Multi-Attribute Combinatorial Marketplaces for Cloud Resource Trading

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***Abstract*— Cloud Computing represents a new era where computing is offered as a service rather than as a physical product. The next level of flexibility will be achieved when Cloud Computing services can be automatically traded. This paper focuses on providing the foundation for simple and flexible Cloud resource trading. This is achieved by proposing vocabularies for the trading of Cloud resources and algorithms for a Cloud marketplace. A multi-attribute combinatorial marketplace is proposed as a solution for situations where Cloud resources need to be traded in combination (bundles). Vocabularies are introduced to serve as a foundation to build standards for Cloud resources trading.**

Keywords-component; Bidding, Combinational Auctions, Cloud Computing, Cloud Marketplace, Cloud Resources, Marketplace.

I. Introduction

Cloud Computing represents a transitional shift from computing as a physical product to computing as a service. Cloud Computing provides infrastructure, platform, and software as services; Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). These services are commonly offered to consumers as subscription-based services in a pay per usage basis. Although they may be offered and charged in similar means, they are highly differentiated in terms of cost, reliability, uptime and performance [17].

Cloud Computing started to have an increasing penetration rate across global markets due to its cost effectiveness and flexibility [6]. It has high potential to provide infrastructure and services to enable massive number of opportunities in the Computing industry. Large providers such as Amazon, IBM, Google, Microsoft and Sun Microsystems have already taken the opportunity to provide various types of Cloud services. Examples are Amazon's EC2, IBM's Blue Cloud, Google's Apps and Microsoft's Azure. Clouds also accommodate wide range of content types; social networking (e.g. Facebook and MySpace), gaming portals (e.g. BigPoint), business applications (e.g., SalesForce.com), media content delivery (e.g. Pando Media Booster), and scientific workflows (e.g. Nimbus) [6].

The current market of Cloud resources is formed, enforced and dominated by large providers and vendors [8]. It is predicted that the Cloud Computing market will contribute up to $121 billion to the computing market by 2015 [18]. Even though the market is dominant by several large players, current offerings still lack several functions that limit to some extent the boundaries of the market [25]. That includes lack of interoperability, enterprise level SLAs, price transparency and limited number of players in the market including small and medium enterprises (SMEs) [17]. Therefore, the need for Cloud resources marketplace is necessary to enable free trading of such resources in a massive scale.

This paper argues that a global multi-attribute combinatorial marketplace for Cloud resources is desirable and will benefit both providers and consumers. This is supported by the need for, specifying architecture of and defining notation for combinatorial marketplace of Cloud resources. Although there are proposed market architectures and algorithms [6, 7, 8, 12, 16, 23, 27, 31, 32, 35, 37], this architecture addresses and offsets the limitations exhibited by the existing offerings and some proposed solutions.

The remainder of this paper is as follows. A background of Cloud Computing and Cloud resources trade is presented in section 2. Section 3 discusses the motivations for a Cloud resources marketplace. Vocabularies for Cloud resources trading are introduced in Section 4. Then, the abstract view of the proposed architecture is discussed in Section 5. A case study is developed in Section 6 to assess the proposed architecture. Section 7 is a discussion of the results. Section 8 presents some conclusions.

II. Background

Cloud Computing has drawn significant attention worldwide from businesses, IT vendors, academia and public media. Wide range of definitions was proposed to accommodate various technologies and therefore there is no agreed on and widely accepted definition [6, 8, 34, 36]. Cloud computing, however, can be viewed as a model that enables processing, storage, networking and applications to be securely accessed as services over networks either publicly or privately [36]. Apart from the definition, there are five essential characteristics of Cloud Computing [6, 11, 36]; 1) On-demand self-service; where the resources can be provisioned when needed automatically, 2) Broad network access; resources are available and accessible over a network, 3) Resource pooling; resources can be bundled to serve multiple consumers simultaneously, 4) Rapid elasticity; resources can be elastically provisioned and released, and 5) Measured service; resources usage can be billed, monitored, controlled, and reported.

Technically, Cloud Computing is classified into two main models; 1) service and 2) deployment [21, 36]. Service model categorizes Cloud Computing based on type of service provided while deployment model classifies Cloud

Computing based on the architecture and type of deployment. Cloud implementers are therefore required to choose a cloud service and a deployment model based on their specific business, operational, and technical requirements.

A. Service Model:

This model is composed of three sub-models where service providers usually categorize their offerings under one of them. This model classifies what the Cloud provides (software, platform or infrastructure) rather than how the Cloud will provide (public, private). This model covers the following services;

1) Software as a Service (SaaS): The resources provided to the consumer are applications running on the provider's infrastructure. The applications are accessible on-demand through a network either by a thin client interface, such as a web browser or a program specific interface [17]. The provider manage and control the underlying cloud infrastructure including network, servers, operating systems and storage while the consumer may control limited user-specific application configuration settings [36].

