An Overlapping Coalition Formation Approach to Maximize Payoffs in Cloud Computing Environment

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***Abstract*—Data-intensive applications are anticipated to increase day by day. The amount of computing and storage resources required by these are also increasing simultaneously, creating high demands for cloud resources. Cloud provider's limited resources are not adequate to meet the elastic demand of consumers. Cloud coalition is the key approach to deal with such elastic demand of resources in the environment. But traditional coalition formation mechanism allows a cloud provider to participate into a single coalition which leads to under-utilize of coalition resources with increasing security risk like *botnet* attacks. In this paper, a mathematical framework from cooperative game namely overlapping coalition formation (OCF) game to overcome the under-utilization problem and to reduce security risk for cloud providers (CPs) is introduced by permitting a CP to participate into multiple small coalitions. First, the concepts of OCF game in cloud is presented and then, an algorithm for the stability in OCF game is introduced. We analyze the performance of the proposed approach with traditional coalition formation and no-coalition scenarios in perspective of payoffs, yielding higher payoffs for the participating CPs.**

***Keywords*-cloud provider; elastic demand; overlapping coalition formation; payoffs; stability;**

I. Introduction

Cloud computing is a new archetype tempting an increasing number of customers due to its various advantages including accessibility, cost-efficiency, elasticity , protection, ease of deployment, resource management efficiency, etc. There is no doubt about the significant expansion in the quantity of data stored for different purposes including authoritarian compliance by organizations. As cloud computing is getting popular, the consumers are free from building and maintaining their own database, which is very costly. With the growth of cloud computing, the data outsourcing option is practical and efficient. The on demand business model of cloud computing assures a number of benefits such as low capital investments, elasticity and easy setup. By the way, it offers better capacity and better services without investing heavily in new infrastructures[1]. Cloud computing is anticipating to make possible remote and on-demand access to shared and configurable computing resources whenever you like. Currently, consumers are able to take advantages of cloud resources and services in a pay-as-you-go manner at anytime from anywhere. There are different mechanisms to distribute cloud services to consumers and Infrastructure as a Service (IaaS) is one of them. It permits cloud providers to trade resources in the form of Virtual Machines (VMs) to the cloud consumers. VMs are provided in the name of instances where instance types consists with varying combinations of CPU, memory, storage and networking capacity. Consumers can purchase the instances using one of the three models namely on-demand, reserved and spot. Amazon Web Services (AWS) charges consumers by rounding up the number of hours used with minimum use hour is one and Google Cloud Platform(GCP) charges for instances based on usage in minutes with a minimum of 10 minutes [2]. GCP announced a sustained-use pricing [3] for compute services where discount will be provided for a particular instance if it is used for a larger percentage of the month. Azure charges customers by rounding up the number of minutes used for on demand. It also offers short-term commitments with discounts. The price of the instance depends on its type and provider and reserved instance save upto 75 percent of consumers' cost compared to on-demand instance pricing in case of AWS [4].

The amount of computing and storage resources required by different data-intensive applications are increasing dramatically, which is generating high demand for cloud resources. But this demand is resilient and a cloud provider cannot fulfill the demand of its' consumers with limited resources. Coalition formation among CPs is the key mechanism to deal with such scenarios. The most straightforward solution is to form grand coalition as it is simple and easy to implement. But there are situations when the grand coalition does not produce the optimal payoffs for the involved CPs and a more sophisticated coalition is necessary [5]. But most of the existing works focus on maximizing payoffs by allowing a provider to participate in a single coalition. Sometimes , this turns into under-utilization of available resources in the coalition due to the lake of demands in that coalition and it also increase the opportunity of *botnet* attacks due to lots of resources are sharing in the process. So it is necessary to permit a cloud provider to take part in multiple coalitions, and consequently, provide more opportunity for the players to utilize their resources, reduce the chance of botnet attacks by making smaller coalition, reduce unsatisfied cloud consumers, which leads to higher payoffs.

