyd S. Shapley) is based on the *coalitions* building and usage of *transferable utility* [15]. The coalitions consist of players who wish to play (or to work) together to increase their benefits, as the cooperative game (or work) should bring more benefit as by playing alone. It is a principle of *stability* that makes coalitions attractive.

Consider a set of players $P = \{1, 2, 3, \ldots, n\}$. $C \subseteq P$ is a coalition with a transferable utility (any sum of money or other recourses) for this coalition with the value *v(S)*. Let x_i denote the profit of each individual player in the coalition. The coalition is called *stable*, if $\sum_{i \in C} x_i \geq v(S)$.

The transferable utility can be strategically divided between players or transferred if necessary to any of them. To support the principle of *incentive compatibility* all players (as well as men and women in the stable marriage problem) must provide (ideally simultaneously) their (truly) information about payoffs (benefits, preferences) for running a *revelation mechanism*, a mechanism provided by a third party (or mediator) in the play who gathers this information, unveils and analyzes it, and provides with advices and decisions (e.g., matching, partner selection).

Last but not least in this Section - in 2012, the Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel was awarded to Lloyd S. Shapley and Alvin E. Roth "for the theory of stable allocations and the practice of market design" [18].

4 Initial Ideas to the Application of Stable Marriage Algorithms and the Cooperative Game Theory to the Building of Cloud Collaborations

As mentioned above, the building of cloud collaborations has its similarity with the building of coalitions in the cooperative game theory and the selection process of a "compatible" collaborative partner has its similarity with the stable matching problems. In our research we aim at the elaboration of a solution for a stable allocation of cloud providers within cloud collaborations in cloud markets in accordance to their security requirements.

We consider a set of cloud providers $P = \{1, 2, 3, \ldots, n\}$ of any cloud market and $C \subseteq P$ as *stable cloud collaboration* (coalition) with a transferable utility (compute capacity, storage, etc.) for this collaboration with the value *v(S)*. Let x_i denote cloud recourses, which each individual cloud provider possesses. So, $\sum_{i \in C} x_i \geq v(S)$, and this stability motivates cloud providers to enter such cloud collaborations. We consider the incentives of individual cloud providers to form this collaboration to avoid any conflicts of interest within the collaboration that can be solved by binding agreements, policies, and contracts. The *idea of transferable utility* enables freely transfer and sharing of cloud resources among collaboration partners.

Any collaboration has its preference list for new participants, in order to benefit from their entering. In the context of cloud markets this preference list can include technical aspects (number of virtual machines, storage sizes, and capacity parameters), financial aspects (prices, calculated budget for further investments, risk calculations) and security legal aspects (implemented security level, necessary compliance with governmental, local and industrial requirements, etc.). The preference lists can be also seen as a set of constraints for new partners to provide safety within collaborations, e.g., security rating = very high, datacenter tier level = 3, etc.)

The market participants must be appropriately matched in order to trade with each other. The matching is *unacceptable*, if it is worse than remaining unmatched. To provide incentive compatibility, a centralized mechanism for running a revelation mechanism is necessary. Such mechanism in the cloud market context is supposed to be provided by a *cloud broker* or any *cloud exchange*. So, the participants of the market submit their ordered lists of preferences, ideally simultaneously, and a cloud broker allocates them. The truth-telling and the completeness of submitted information is very important here, as misrepresenting of the preferences can lead to the loss of benefits.

The evaluation of our first ideas with extended (weighted) Gale-Shapley algorithm based on the *deferred acceptance* tactic [16] (i.e., the final matching of participants occurs only after the consideration of preferences of all participants) terminated in the *polynomial time*. Parameters, we included for matching, were: types of collaboration services (only IaaS cloud services), predefined overall minimum for the security rating (without particular values for security controls), maximum budget for collaboration and unlimited number of collaborative partner.

5 Future Work

In our future work, we are going to extend our model and evaluate it for the cases when the information in preference lists is not complete. One possible solution here can be the usage of cloud providers' historical data. The next extension that must be considered is a possible multiple collaboration of cloud providers. If cloud providers (simultaneously) enter different collaborations with different preference lists and what impact it can have especially for their security rating. The security rating approach is intended to be developed as well.

Our next challenge is the definition of quota (limited number of partners) in collaborations and integration of waiting lists, in case the possible matching is unacceptable. Furthermore, more granular security requirements are planned to implement for different cloud services and for proper cloud provider selection.

Acknowledgment. This work is supported in part by E-Finance Lab e. V., Frankfurt am Main, Germany (http://www.efinancelab.com).

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