Cloud Federation Formation Using Coalitional Game Theory

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Abstract. Cloud federation has been emerged as a new paradigm in which group of Cloud Service Providers (SP) cooperate to share resources with peers, to gain economic advantage. In this paper, we study the cooperative behavior of a group of cloud SPs. We present broker based cloud federation architecture and model the formation of cloud federation using *coalition game theory*. The objective is to find most suitable federation for Cloud SPs that maximize the satisfaction level of each individual Cloud SP on the basis of Quality of Service(QoS) attributes like availability and price.

Keywords: Cloud federation, Coalition game, satisfaction level, cloud broker, Cooperative game.

1 Introduction

Delivering cloud services are often a delicate balancing act where service provider (SP) has to balance resource request traffic, maximize resource utilization and accommodate spikes in demand while satisfying service consumer's service level agreements (SLAs). With more awareness and growth in the cloud market, demand for cloud resources has increased and it will become difficult for individual SPs to fulfill all resource requests without violating SLAs. Hence this necessitates cloud SPs to form federation for seamless provisioning of resource requests across different cloud providers. Cloud federation is the practice of interconnecting the cloud computing environments of two or more SPs where each SP can share resources with peers to gain economic advantages. In the last few years, many cloud service providers are moving into federation, some relevant research works in this field can be found in [1],[2],[3],[4],[5]. However, none of these works in the literature considered the cloud federation formation based on cloud SP QoS attributes, from the game theoretic perspective. The major contribution of this paper is to formulate the cloud federation as a coalitional game. The proposed cloud federation mechanism is based on satisfaction level of cloud service provider QoS attributes (availability and price).

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2 Cloud Federation Architecture

In this section, we propose a broker based cloud federation architecture, which is an extension of the cloud service broker architecture [6]. It finds the best federation from a set of federations $fd = \{fd_1, fd_2, \cdots fd_y\}$ where each $fd_j = \cup SP^i$, $SP^i \in \eta$ where $\eta = \{SP^1, SP^2, SP^3, \cdots\cdots SP^Z\}$ denotes set of cloud service providers. The components of cloud federation architecture are (a) *Service Provider Broker (SPB):* administers a set of registered cloud SP and set of federation formed by different cloud SP, (b) *Broker Coordinator (BC):* handles all internal request for fd_j and intimate every update to SPB, (c) *Virtual machine instance type ($VMIT_{I_x}$):* keep homogeneous types of instances information of different SP in fd_j where $I = \{I_A, I_B, \cdots\cdots I_y\}$, define the particular type of instances and (d) *Sub Broker Coordinator (SBC):* is part of each $VMIT_{I_x}$ and maintain records of all virtual machine and simultaneously handles all request received by BC. Two important QoS attributes for a cloud SP are the price and availability. Availability is defined as the uptime of the service and price is defined as the amount of charge that a cloud Service Consumer (SC) has to pay to use the service. It is assumed that a SP with high availability will charge high price for its services. Let availability and price of SP be $a = \{a_1, a_2, \cdots a_\eta\}$ and $p = \{p_1, p_2, \cdots p_\eta\}$. Then we can formulate the relation between price and availability as $p_i = \rho * a$, where we consider ρ as a proportionality constant and its value denotes price of SP whose availability is 1, here the assumption is that all SP with same availability will have same price to offer.

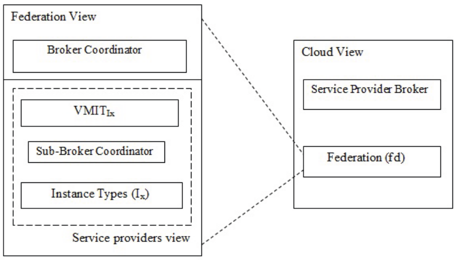

Fig. 1. Cloud federation architecture

3 Formation of Cloud Federation as a Coalition Game

In this section we model cooperation among autonomous rational cloud service provider based on coalition game theory, and design a systematic approach that helps SP to form a set of coalition or federation *fd*. A cooperative game or a coalition game with transferable utility is defined as a pair (η, v), where η is a set of players and $v : 2^\eta \rightarrow \Re$ is a characteristic function (value), with $v(\emptyset) = 0$ and $v(\eta) \geq \sum_{i=1}^{z} SP^i$. Here value represent the profit achieve by federation when different cloud SP work as a group [7].