In this paper, we propose a mathematical framework for overlapping coalition formation among CPs by using cooperative game for getting better payoffs for the participating players, joining in multiple coalitions simultaneously. The rest of the paper is organized as follows. In Section II, we describe some of the literature review. In Section III, we discuss about problem formulation with an illustrative example. Stability in OCF game is discussed with an algorithm in Section IV. In Section V, we present the results from an experimental evaluation to show the effectiveness of the proposed approach. Finally the paper is concluded in Section VI with some future direction.

II. Literature Review

We find no research work based on OCF game of clouds depending on cooperative game in the literature. We find some works using cooperative game on OCF structure in wireless communication system [6], [7]. But there are lots of works in cloud that focus on maximization of payoffs depending on federation mechanisms [8]-[19]. Rochwerger et al. discussed the primary requirements for forming federations or coalitions of CPs [8]. In the paper [9], authors provided a model to take easy decision for forming cloud federations among providers in order to maximize profit. But they did not consider the profits of other clouds when they provided resources and they also did not take into account different types of VMs and their heterogeneous resources. Hasan et al. proposed a game based solution for allocating resources dynamically in a cloud federation [10]. They defined a price function for cloud provider that distribute incentives to other cloud providers who contribute to make federation. In [11], Niyato et al. studied the behavior of multiple cloud providers when they form coalition by using stochastic linear programming game. Here cloud providers can cooperate and form a logical pool of computing resources to accommodate the internal and external demands from the consumers. They found two major challenges due to cooperation among providers: sharing of gains and stability of coalition. They present a cooperative model composed of two interconnected cooperative games to dill with this challenges. They didn't consider the individual cost of each cloud provider. Mashayekhy and Grosu modeled cloud federation formation problem depending on the coalitional game and formulate the problem as a Integer Programming based optimization approach in [12]. They want to maximize the profits of cloud providers by dynamically forming cloud federation along with stable coalition. The authors only consider resource constraints at low-level but don't consider operational cost of the provider which is an important factor in case of economic model and strategic composition of collaboration.

In the research work [13], Li et al. explored profit maximization techniques of cloud providers, forming cloud federation by selling VMs through auctions. They used a truthful double-auction based method for trading VMs within the federation for clouds. In [14], the problem of sharing idle resources in a federation of cloud providers for VM spot marketing is formulated as a non-cooperative repeated game. The objective of cloud provider is to maximize profit by selling unused capacity in spot market. They used Markov model to predict non-spot workload of future. They also initiated a set of resource sharing mechanisms that maximize long-term revenue of the federation by proposing a dynamic programming algorithm to find the allocation rules.

Guazzone et al. extended their previous work in [15] and also proposed a cooperative game-based framework to solve the problem of cloud federation formation in an energy-aware and distributed manner by using hedonic game. The mechanism mostly focus on individual profit gains of cloud providers when they makes federation. This profit mostly depends on number of resources it provides and cost of providing resources to the coalition. They didn't take into account the impact of unreliable cloud providers into the federation.

Sekar and Maniatis [16] proposed verifiable resource accounting for cloud computing that is beneficial both for cloud providers and consumers. The approach gives consumers assurance that the bill s/he is paying depending on the consuming amounts of resources. On the other hand, providers can get the chance to improve their revenue level by more perfectly accounting resources and by escalating their resource utilization via increased cloud adoption. There is a Trusted Third Party (TTP) in the centre of the system and provider and consumers need to rely on it totally or partially for the accounting process.

Cloud federation is the prime technique considered for cloud elasticity to surmount the dilemma of scarcity of resources. The major challenge of such federation is revenue sharing mechanism based on the effective resources of the cloud providers. Fairness of distribution of revenue and stability of cloud federation are two important issues. In the paper [17], Zant et al. proposed a novel pricing and revenue distribution model for the federated cloud environment. But they didn't take into account the resource allocation process with future demand and available capacity of the providers.