2) Infrastructure as a Service (IaaS): Processing, storage, networks, and similar resources provisioned to the consumer to enable deploying and running software or processing and storing data on the provider's infrastructure [17]. The provider manage and control the underlying cloud infrastructure whereas the consumer has control over operating systems, storage, and deployed applications and stored data [34].

3) Platform as a Service (PaaS): The Cloud provides application-hosting environment to consumers using programming languages, libraries, services, and tools [17]. The environment enables consumers to develop, test or run platform-specific or cross-platform solutions. The provider manages and controls the underlying Cloud infrastructure whilst the consumer controls the deployed applications [36].

B. Depolyment Model:

This model consists of four sub-models where Clouds are classified based on how they are deployed rather than what they provide. This model covers the following deployments;

1) Public Cloud: The Cloud infrastructure and its computational resources are provisioned and made available for the general public [34]. A single or multiple providers can own, manage, and operate the Cloud to deliver Cloud services to consumers. The Cloud physically exists on the provider's premises. The public Cloud is the dominant over other types because of the involvement of large players such as Amazon (EC2), IBM (Blue Cloud), Google (AppEngine) and Microsoft (Windows Azure) [18].

2) Private Cloud: The cloud infrastructure is provisioned and operated exclusively for a single organization. The private Cloud may be owned, managed, and operated by the organization, a third party, or a combination of them [34]. It may be hosted on or off organization's premises. This type of Clouds offers the organization with better control over the underlying infrastructure, resources and consumers [36].

3) Hybrid Cloud: The cloud infrastructure is intended to be a best composition of two or more distinct Clouds (private or public). Each Cloud remains independent entity but interconnected by a shared technology or protocol which enables data portability [34]. The Hybrid Cloud can be implemented widely to overcome both public and private limitations.

4) Federated Cloud: A pool of accessible shared resources (both internal and Cloud) that are owned, managed and operated by independent interconnected providers and where customers can select the demanded computing environment with the ability to distinguish between providers by cost and trust levels [13]. The federated Cloud can be viewed as a solution for interoperability issues, limited scalability and performance instability that encounter public and private Clouds users [23, 26].

C. Cloud Resources Trading

Offering Cloud resources as tradable services is increasingly becoming a common market trend [18]. Market forecasts indicate a significant growth from $37.8 billion in 2010 to $121.1 billion in 2015 with compound annual growth rate of 26.2% where SaaS dominate the market with the largest segment approx. 73% of the market revenue [18].

The current Cloud market forms two business models; Business to Business (B2B) and Business to Consumer (B2C), whereas the other two models are merely missing; Consumer to Consumer (C2C) and Consumer to Business (C2B) [5]. This is also reinforced by the players where each player has its marketplace to offer its resources. This limits various opportunities available to consumers including bidding for Cloud resources, allocating dynamic resources, requesting from multiple providers, obeying standard enterprise SLAs and avoiding interoperability issues among providers.

To cope with such challenges, a multi-attribute combinatorial Cloud marketplace is proposed. The marketplace will have the potential to enable trading of Cloud resources on a massive scale that is far beyond the single provider level. It is to efficiently open up the Cloud space to a wider range of customers to whom Cloud resources and services were previously unavailable or not affordable [17].

That will include small and medium enterprises (SMEs), scientific workloads and academic research. For instance, SMEs will have access to geographically distributed systems in a way that was previously affordable only to large enterprises.

There are various attempts that address those challenges and even delivered wide range of designs and algorithms but efforts to standardize the trading of Cloud resources and offerings do not exist. This is also supported by nonexistence of vendor-independent marketplace for trading Cloud resources where multitude providers and consumers meet and where other attributes than a price exist [1, 2, 27, 28, 35]. A multi-attribute combinatorial marketplace for Cloud resources therefore seems feasible as a solution in which heterogeneous and highly differentiated Cloud resources can be traded to benefit all parties involved. This also should enable liquidizing Cloud resources in a way those resources will be exchanged and Cloud-based workloads will become more transportable between involved parties, so Cloud resources can easily fit into different environments as they are extensively exchanged [11].

III. MARKETPLACE MOTIVATIONS

The rapid growth of Cloud implementations motivated researchers to address and resolve issues related to interaction between multiple Clouds and providers. One of the main trends is through a marketplace that achieves increased Cloud utilization and reduced cost [20]. Building a worldwide marketplace for Cloud resources should have significant advantages over the current market [33]. This section identifies and discusses unfulfilled Cloud trading opportunities as well as the limitations of the current offerings. Although the list might be an open ended of various motivations, some may attract new arguments based upon technical difficulties that may be interpreted as this architecture is still not sufficient to ensure its success. Despite that assumption, this marketplace has greater advantages over the current offerings as follows;

A. *Enabling Interoperability:*

Cloud Computing resources will be truly utilized only if customers are not restricted to a particular service provider and can easily switch between vendors due to requirements or offerings change. The existing offerings include highly differentiated services that harden the chance of moving any critical workload to different provider. This may involve large costs incurred when migrating the workload and reprograming applications to use new vendors' APIs [14, 17, 20].