Availability of a service (here $VMIT_{I_x}$) in a federation is very important and is achieved by the cooperation among members in a federation and their individual availability. The cooperation among SP in federation are managed by BC, according to optimal arrangement order, $\alpha = \{E_j^{SP^i} | j = 1, 2, \cdots z \text{ and } SP^i \in \eta\}$. Request of SC is processed based on arrangement order of SP in α. Therefore based on conditional probability, unavailability of $VMIT_{I_x}$ of federation fd_j is given by $U_{fd_j}^{VMIT_{I_x}}(\alpha) = \prod_{i=1}^{N} u_{I_x}^{sp^i}$.

Therefore availability will be given as $A_{fd_j}^{VMIT_{I_x}}(\alpha) = 1 - U_{fd_j}^{VMIT_{I_x}}(\alpha)$, where $u_{I_x}^{sp^i}$ are the event of unavailability of I_x and $U_{fd_j}^{VMIT_{I_x}}(\alpha)$ and $A_{fd_j}^{VMIT_{I_x}}(\alpha)$ denotes unavailability and availability of $VMIT_{I_x}$ in federation fd_j. Here it shows that availability of $VMIT_{I_x}$ arranged in pre-defined order of SP, based on availability of independent elements with equivalent distribution in a federation is the product of availability of each instance $I_x^{sp^i}$ of SP^i.

We consider a set of rational Cloud Provider as η which will form federation among them. Suppose SP^i offers $I_x^{SP^i}$ where each instances are differentiated based on specific number of cores $Co_{I_x}^{sp^i}$, amount of compute unit $Cu_{I_x}^{sp^i}$, amount of storage $m_{I_x}^{sp^i}$ and amount of memory $s_{I_x}^{sp^i}$. Each cloud SP^i incurs cost when providing resources. The respective cost of $I_x^{SP^i}$ type of instance of SP^i can be derived as follows $c_{I_x}^{sp^i} = Co_{I_x}^{sp^i} \cdot p_C + Cu_{I_x}^{sp^i} \cdot p_{Cu} + m_{I_x}^{sp^i} \cdot p_m + s_{I_x}^{sp^i} \cdot p_s$, where p_C is the cost of each core, p_{Cu} is the cost of one compute unit, p_m is the cost of one GB of memory and p_s is the cost of one GB of storage. In cloud federation, the cost of federation is based on availability of each $VMIT_{I_x}$. The cost of each $VMIT_{I_x}$ in federation relies on the cost(offered price) and availability of individual instance $I_x^{sp^i}$ of SP^i. The cost of federation fd_j will be the sum of cost of each instance I_x of federation fd_j provided by SP^i is defined as:

$$C_{fd_j}(\alpha) = \sum_{I_x \in I} \sum_{i=1}^{N} \prod_{k=1}^{i-1} u_{I_x}^{sp^k} \cdot a_{I_x}^{sp^i} \cdot c_{I_x}^{sp^i} \quad (1)$$

where $a_{I_x}^{sp^i}$ denotes the availability of service provider SP^i of instance type I_x. The total chargeable price of instance I_x in federation fd_j is defined as:

$$P_{fd_j}(\alpha) = \sum_{I_x \in I} \rho_{I_x}^{sp^i}(\alpha) \cdot A_{fd_j}^{VMIT_{I_x}}(\alpha) \quad (2)$$