Xu et al. proposed a cooperative algorithm for allocating federated cloud resources using game theory in the research paper [18]. The technique considers QoS constraints and provides two different approaches for cost-sensitive and time-sensitive cloud consumers. They don't consider the time of allocated VMs for their work. A set of self-interested cloud providers form a federation that provides requested resources to the consumers by creating a virtualized resource pool provided by the cloud providers with guaranteed QoS. As a result forming coalition facilitates to realize greater scalability and performance. Mashayekhy et al. [19] proposed a profit-driven game theoretic approach for offering cloud IaaS services to the consumers by forming cloud federation. Such federation can offer cloud resources to the consumers at a lower costs. Their mechanism produces a stable cloud federation with high revenue.

The popularity of the cloud service leads to the dilemma between cloud providers and consumers as both parties want to maximized their gains from the system. The non-cooperative decisions of provider and consumer will possibly result in corresponding loss of welfare for the both parties. In the paper

[20], the authors model the interaction between provider and consumer as a Stackelberg game and welfare of both parties are maintained by applying Nash Bargain Solution (NBS).

Most of the existing works focus on maximizing profits by allowing providers to participate in a single coalition. In our work, we assume that CPs are able to participate in multiple coalitions simultaneously, forming overlapping coalition structure among the CPs.

III. Problem Formulation

To provide on-demand resources to the consumers and to increase the utilization of resources, CPs generally form coalitions. Thus they try to reduce the dissatisfaction cost from the customers. Most of the existing works that focus on maximizing profits, but don't consider the security cost and cooperation cost of forming coalition. With the increase of the size of coalition, the probability of *botnet* attacks increase and also increase the cooperation cost for the providers and sometimes make some resources under-utilized. On the other hand, overlapping coalition formation gives providers the opportunity to take part into multiple coalition with required resources, making coalition small and better utilize their resources, reduce *botnet* attack probability, reduce unsatisfied consumers, makes the payoffs better. Each cloud provider (player) posses a certain amount of resources in OCF game. The players form coalitions by contributing a portion of their resources and get payoffs from there. A coalition can be characterized by the resource vector $\mathbf{C} = (R_1, R_2, ..., R_N)$ of the participating members of the coalitions where R_i is the resource contributed by player i. The coalition value (the total payoff generated by the coalition) is determined by a function $v : \mathbf{C} \mapsto \Re^+$. For our work, we have considered the following equation to calculate the payoffs of a coalition where the meanings of the symbols are shown in the Table I.

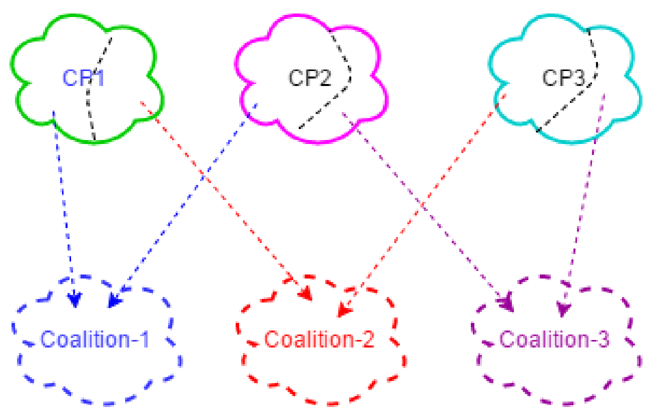

Fig. 1. Basic structure of OCF among CPs

$$\nu^{\mathbf{C}} = \sum_{i=1}^{N} R_i^g b - (\sum_{i=1}^{N} R_i^r - \sum_{i=1}^{N} R_i^g) c_d - \sum_{i=1}^{N} R_i^c c_s - c_c^N \quad (1)$$

In cooperative game, CPs intend to form coalitions in order to boost their payoffs. For the stability of the coalitions, payoffs should be fairly distributed among the participants of the coalition. For ensuring the fairness in the distribution of payoffs, we consider the marginal contribution of the participants in the coalition as in the case of Shapley value [21]. Particularly, the payoff of player i from the coalition $\mathbf{C}$ can be defined as shown in equation (2).