B. *Empowering Small and Medium Vendors:*

Providing Cloud Computing services usually need large investments which are not affordable by most SMEs. Yet, this is reflected on the lists of leading Cloud Computing vendors where large enterprises usually occupy the top 10 to 50 [18]. A marketplace of Clouds will enable small and medium service providers to be involved in Cloud Computing business. This can also attract smaller customers with specialized needs who are best served in a retail basis rather than a wholesale basis. In aggregate, a large number of small providers will form a Cloud with a wider geographical distribution than the largest single provider could afford and support. This will target and address local markets with specific requirements such as low-latency access to interacting customers or devices. This model has already shown several success stories: Akamai, Limelight Networks and BitGravity [24]. Those small providers host their content distribution system by purchasing computation capacity in ISPs around the world instead of building their own data centers to serve each territory [17].

C. *Improving Service Level Agrements (SLAs):*

The current offerings lack of well-defined service level agreements (SLAs) by cloud providers. This shortage includes basic parameters such as guaranteed uptime, guaranteed levels of performance and failure repercussions [6, 14]. This goes further when it comes to federated Clouds where each provider has its own SLA. There is no standard SLA to address what happen and how it happens when a customer wants to move from a provider to another. What happens to the data and how? This matter can cause further credibility issues between service providers and customers [17]. Some enterprises however, have good SLAs that protect them as providers but expose their customers.

The lack of enterprise-grade SLAs is resolved in the marketplace model. The market has a standard SLA that technically defines the minimum terms of contracts that will cover both providers and customers. Those terms are based on the characteristics of a service rather than a provider or a customer based agreement. Both providers and customers can negotiate further terms and conditions to be included to their own SLAs without breaking the basic market SLA. A standard SLA has some benefits including better legal protection for customers and providers and improved standard for market entry [10, 33].

D. *Avoiding Monopoly:*

Hosting the world's Cloud Computing resources on a small number of providers increases the risk of a single provider technical failures as well as single vendor lock in. Technical failures; bugs, misconfigurations and security breaches can have a huge impact on the operations of many customers simultaneously [17]. A marketplace will enable competitive and independent implementations of Cloud Computing which will greatly reduce any mono-related risks. Customers will also be benefited by enjoying the freedom of choices from multitude of service providers.

E. *Enabling Infrastructure Innovation:*

A marketplace of Cloud Computing will add large number of players into the current market. This will require wide range of infrastructure pieces; CPUs, GPUs, memory units, storage and network equipment [17]. This marketplace model will promote the innovation of a large community of computer vendors selling to many different service providers. Today, it is challenging for infrastructure vendors to produce, market and support wide range of differentiated products. It may result in concealing the value of these products and limiting innovation due to affordability of small number of large Cloud providers [14]. The marketplace model may also motivate the emergence of new infrastructure suppliers.

F. Enabling Programming Innovation:

One of today's market limitations is that there is no standard for Cloud Computing programming [32]. PaaS and SaaS products must be rewritten to be compatible with the unique interface of each Cloud offering. This means reprograming the same solution for every single deployment [17]. In this case, the service providers restrain innovations by locking-in their customers and restricting development to software firms or high level developers. This market model is IaaS oriented which can have great potential to serve as underlying infrastructure for scalable PaaS and SaaS. The market will have a standard interface which allows both software and platform services to be programmed once and then deployed across all Clouds. This can open the market widely to larger community of software developers and therefore balance the advantage to all; providers, developers and customers.

G. Advancing Academic Contributions:

Academic community is a committed source of innovation. The design and implementation of IaaS Clouds pose major challenges for academic research [17]. This is because the current model of large Clouds with complicated interfaces is not favorable for academic research. The marketplace model with simple entities will enable researchers to initiate their own designs and investigate relevant advanced issues.

IV. VOCABULARY FOR CLOUD RESOURCES TRADING

There is no standard in Cloud Computing yet, starting from its definition to its deployment, services and applications. Each Cloud provider has its own definitions and standards for the Cloud resources. When it comes to trading, customers need a standard baseline to start with. This section defines the basic vocabularies for Cloud resources trading as proof of concept. These vocabularies are dynamic, flexible and expandable to meet various Cloud requirements. Detailed information about how they are used will be explained in details in a followed section.