where $\rho_{I_x}^{sp^i}(\alpha)$ is the price of instance I_x whose availability is 1 and $A_{fd_j}^{VMIT_{I_x}}(\alpha)$ is the availability of instance I_x in federation fd_j. The payoff of federation formed among cloud SP is composed of the total gain obtained by the group of cooperative SP in Federation fd_j. The payoff function for any cloud federation fd can be expressed as $v_\alpha(fd_j) = P_{fd_j}(\alpha) - C_{fd_j}(\alpha)$, where $v_\alpha(fd_j)$ is the total payoff obtained by federation fd_j, which is equal to difference between the revenue received $P_{fd_j}(\alpha)$ from the cloud service consumer and the cost $C_{fd_j}(\alpha)$ incurred by cloud SP. All cloud SP produces the extra payoff through forming federation. Therefore for fair distribution of possible payoff, we choose Shapley value to decide a fair allocation in a cooperative game theory [7].

In this paper we have defined satisfaction level as in [6] (i) to measure satisfaction $sat^{SP^i}(fd_j)$ of SP^i in federation fd_j and satisfaction $sat^{SP^i}(I(SP^i))$ ($I(SP^i)$ (denotes the identity federation i.e federation consisting of single SP) of SP^i without being in any federation and (ii) to measure satisfaction $sat(fd_j)$ of federation. In our research satisfaction level $sat^{SP^i}(fd)$ and $sat^{SP^i}(I(SP^i))$ are calculated based on service provider two QoS attributes profit and availability. Whereas satisfaction level $sat(fd_j)$ of federation are calculated based on value and availability of federation. Thus the total satisfaction level $sat^{SP^i}(fd_j)$ for SP^i in federation fd_j is given by sum of $sl^{SP^i}_{fdj}(G) \cdot w^{SP^i}_G$ and $sl^{SP^i}_{fdj}(A) \cdot w^{SP^i}_A$, where weight w represent the factor of importance of corresponding attributes satisfaction level. We have assume equal value of weights w $(w_G + w_A = 1)$.

Distributed approach of coalition formation *algorithm* for cloud federation is presented here. It is assumed that at any time any SP or any formed coalition can join a new coalition or leave a current coalition. SPB on receiving merge or split request from any SP or coalition, it first evaluates the request and then perform required actions. Other than this SPB at every time interval checks for availability of $VMIT_{I_x}$ type of resource for every federation (coalition). If any type of $VMIT_{I_x}$ of any federation is below threshold value (predefined) then SPB intimates BC of following federation. BC on receiving SPB intimation, it acknowledges that with new request to merge with new SP or federation. In order to form a federation, we define some set of preference rules based on satisfaction level over possible federation(coalition) partition λ [8], where (i) a service provider will merge any federation if it's individual satisfaction level increases in federation otherwise will split, (ii) federation will merge with other federation or service provider only if it get some gain in terms of satisfaction level.

4 Simulation Result

In this section we analyze how SPB help different SP to form federation based on defined preference rules. We have considered twelve cloud SP. Each cloud SP provide three types of instances namely small, medium and large as specified in Amazon EC2 [9]. The details of cloud SP based on small instance, are provided in Table 1. We have evaluated four scenarios (Figure 2) of federation formation as shown in Table 2. Figure 2(a) compare average satisfaction level of individual SP in identity federation for two different cases. From Figure 2(b), it is noticed that federation $fd(SP-6, SP-2)$

Table 1. Profit obtained by each service provider on each instance

Service Provider	Availability	Instance cost	Chargeable Price	Profit	Satisfaction level
SP-1	.95	148	250	102	0.60636
SP-2	0.90	140	200	60	0.53966
SP-3	0.85	130	194	64	0.51521
SP-4	0.80	124	190	66	0.48893
SP-5	0.77	120	185	65	0.47113
SP-6	0.75	117	178	61	0.43621
SP-7	0.70	109	165	56	0.42349
SP-8	0.65	101	160	59	0.398125
SP-9	0.60	93	148	55	0.36632
SP-10	0.55	85	140	55	0.33820
SP-11	0.50	78	115	37	0.29354
SP-12	0.45	70	100	30	0.25899