$$\phi_i(\mathbf{C}) = \frac{R_i^g}{\sum_{j=1}^{N} R_i^g} \nu^{\mathbf{C}} \quad (2)$$

If $\Pi = \{\mathbf{C}^1, \mathbf{C}^2, ..., \mathbf{C}^M\}$ represents the set of all the coalitions formed by the players then individual payoff obtained by the player i is $P_i(\Pi) = \sum_{j=1}^{M} \phi_i(\mathbf{C}^j)$ where $\phi_i(\mathbf{C}^j)$ is the payoff that player i receive being a member from coalition $\mathbf{C}^j$. The overlapping composition may offer more freedom for the players to utilize their resources and potentially shows the way to outcome with higher payoffs.

TABLE I
Parameters used in the Problem Formulation

Symbol	Meaning
ν^C	Payoffs generated by a coalition **C**
R_i^g	Granted resources from C contributed by CP_i
b	Resources requested to CP_i
R_i^r	Resources requested to CP_i
c_d	Dissatisfaction cost of CP for per unit resource
R_i^c	Amount of resources contributed by CP_i in the coalition
c_s	Security cost of CP for per unit resource
c_c	Cooperation cost for the provider
N	Number of CPs in the coalition

To demonstrate, let us consider three different CPs, named CP_1, CP_2 and CP_3, whose operational scenarios are characterized by the values shown in the Table II using $b = 2$, $c_d = 2$, $c_s = 0.25$, $c_c = 2$. Now, let us consider the simple scenario when there is no coalition among the providers, the payoffs obtained by the providers are shown in the Table III. When we consider the traditional coalition formation mechanism, the payoffs are shown in the Table III. Comparing from these scenario, we get that the traditional coalition formation mechanism provides less payoffs to the providers than there is no coalition, even from grand coalition. In the traditional coalition formation game, the players are assumed to form disjoint coalition and they only cooperate with players within the same coalition. They only get payoffs from one coalition. Conversely, there are situations when players can participate in multiple coalitions simultaneously by splitting their resources and can get payoffs from that coalitions where they are the members. Scenario 3 of Table IV shows the overlapping coalitions among the provider with respective payoffs. The payoffs of CP_1, CP_2 and CP_3 are 20.0, 21.0 and 20.0 respectively which are better than that of the traditional coalition formation game and even no coalition.

TABLE II
SAMPLE: AVAILABLE RESOURCES AND REQUESTED RESOURCES

Provider	Resources	Requested Resources
CP_1	[10 5 0]	[5 8 0]
CP_2	[0 10 5]	[0 5 5]
CP_3	[5 0 10]	[5 2 5]

TABLE III
SAMPLE:TRADITIONAL COALITION AMONG CPS

Coalition	Payoffs CP_1, CP_2, CP_3
$\{\{CP_1\},\{CP_2\},\{CP_3\}\}$	[14.00 20.00 16.00]
$\{\{CP_1,CP_2\},\{CP_3\}\}$	[15.00 19.50 16.00]
$\{\{CP_1,CP_3\},\{CP_2\}\}$	[09.25 20.00 09.25]
$\{\{CP_1\},\{CP_2,CP_3\}\}$	[14.00 17.73 14.77]
$\{CP_1,CP_2,CP_3\}$	[14.50 21.50 14.50]

TABLE IV
SAMPLE:OVERLAPPING COALITION AMONG CPS

Coalition	Payoffs
$\{CP_1^1\}$	[20.0]
$\{CP_2^1\}$	[20.0]
$\{CP_3^1\}$	[20.0]
$\{CP_1^2,CP_2^2,CP_3^2\}$	[0.0 1.0 0.0]

IV. STABILITY OF CPS IN OCF GAME

In cooperative game, we want a coalition structure that is stable. In case of traditional coalition formation game, a coalition is stable if no players find it profitable to leave the current structure and form a new coalition. On the other side, OCF game is more complicated for its' overlapping nature and finding stability is a cumbersome task. Some of the players may partly deviate from the current coalition and can form one or more coalitions that is profitable for them.