1) Cloud Service Vocabulary

This section focuses on defining attributes associated with the Cloud resources and may contribute to their final prices. This includes trust, security (e.g. credentials, encryptions, and firewall), privacy, location and legal aspects. It is assumed those attributes can be negotiated as essential part of the deal.

Attributes are dynamic and applicable to all Cloud resources. Each Cloud resource should be assigned one or more attributes. This model is designed to accommodate wide range of attributes as each Cloud resource should have different ones based on the nature of each resource. Providers submit requests to the marketplace to offer their resources along with attributes and their costs. The marketplace has the ability to verify the accuracy of technical attributes in specific (e.g. security mechanisms, location of resource, hardware architecture and operation system).

It is assumed those attributes can be assigned integer values based on their real market valuation so there is a finite set of associated attributes AT to each resource. Let AT represents the set of attributes, $AT = \{at_1, at_2, ..., at_n\}$, and R donates the set of resources where $R=\{r_1, r_2, .., r_n\}$. Attributes AT has a certain valuation V where $V=sum(v_1, v_2, .., v_n)$ and $V \geq 0$. The value V consists of a set of predefined values assigned by the market according to the real value of each attribute. Suppose V contributes to the total price P of r resources. Then, the total price of r is

$$P(r)=p(r)+V(AT)$$

To illustrate, a resource r that is provided with 128 bit encryption will have lower value v than the same resource when provided with 256 bit of the same type of encryption and so on. The valuation of attributes is considered at this stage to 1) demonstrate its importance, 2) simplify the auction process in later stages where the case is to bid for multi-attributes bundles of resources. The final value of all possible attributes $V(AT)$ will be added to the final price of resource r at the close of bidding stage based on the required attributes by the consumer. This valuation process is possible in the case of a single resource or bundle of resources.

2) Vocabularies for Cloud Resources Trading

This section is intended to provide standard vocabularies for Cloud resources trading. That is proposed as a foundation for the marketplace of the Cloud resources. The following vocabularies cover the basic entities of the marketplace as well as the trading transactions needed for various types of Cloud resources including IaaS, SaaS and PaaS.

In the marketplace M, there is a set of providers S and a set of consumers C where the providers S offer set of resources R. Bundle B is a combination of resources where $B \subseteq R$, for which consumers may submit a bid. Assume b_i donates the set of bids $b_i=\{b_1, b_2, b_3, ..., b_n\}$. A bid [30] is a tuple $b_i= \langle B_i, p_i \rangle$ where $B_i \subseteq R$ is a set of resources and $p_i \geq 0$ is a price. In single resource auction, a single resource only is requested by the consumer C where the final form of the transaction outcome should include a single provider, a single resource and a single consumer. In resource bundle auction, multiple resources are requested by the consumer to form a complete transaction that includes multiple providers, multiple resources and a single consumer.

The providers submit their resource offerings to a pool of n resources R. Consumers C submit resource requests to the marketplace system, which matches the consumers' requirements with available resources. There is a wide range of matching algorithms that can be considered to search for the best matches and many of them can be modified for different design choices. This architecture adopts CABOB algorithm, which is considered one of the fastest search algorithms for combinatorial auctions yet [30]. However, any other algorithms can be used to meet the requirements of the marketplace.

The bundle will be auctioned by a set of single bids for the whole bundle rather than for each resource within the bundle. CABOB uses five heuristic methods to match request with resources and determines the winning bid [30]. This architecture uses Normalized Shadow Surplus (NSS) due to its advantages over other ones [30]. This method weights the resources by their values using a shadow price y_i for each resource. Then it searches for the bid whose price gives the highest surplus above the price requested by the provider as minimum willing to sell. w_j represents the highest and winning bid [30],

$$w_j = \frac{p_i - \sum_{i \in B_i} y_i}{\log\left(\sum_{i \in B_i} y_i\right)}$$

Defining a way for distributing revenue among providers is essential in auctions especially in resource bundle auctions. The marketplace rules specify the individual revenue percentage for each provider, whose resource has been auctioned in a bundle. RV donates individual revenue and w_j represents the winning bid. Let CN be the predefined percentage of each resource contribution to the final value of the bundle. Obviously;

$$RD = w_j \times CN\%$$

The revenue may greatly vary due to the variation in each predefined rules. Some resources may attract higher $CN\%$ due to their type, usage or attributes.

Listing or insertion fees are also crucial to keep the marketplace alive. The marketplace is expected to charge for at least every successful auction. F gives the predefined listing fee for each resource. The individual listing fees LS_p can be calculated as follows;

$$LS_p = RD \times F\%$$

The total listing fees TLF for bundle auction can be calculated as:

$$\mathrm{TLF} = \sum_{p=1}^{n} \mathrm{LS_p}$$

Total listing fees are predefined based on the final value of winning bid. The higher winning bid is, the higher LS_p will be. However, TLF may seem to be negligible but it is important for the marketplace and worth studying.