Table 2. Four scenarios of federation formation

Scenario	Description
Request by identity federation(single SP) to merge with other identity federations	Four different identity federations, say, $fd(I(SP-2)), fd(I(SP-7)), fd(I(SP-9)), fd(I(SP-11))$ send request to SPB for federation formation. These identity federations form a new federation among themselves as shown in Figure 2(a).
Request by federation to merge with new identity federation(single SP)	Federation $fd(SP-6, SP-2)$ send a request to form a federation with identity federation. SPB will find best identity federation, Figure 2(b) shows that federation $fd(SP-6, SP-2)$ receives improved satisfaction level when it merges with $fd(I(SP-3)$. Thus the new federation is $fd(SP-6, SP-2, SP-3)$.
Request by SP to split from current federation to merge with new federation	Identity federation $fd(I(SP-9))$ will merge with federation $fd(SP-8, SP-5, SP-9)$ because satisfaction level of $fd(I(SP-9))$ increases in this new federation, in compared to its satisfaction level in existing federation as shown in Figure 2(c).
Request by federation to merge with new federation	A federation $fd(SP-10, SP-4)$ sends request to SPB to find a suitable federation, such that it gives rise in satisfaction level as shown in Figure 2(d).

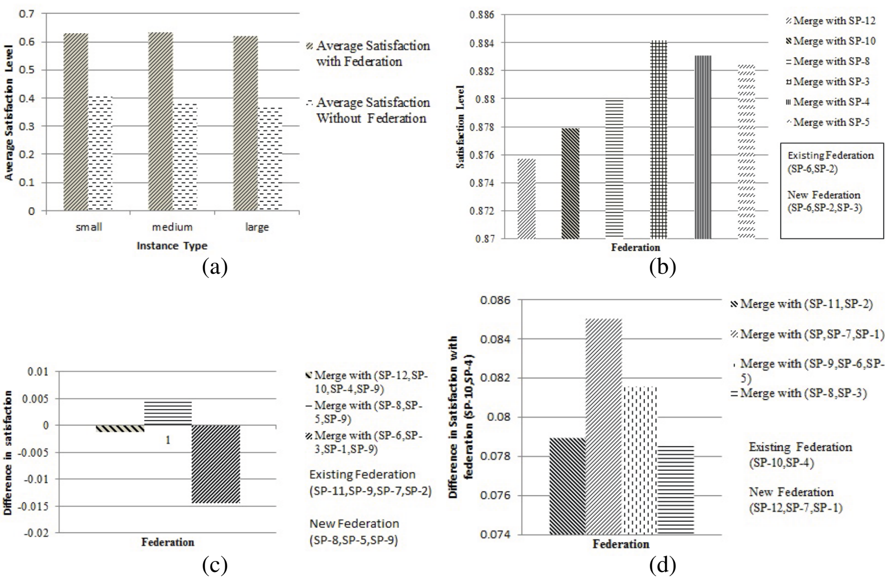

Fig. 2. Satisfaction level in (a) scenario 1 (b) scenario 2 (c) scenario 3 (d) scenario 4

will achieve highest satisfaction level when it merge with fd(I(SP-3). Figure 2(c) shows satisfaction level difference between existing federation and new federation of SP-9 and Figure 2(d) shows difference in satisfaction level of federation $fd(SP-10, SP-4)$ with other new federation.

5 Conclusion

The main objective of this paper is to study the cooperative behavior of group of cloud service provider in federation. First we present broker based cloud federation architecture. Then a coalitional game model has been proposed to obtain cooperation decision of the cloud service provider in different cloud federation. In this paper we design a scheme of coalition formation of cloud SPs based on their individual QoS attributes like availability and price. SPB makes decision to merge or split based on satisfaction level of service provider and federation. Based on cloud federation framework, we show how federation can be formed between different cloud service providers. The simulated result presents four different scenarios of federation formation.

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