Given a coalition structure Π and S is the set of players that want to deviate from their current structure and $S \subseteq N$. The players of S can withdraw full or a part of their resources from Π and the amount of withdrawn resources $\mathbf{W}_S = \sum_{\mathbf{C}\in\Pi} w^{\mathbf{C}}$, where $w^{\mathbf{C}}$ is the withdrawn resources from coalition $\mathbf{C}$ by the players of S. The deviators S can form an overlapping coalition structure by using $\mathbf{W}_S$ and let $\Pi(\mathbf{W}_S)$ be the set of all possible coalition structures that can be formed by the players of S. The optimal coalition structure formed by $\mathbf{W}_S$ is given by $\Pi_{\mathbf{W}_S} = argmax_{\pi\in\Pi(\mathbf{W}_S)} \sum_{\mathbf{C}\in\pi} \nu^{\mathbf{C}}$.

The deviators may receive payoffs from the modified coalition structure $\Pi^{'}$ and new coalition structure $\Pi_{\mathbf{W}_S}$ where they are participating with some resources. The total payoff that the deviators S get from $\Pi^{'}$ depends on some arbitrary function as indicated in the paper [22]. In our case we have used optimistic arbitrary function and can be represented by $\nu^o = \mathcal{O}(\Pi^{'}, S) = \sum_{\mathbf{C}\in\Pi^{'}} \nu^{\mathbf{C}} - \sum_{i\in N\setminus S} \phi_i(\Pi^{'})$. A coalition structure is stable if there is no such i for which equation (3) is true.

$$P_i(\Pi) < P_i(\Pi_{\mathbf{W}_S}) + \phi_i(\nu^o) \quad (3)$$

Algorithm 1 Statbility in OCF Game

1: Initial coalition structure $\Pi = (\mathbf{C}^1, \mathbf{C}^2, ..., \mathbf{C}^N)$ where $\mathbf{C}^i = \{R_i\}$. That means CPs form no coalition
2: Initialize S by the set of players who want to deviate from their current coalition structure
3: **if** S is empty **then**
4: Goto step 13
5: **end if**
6: The players of S will withdraw part or full resource(s) from the current coalition structure Π and the amount of withdrawn resources are $\mathbf{W}_S = \sum_{\mathbf{C}\in\Pi} w^{\mathbf{C}}$
7: Find the optimal coalition structure by $\mathbf{W}_S$ that is $\Pi_{\mathbf{W}_S} = argmax_{\pi\in\Pi(\mathbf{W}_S)} \sum_{\mathbf{C}\in\pi} \nu^{\mathbf{C}}$ where $\Pi(\mathbf{W}_S)$ is the set of all possible coalition structure that can be formed by $\mathbf{W}_S$
8: **if** $P_i(\Pi) < P_i(\Pi_{\mathbf{W}_S}) + \phi_i(\nu^o)$ is true for all $i \in S$ **then**
9: Update coalition structure Π by $\Pi^{'}$ and $\Pi_{\mathbf{W}_S}$
10: **else** {Hint: Check for newly unsatisfied set of players}
11: Goto step 2
12: **end if**
13: Update final payoffs $\mathbf{x} = P_i(\Pi)$ for all $i \in N$

Due to the limited number of resources, cooperation cost among deviators, security cost, we assume the number of deviators in a coalition structure is limited. Algorithm for stability in OCF game among CPs is shown in Algorithm 1.