The implementation of the above listed vocabularies should be possible for all types of Cloud resources. The trade of any XaaS is considered one of the main objectives of the marketplace, where X is infrastructure, platform or software. The resource model therefore must be designed carefully in order to accommodate all technical and business specifications of any XaaS offering [22]. Figure 1 shows the resource model as an XML schema. The design uses XML to facilitate the exchange of Cloud instances among the marketplace components. In similar cases, XML however, can be replaced with any other language to meet specific requirements of the marketplace.

The resource model includes the following information about each resource [22];

- *Resource_ID:* to assign a unique identifier with each resource.
- *Resource_Name:* the name of the resource shown in the marketplace to all members.
- *Resource_Description:* A customer friendly description of the resource.
- *Publication_Date:* Date of adding the resource to the marketplace.
- *Validity_From:* Date from which resource is listed in the marketplace.
- *Validity_Until:* Date until the resource can be listed for.
- *Version:* Version of the resource
- *Brand:* Commercial brand of the resource
- *Service_Provider_ID:* a unique identifier for the provider in the marketplace.
- *License:* Type of license that applies to the resource (if applicable)
- *Attribute:* a set of attributes that enable consumers to customize the resource for their needs. The attributes vary based on the resource type.
- *Price:* specifies the minimum acceptable price for the resource to be allocated. It is based on technical and business parameters that are predefined by the provider.
- *Status:* This defines the status of the resource so other members can know about it.
- *Type:* unique type for each resource (IaaS, SaaS, PaaS or other)
- *Category:* This is a subtype of for the resource so it can be categorized under a genuine class of resources.

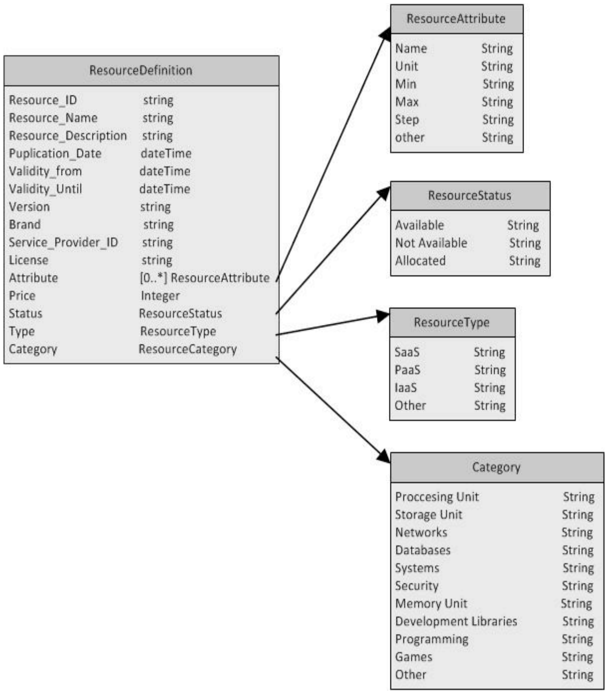

Figure 1. Resource XML Schema. Inspired by [22]

V. BASIC ARCHITECTURE

This architecture is intended to solve the problem of existing offerings where the buyer is limited to specific resource or set of resources from a single provider only. This architecture forms a marketplace where Cloud resources can be allocated by the market members. Cloud resources can be either allocated as a single isolated resource or as resource bundles. The bundle may include set of Cloud resources from a single or multiple parties [15]. This model tries to reduce the impact of traditional market classifications where members can be sellers only, buyers only, or byers from a single provider at the same time). Each party can be involved in one or more type of transactions with different parties at the same time. This would ensure that the consumer's requirements are matched with resources. Bundles composed by different providers also reduce the risk of failures or resource unavailability in case of a single provider [20].

This marketplace is composed of three entities; 1) Consumer (buyer), 2) Provider (seller) and 3) Marketplace system [7, 12, 15]. The consumer can be a) end-consumer who will consume the resource(s) individually and b) business consumer (e.g. SME) who will take the advantage of the Cloud resources in other business operations. On the other side, there are a) SaaS b) PaaS c) IaaS providers.

The marketplace works in the following simplified manner; providers submit their offers to a pool of resources or resources directory where the market system stores relative information about resources. Resources are traded as individual resources unless marketplace rules specify which resources are permitted combinations [15]. That is to enable trading of resource bundles in conjunction with other resource bundles from various providers.