TABLE V
RESOURCES OF THE CPS

CPs	VMs (Class 1)	VMs (Class 2)	VMs (Class 3)
CP_1	50	20	0
CP_2	30	0	30
CP_3	10	0	60

V. EXPERIMENTAL EVALUATION

In all scenarios, we consider 3 CPs, whose resources are characterized as reported in Table V and we use the same parameters as mentioned in Table I. We assume that all CPs use the same revenue rate policy for all classes of resources with the value $b = 2$, $c_d = 2$, $c_s = 0.25$, $c_c = 2$. To avoid the difficulty, we assume that the resources are given by integers and players can partition their resources in a discrete manner. We also suppose that the requested resources are also in discrete numbers.

TABLE VI
CASE 1: REQUESTED VMS TO THE CPS

CPs	VMs (Class 1)	VMs (Class 2)	VMs (Class 3)
CP_1	30	10	10
CP_2	0	10	20
CP_3	30	0	30

Starting from the configuration shown in the Table V, we take 5 cases of requested resources by the consumers that differ from each other in the workload of the various CPs shown in the Table VI to Table X.

TABLE VII
CASE 2: REQUESTED VMS TO THE CPS

CPs	VMs (Class 1)	VMs (Class 2)	VMs (Class 3)
CP_1	40	15	10
CP_2	20	0	20
CP_3	25	5	40

TABLE VIII
CASE 3: REQUESTED VMS TO THE CPS

CPs	VMs (Class 1)	VMs (Class 2)	VMs (Class 3)
CP_1	20	20	0
CP_2	20	5	40
CP_3	20	5	50

In Figure 2, we compare the performance in terms of payoff obtained by CP_1 through OCF game with respect to the no-coalition case and traditional coalition mechanism with different level of workload. As can be seen from the figure, OCF game provides better payoff than traditional coalition (federation) and no-coalition (no-federation). This is because, OCF mechanism provides flexible way to utilize the resource by partitioning and giving opportunity to attain in multiple small coalition. Thus the approach reduces the security risk cost and in the same time reduce the dissatisfaction cost by better utilizing the resources. CP_1 gets 11.13% more payoff than traditional coalition approach and 31.57% more payoff than no-coalition approach by utilizing OCF mechanism on average.

TABLE IX
CASE 4: REQUESTED VMS TO THE CPS

CPs	VMs (Class 1)	VMs (Class 2)	VMs (Class 3)
CP_1	40	0	20
CP_2	10	10	50
CP_3	30	5	20

TABLE X
CASE 5: REQUESTED VMS TO THE CPS

CPs	VMs (Class 1)	VMs (Class 2)	VMs (Class 3)
CP_1	60	10	10
CP_2	15	0	45
CP_3	0	10	30

We compare the performance of CP_2 and CP_3 in terms of payoff through OCF game with respect to the no-coalition and traditional coalition mechanism with different level of workload are shown in the Figure 3 and Figure 4 respectively. OCF game gives superior payoff than traditional coalition and no-coalition for both CP_2 and CP_3. By employing OCF approach CP_2 finds 12.57% more payoff than traditional coalition

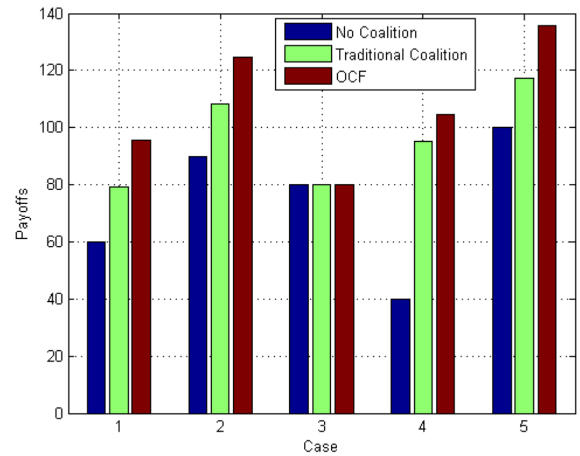

Fig. 2. Payoff comparison of CP_1

approach and 49.99% more payoff than no-coalition approach and CP_3 obtains 12.54% more payoff than traditional coalition and 57.96% more payoff than no-coalition approach by using OCF technique on average.

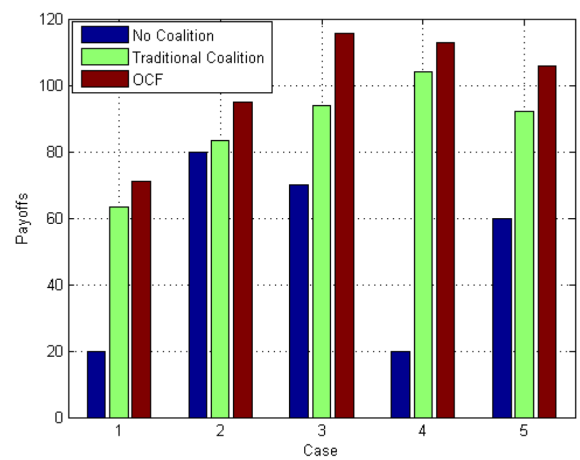

Fig. 3. Payoff comparison of CP_2

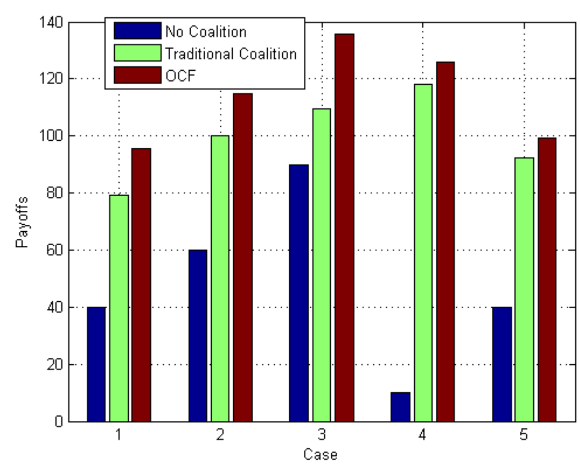

Fig. 4. Payoff comparison of CP_3

In Figure 5, we compare the average payoff differences of

CPs between OCF and Traditional coalition formation, and OCF and No-coalition. On average, using OCF game CPs get 12.08% more payoff in than the traditional coalition formation game and 46.51% more payoff than no-coalition scenarios.

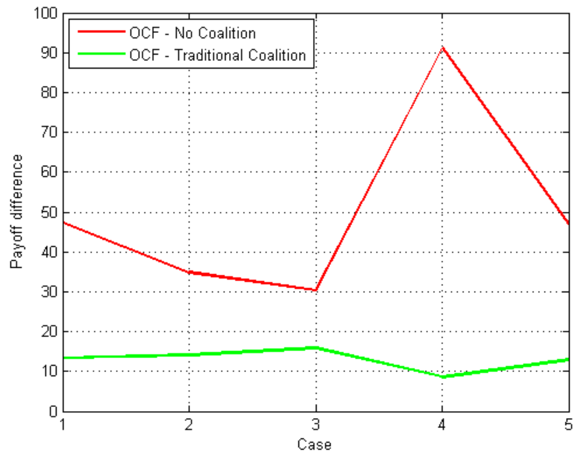

Fig. 5. Average payoff differences of CPs in OCF game with Traditional coalition and No-coalition

VI. Conclusion

In this paper, we proposed a mechanism that improves the CPs' payoffs by giving them freedom to participate in multiple overlapping coalitions with the help of cooperative game. In the process, CPs reduce under-utilization problem of resources and reduce security risk by partitioning resources and thus meet the elastic demands in clouds. Stability of the OCF game is checked by the proposed algorithm and the payoffs of the coalition is distributed among the CPs based on their marginal contribution in the coalition. The results showed that the proposed mechanism gives higher payoffs for all the CPs than traditional coalition and in case of no-coalition. Our method increases the payoffs above 12% than traditional coalition and over 46% than no-coalition on average for CPs. For the future work, we plan to consider resources as continuous rather than discrete and queuing model for resource demand to maximize the payoffs of the CPs.

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