The consumers submit their resource requests to the marketplace system, which uses a matching algorithm (CABOB) to search, extract the best match and determine the winning bid. This may or may not fully match the request constraints (e.g. resource quantity, time required, price and other attributes) [1, 5, 15, 25, 35]. Therefore, the price will not be the sole judge for the winning bid determination. The auctioneer in CABOB determines the winning bid based on the returning liner program (LP) value from the search algorithm. It makes the bid with $x_i=0$ losing and the bid with $x_i=1$ winning [30]. However, if the returned values are not integer, simply CABOB rejects them. Figure 2 shows the marketplace components.

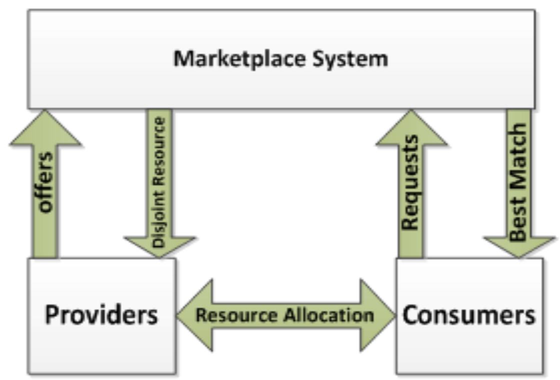

Figure 2. Marketplace Components

VI. EVALUATION

The aim of this evaluation is to demonstrate one specific example of trading Cloud resources. It is assumed that requested resources are highly differentiated to form a bundle of IaaS, PaaS and SaaS resources. This demonstration shows the simplicity and flexibility of this architecture.

Assume a consumer is submitting a resource request for the following resources; 2 storage units, 3 GPUs, 3 high CPUs, Microsoft Azure and email protection software. All required resources include different attributes (e.g. certain throughput, graphics accelerator, specific processor speed, development kits and libraries, complementary services: Content filtering, email disaster recovery, email attacks filter and security policies management) [19]. Table 1 shows the required resources in the view of the resource model.

Suppose the submitted bid along with the resources request is X. Using the CABOB search algorithm [30];

$$w_j = \frac{p_i - \sum_{i \in B_i} y_i}{\log\left(\sum_{i \in B_i} y_i\right)}$$

The marketplace system checks the resource availability. If resources request does not match the available resources $Q \notin R$, then the system holds the request for specific time interval until resources are matched or time interval expired. If $Q \in R$, then the system verifies if bid is lower than the minimum price required by the providers then the bid will be rejected $X < P(r)$. But if $X \geq P(r)$, the system will effectively be using CABOB algorithm to match the best combination of resources in terms of price and requirements (e.g. quantity of resources and other attributes).

After the auction closes, revenue distributions among providers start using the following: $RD = w_j \times CN\%$

Finally; the listing fees are deducted from the revenue RD.

$$LS_p = RD \times F\%$$

Table 1. Resource Model Description

	R1	***R2***	***R3***	***R4***
ResourceID	0001	0002	0003	0004
Resource Name	CPU	GPU	Storage	Email
Publication Date	01/07/12	29/06/12	02/07/12	30/06/12
Validity From	01/07/12	29/06/12	02/07/12	30/06/12
Validity Until	10/07/12	05/07/12	13/07/12	08/07/12
Version	2011	1	3	2.3
Brand	Intel	ATI	WD	MS
Service Provider ID	1000	1100	1200	1300
License	N/A	N/A	N/A	enterprise
Attribute	Speed, architecture	Capacity, Acceleration	Capacity, encryption	Backup, security
Price	$0.080	$0.005	$0.050	$0.240
Status	Available	Not available	Allocated	available
Type	IaaS	IaaS	IaaS	SaaS
Category	Processing	Graphics	Storage	Email

VII. DISCUSSION

In the previous section, an evaluation was presented to examine the feasibility of multi-attribute combinatorial marketplace for Cloud resources trading. It is shown that highly differentiated Cloud resources can be traded in bundles using combinatorial auction. The importance of combinatorial auction is clearly demonstrated by better economical allocations it delivers. Although the evaluation covered limited number of resources, combinatorial auction demonstrated its ability to manage extreme large number of differentiated resources. Heuristic research algorithms facilitate the matching process between consumers' requests and available resources. Methods to calculate the revenue for each provider and the listing fees for the marketplace were also introduced.

This study also aims to open the space for trading Cloud resources by offering standard vocabularies which are important to build the foundation that future contributions can be built on. The review of the existing offerings addressed their limitations and motivated for a worldwide marketplace for Cloud resources. The use of resource model in this marketplace enables SaaS, PaaS and IaaS to be traded in a unified way.

The design of multi-attribute combinatorial market benefits the consumer in a way the consumer retains high level of utilization and control over requested bundles. This can be extended to include control over the performance of the resources which is usually under the provider control [20]. The design of the marketplace can also improve the way of implementing different types of Clouds. The interaction between consumers and providers or between providers and other providers will enable heterogeneous implementation of Clouds [20].

Issues are also expected to be encountered in such marketplace. In case of Cloud-based service failure or resource unavailability, issues related to SLAs will be raised. It would be required to have an automated renegotiation system that rapidly resolves any related issues [4, 20]. Another potential issue is the security of detailed information about resources exchanged between the marketplace system and the providers. The marketplace system requires detailed information about every single resource so it can be offered, allocated and released by the marketplace system. Providing enough details about a resource in Cloud environment therefore can pose security risks [9].

VIII. CONCLUSION

While the existing offerings of Cloud resources suffer from various limitations, market researches predicate promising and glorious future as more players join the market. Cloud deployment models may be developed to form new models that can accommodate the requirements of Cloud Computing trade. Federated Cloud is therefore the most appropriate existing model [9, 13, 23] for trading Cloud resources that can accommodate Cloud resources in massive scale which is extremely far away from any single provider level.

Although this study attempted to introduce standard vocabularies for Cloud Computing trading, further research is necessary to develop wider range of standards that can be adapted by any Cloud marketplace design. The proposed architecture can also be described as a genuine solution (proof of concept). Search and winning bid determination algorithms are also adaptable to meet the marketplace requirements. The case study demonstrates the feasibility of the solution but the problem and solution can be further large and complex.

This solution in conjunction with other proposed ones seems to break the problem theoretically, but other challenges and considerations should be tackled in practice. The first on the list should be the technical issues (e.g. compatibility) [14]. Security, privacy and legal [13, 17] are all aspects need to be carefully considered prior to design any marketplace for large-scale Cloud resources.

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REFERENCES

[1] M. Andersson and T. Sandholm, "Time-Quality Tradeoffs in Reallocative Negotiation with Combinatorial Contract Types," in THE NATIONAL CONFERENCE ON ARTIFICIAL INTELLIGENCE, 1999, pp. 3 - 10.

[2] J. S. Banks, J. O. Ledyard, and D. P. Porter, "Allocating Uncertain and Unresponsive Resources: An Experimental Approach," The Rand journal of economics, vol. 20, p. 1, 1989.

[3] C. Boutilier, "Sequential auctions for the allocation of resources with complementarities," pp. 527-534, 1999.

[4] D. Breitgand and A. Epstein, "SLA-aware placement of multi-virtual machine elastic services in compute clouds," in Integrated Network Management (IM), 2011 IFIP/IEEE International Symposium on, 2011, pp. 161-168.

[5] B. Burmeister, T. Ihde, T. Kittsteiner, B. Moldovanu, and J. Nikutta, "A practical approach to multi-attribute auctions," in Database and Expert Systems Applications, 2002. Proceedings. 13th International Workshop on, 2002, pp. 670-674.

[6] R. Buyya, S. Pandey, and C. Vecchiola, "Cloudbus Toolkit for Market-Oriented Cloud Computing," Springer, 2009.

[7] R. Buyya and S. Vazhkudai, "Compute Power Market: Towards a Market-Oriented Grid," in First IEEE International Symposium on Cluster Computing and the Grid, Brisbane, Australia 2001, p. 574.

[8] R. Buyya, C. S. Yeo, and S. Venugopal, "Market-Oriented Cloud Computing: Vision, Hype, and Reality for Delivering IT Services as Computing Utilities," in 10th IEEE International Conference on High Performance Computing and Communications Dalian, China, 2008, p. 9.

[9] C. Byeong-Yun, K. Byeongsik, Y. Seunghyun, and S. Dong-Won, "An evaluation of federated cloud computing effect with service level," in Computational Problem-Solving (ICCP), 2011 International Conference on, 2011, pp. 105-108.

[10] V. Chang, D. Bacigalupo, G. Wills, and D. De Roure, "A Categorisation of Cloud Computing Business Models," in Cluster, Cloud and Grid Computing (CCGrid), 2010 10th IEEE/ACM International Conference on, 2010, pp. 509-512.

[11] G. Chunye, L. Jie, Z. Qiang, C. Haitao, and G. Zhenghu, "The Characteristics of Cloud Computing," in Parallel Processing Workshops (ICPPW), 2010 39th International Conference on, 2010, pp. 275-279.

[12] J. M. Ferris, "METHODS AND SYSTEMS FOR PROVIDING A MARKETPLACE FOR CLOUD-BASED NETWORKS," USA Patent, 2008.

[13] I. Goiri, J. Guitart, and J. Torres, "Characterizing Cloud Federation for Enhancing Providers' Profit," in Cloud Computing (CLOUD), 2010 IEEE 3rd International Conference on, 2010, pp. 123-130.

[14] P. Hofmann and D. Woods, "Cloud Computing: The Limits of Public Clouds for Business Applications," Internet Computing, IEEE, vol. 14, pp. 90-93, 2010.

[15] B. Junjik, E. Beigman, R. Berry, M. L. Honig, and R. Vohra, "Efficiency Bounds for Sequential Resource Allocation Auctions," in Decision and Control, 2007 46th IEEE Conference on, 2007, pp. 765-770.

[16] R. M. Karp, "Reducibility Among Combinatorial Problems," in Complexity of Computer Computations 1972.

[17] O. Krieger, P. McGachey, and A. Kanevsky, "Enabling a marketplace of clouds: VMware's vCloud director," ACM SIGOPS Operating Systems Review, vol. 44, pp. 103-114 2010.

[18] Markets and Markets. (2010). Global Cloud Computing Market to Reach US$ 121.1 Billion by 2015 Available: http://www.marketsandmarkets.com/PressReleases/cloud-computing-market.asp

[19] McAfee.Inc. (2012). McAfee SaaS Email Protection. Available: http://www.mcafee.com/us/products/saas-email-protection.aspx#vt=vtab-Overview

[20] H. Mearns, J. Leaney, A. Parakhine, J. Debenham, and D. Verchere, "An Autonomic Open Marketplace for Inter-Cloud Service Management," in Utility and Cloud Computing (UCC), 2011 Fourth IEEE International Conference on, 2011, pp. 186-193.

[21] P. Mell and T. Grance, "The NIST Definition of Cloud Computing," Communications of the ACM, vol. 53, pp. 50-50, 2010.

[22] A. Menychtas, S. Garc, A. Giessmann, A. Gatzioura, K. Stanoevska, J. Vogel, and V. Moulos, "A Marketplace Framework for Trading Cloud-Based Services," Economics of Grids, Clouds, Systems, and Services, vol. 7150, pp. 76-89, 2011.

[23] M. Mihailescu and Y. M. Teo, "Dynamic Resource Pricing on Federated Clouds," in Cluster, Cloud and Grid Computing (CCGrid), 2010 10th IEEE/ACM International Conference on, 2010, pp. 513-517.

[24] A. Ojala and P. Tyrvainen, "Developing Cloud Business Models: A Case Study on Cloud Gaming," Software, IEEE, vol. 28, pp. 42-47, 2011.

[25] H. Pengwei and H. Fangxia, "An optimized strategy for cloud computing architecture," in Computer Science and Information Technology (ICCSIT), 2010 3rd IEEE International Conference on, 2010, pp. 374-378.

[26] R. Ranjan and R. Buyya, "Decentralized Overlay for Federation of Enterprise Clouds," Handbook of Research on Scalable Computing Technologies, 2008.

[27] S. J. Rassenti, V. L. Smith, and R. L. Bulfin, "A Combinatorial Auction Mechanism for Airport Time Slot Allocation," The Bell Journal of Economics, vol. 13, pp. 402 - 417, 1982.

[28] M. H. Rothkopf, A. Pekeč, and R. M. Harstad, "Computationally Manageable Combinational Auctions," Management Science, vol. 44, pp. 1131 - 1147, 1998.

[29] T. Sandholm, "Algorithm for optimal winner determination in combinatorial auctions," Artificial intelligence, vol. 135, pp. 1-54, 2002.

[30] T. Sandholm, S. Suri, A. Gilpin, and D. Levine, "CABOB: A Fast Optimal Algorithm for Combinatorial Auctions," presented at the INTERNATIONAL JOINT CONFERENCE ON ARTIFICIAL INTELLIGENCE, 2001.

[31] A. Santos, F. Almeida, V. Blanco, and J. C. Castillo, "Web services based scheduling in OpenCF," The Journal of Supercomputing, vol. 58, pp. 168-176, 2011.

[32] A. V. Singh, V. Singh, T. Wies, and D. Zufferey, "A marketplace for cloud resources," in ACM international conference on Embedded software 2010, pp. 1-8.

[33] M. P. Singh, The Practical Handbook of Internet Computing 1st ed.: Chapman and Hall/CRC, 2004.

[34] B. Sosinsky, Cloud Computing Bible: John Wiley & Sons, 2011.

[35] A. Sunderam and D. Parkes, "Preference elicitation in proxied multiattribute auctions," presented at the 4th ACM conference on Electronic commerce, San Diego, CA, USA, 2003.

[36] L. M. Vaquero, L. Rodero-Merino, J. Caceres, and M. Lindner, "A Break in the Clouds: Towards a Cloud Definition," Computer communication review, vol. 39, pp. 50-55, 2009.

[37] G. Yi-Ke Guo Li, "IC Cloud: Enabling Compositional Cloud," International journal of automation and computing, vol. 8, pp. 269-279, 2011